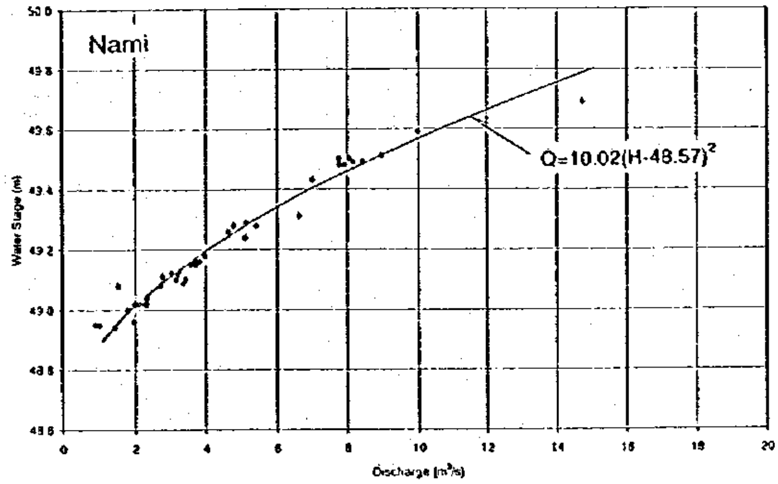
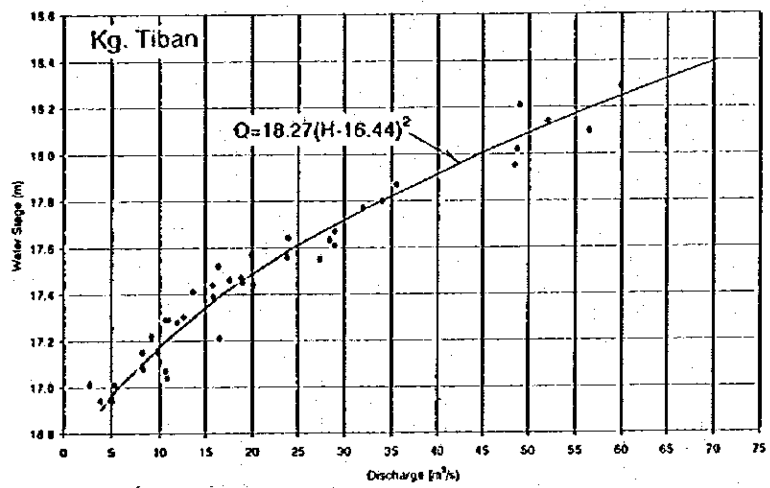
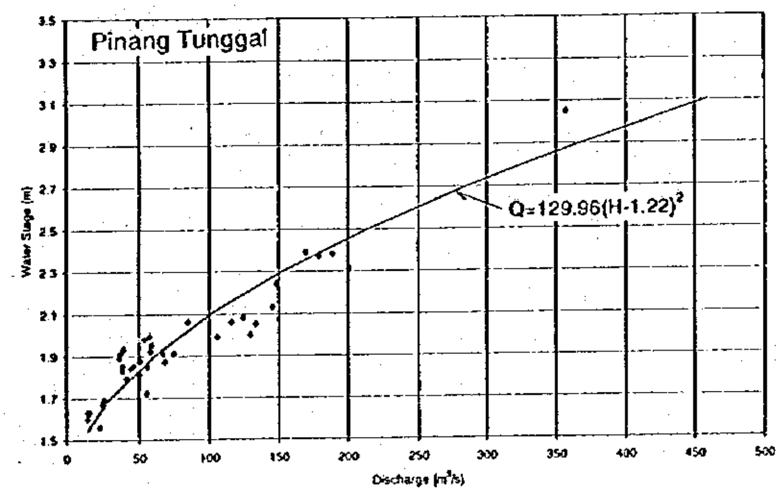
FIGURES

SECTOR I

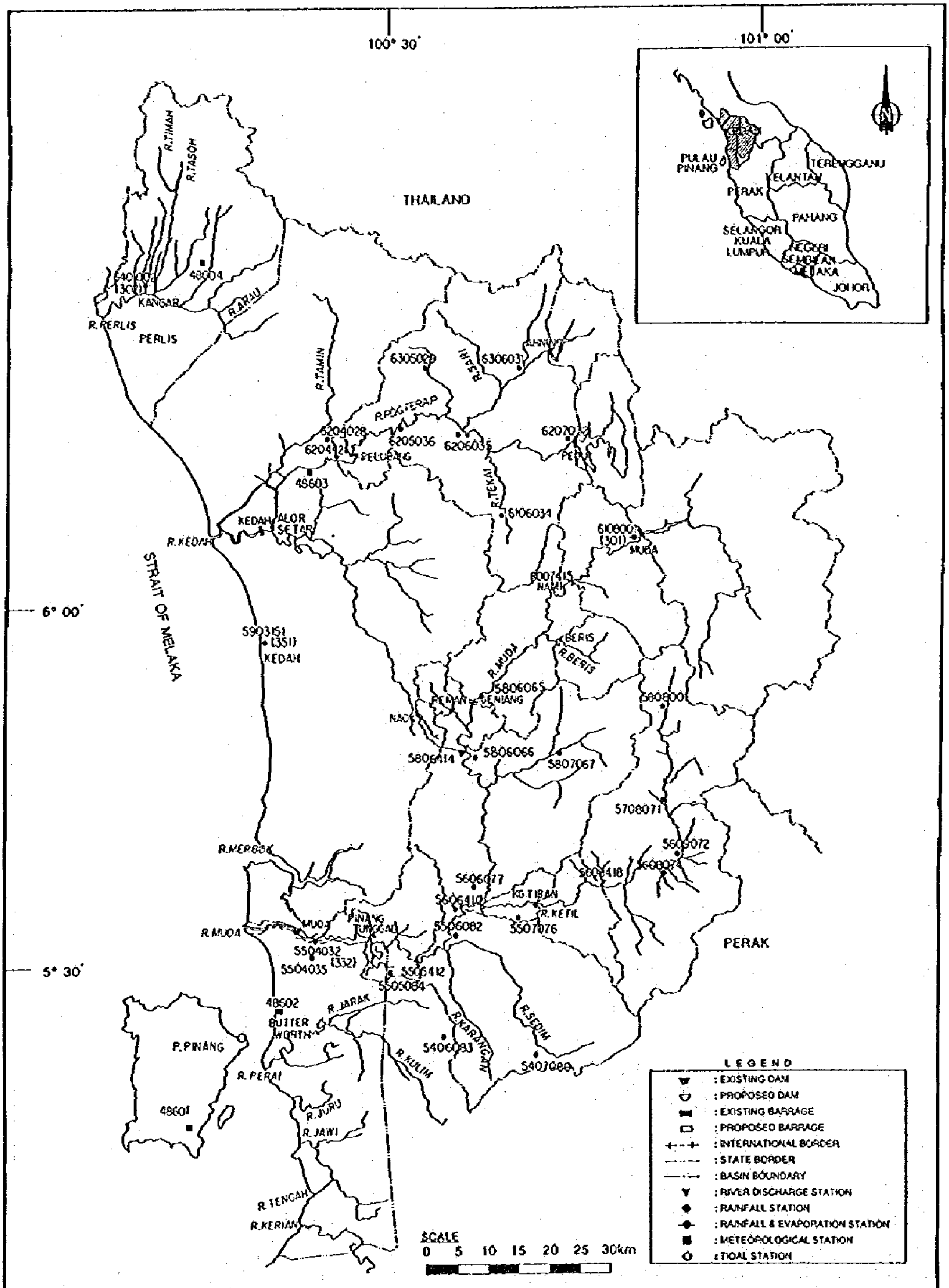
HYDROLOGY







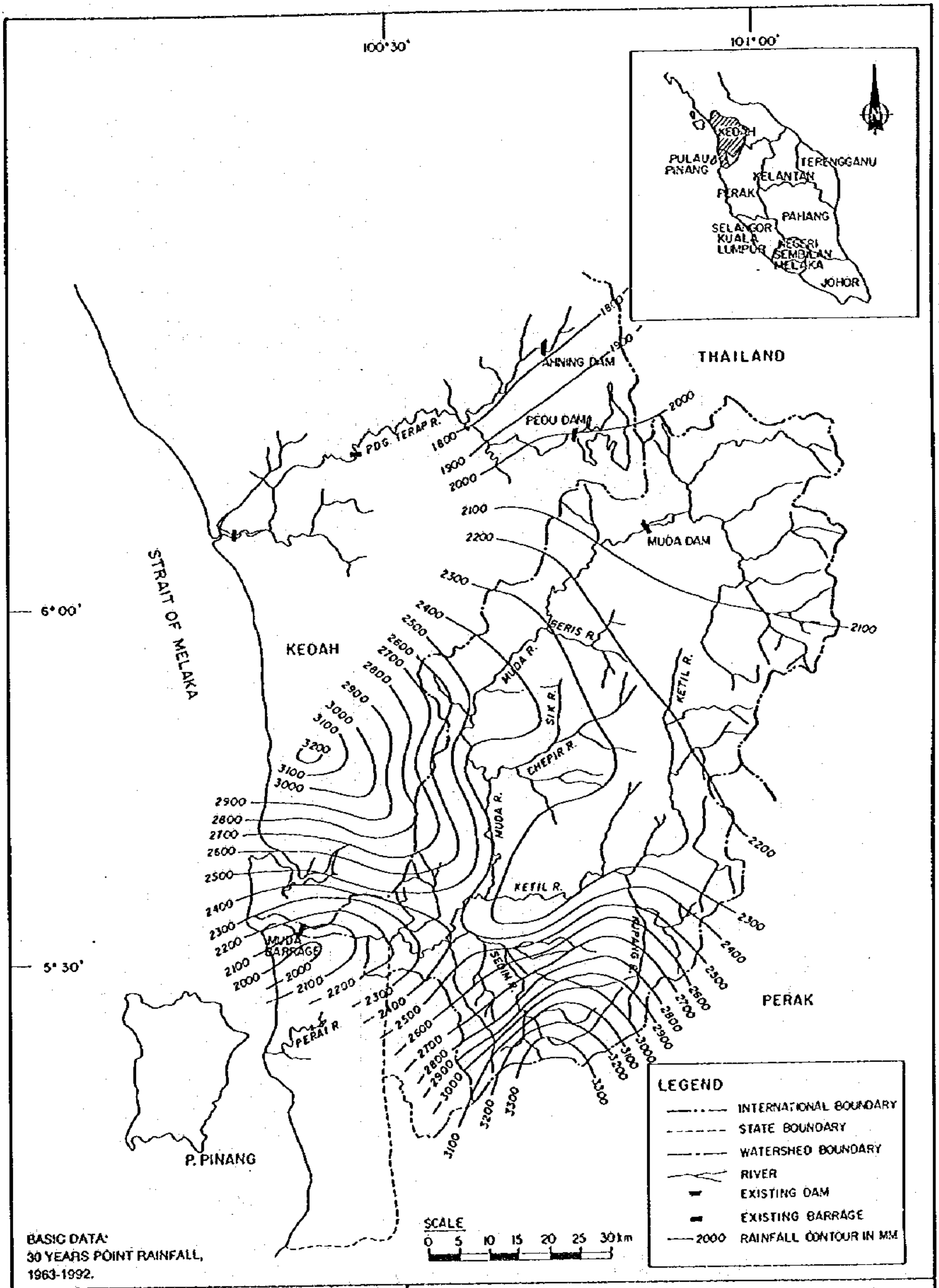
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY	FIG. I. 2.1.1 RATING CURVES OF DISCHARGE MEASUREMENT



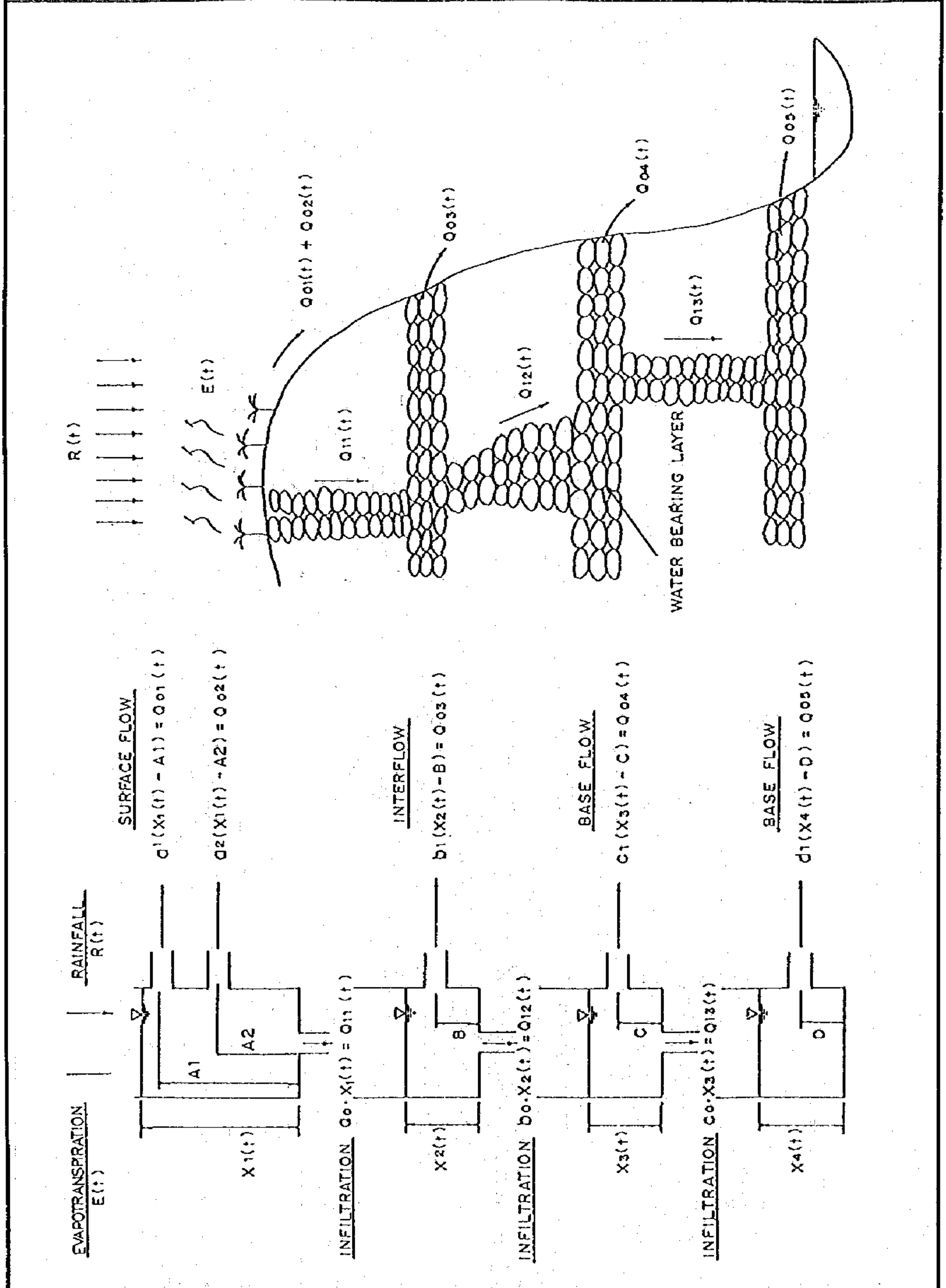
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

FIG. I. 3.1.1
LOCATION MAP OF GAUGING STATIONS AND BASIN BOUNDARIES



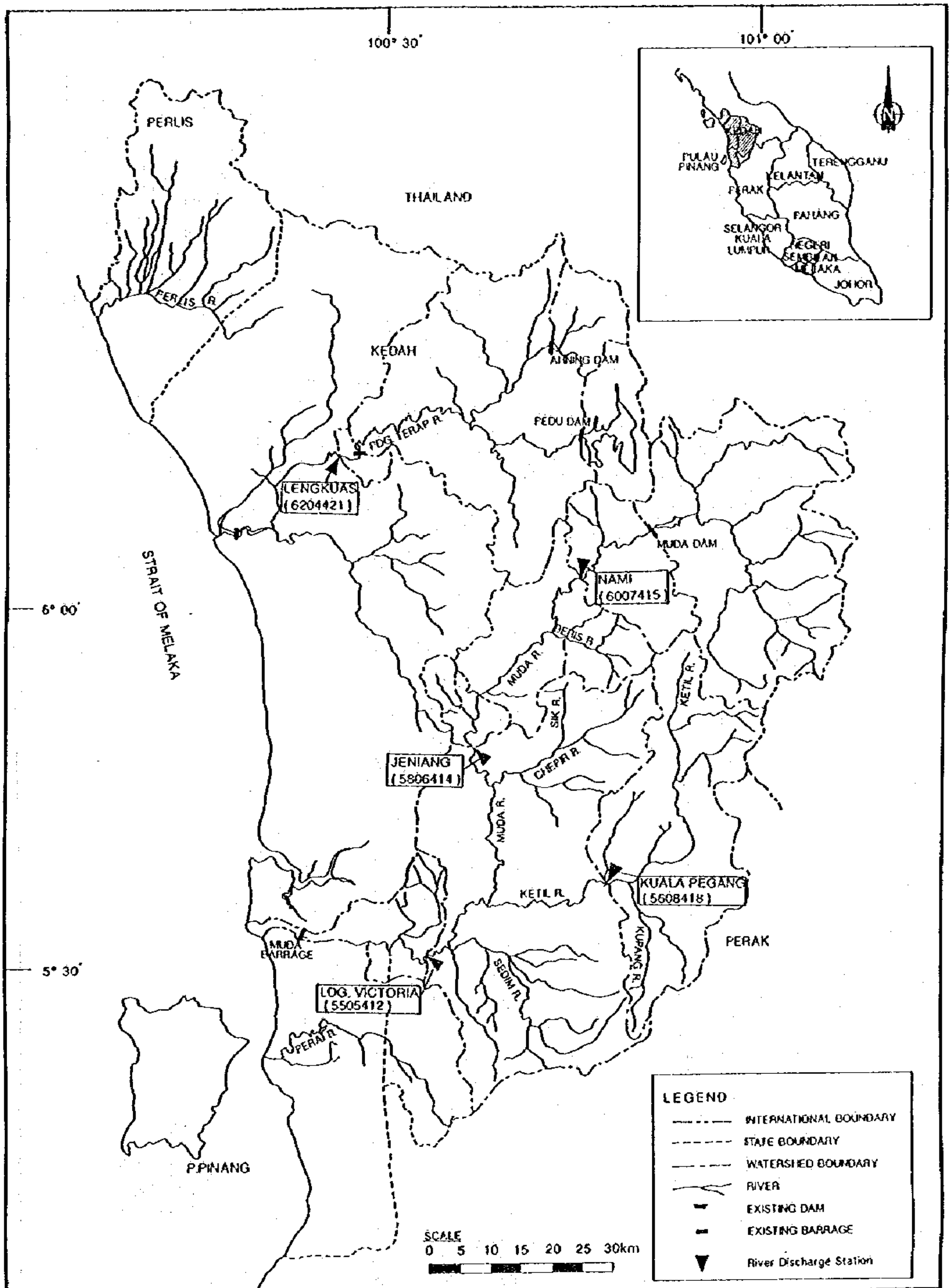
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. I. 4.2.1 MEAN ANNUAL RAINFALL ISOHYETS OF MUDA RIVER BASIN
JAPAN INTERNATIONAL COOPERATION AGENCY	



COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

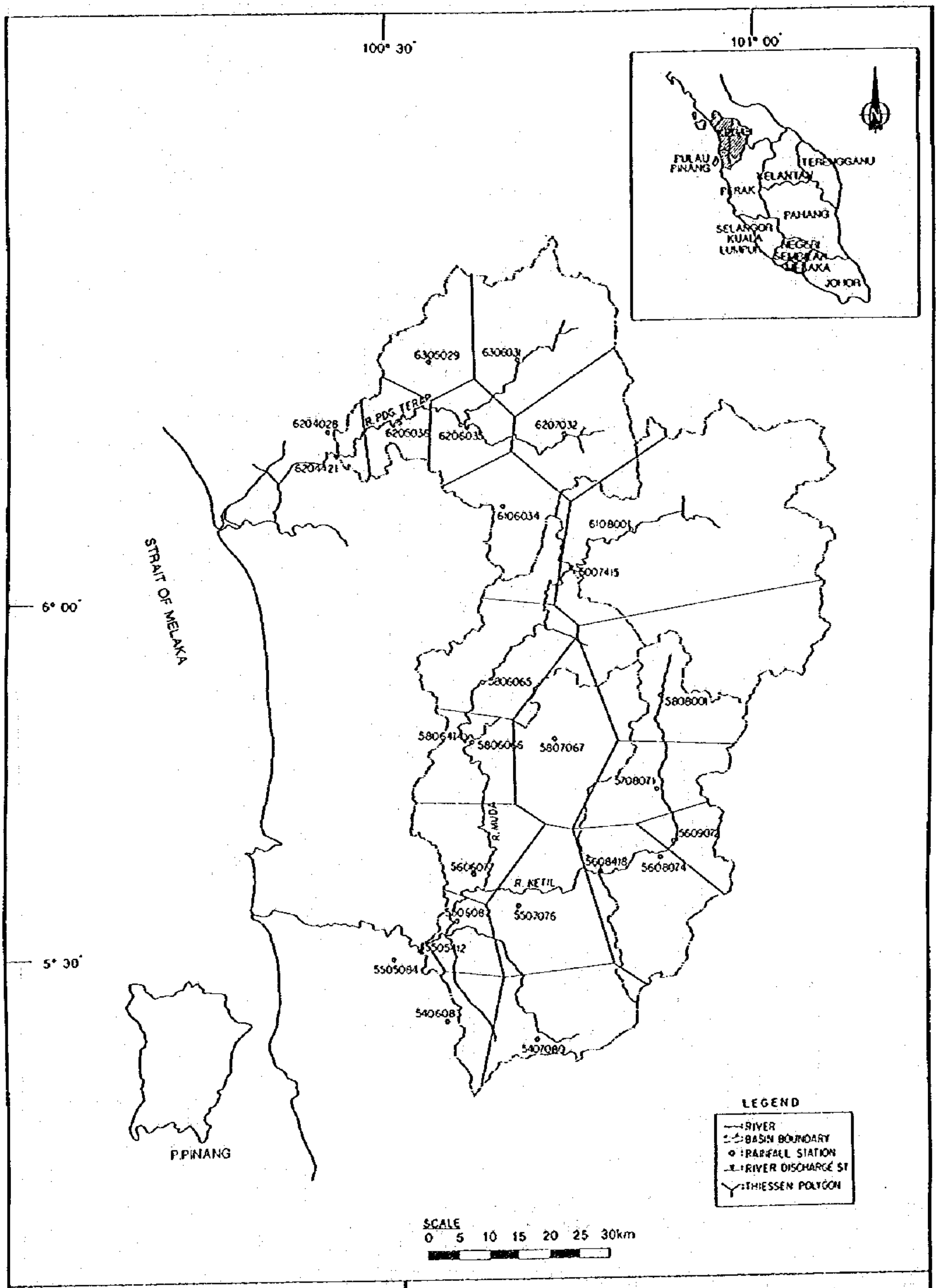
FIG. I. 5.1.1
CONCEPTUAL DIAGRAM OF TANK MODEL



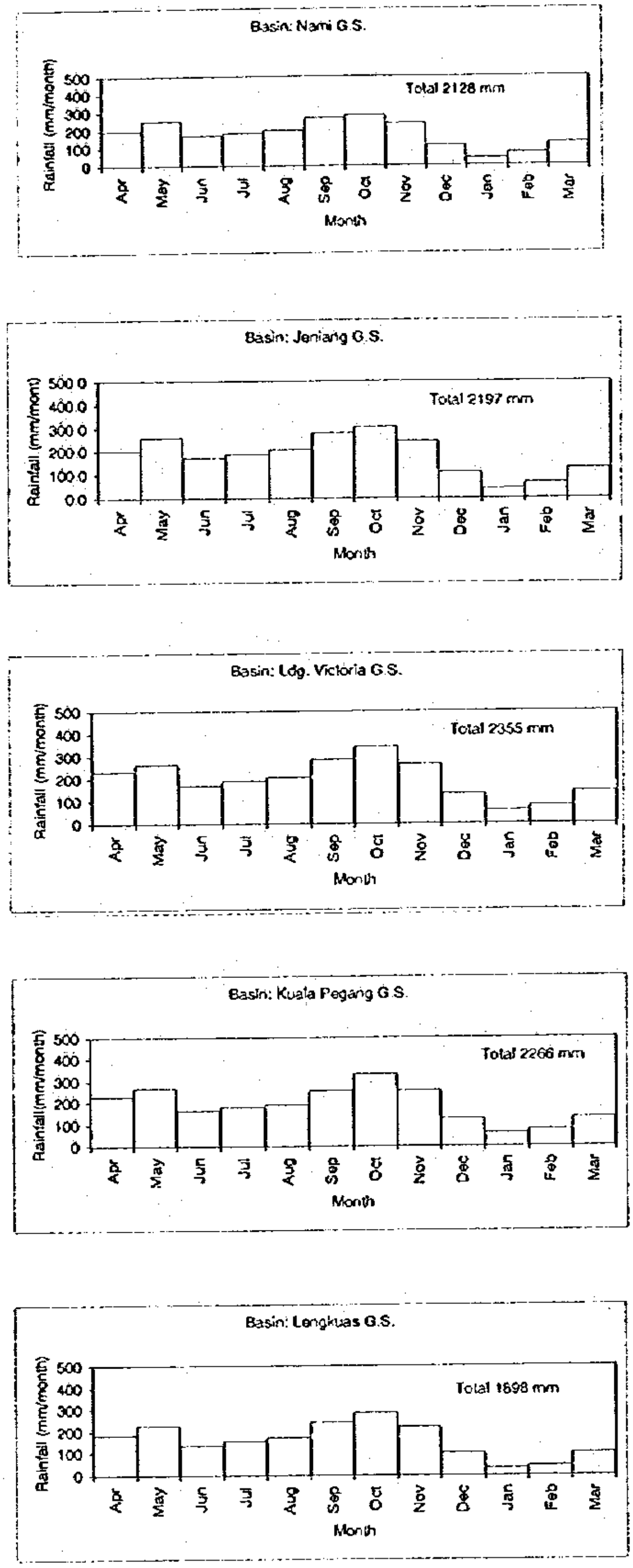
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

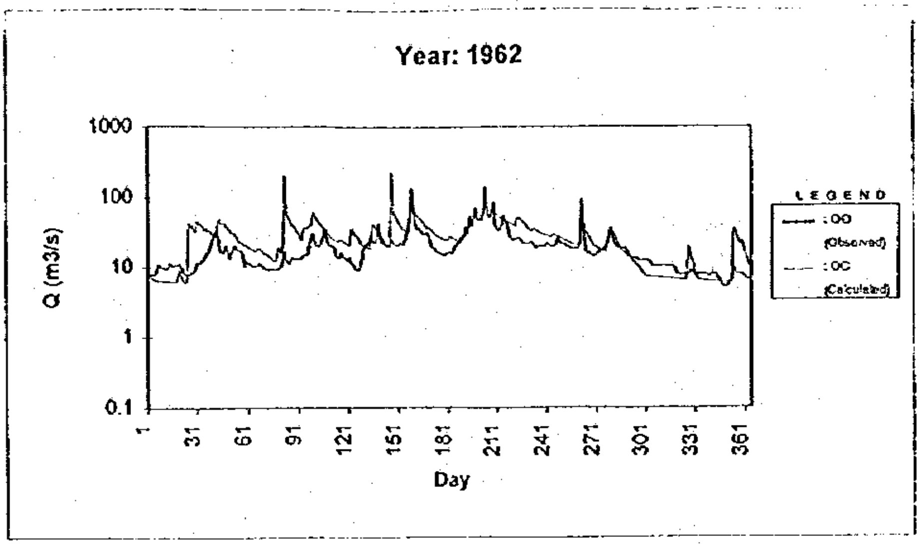
FIG. I. 5.1.2
LOCATION MAP OF REFERENCE POINTS FOR LOW FLOW ANALYSIS

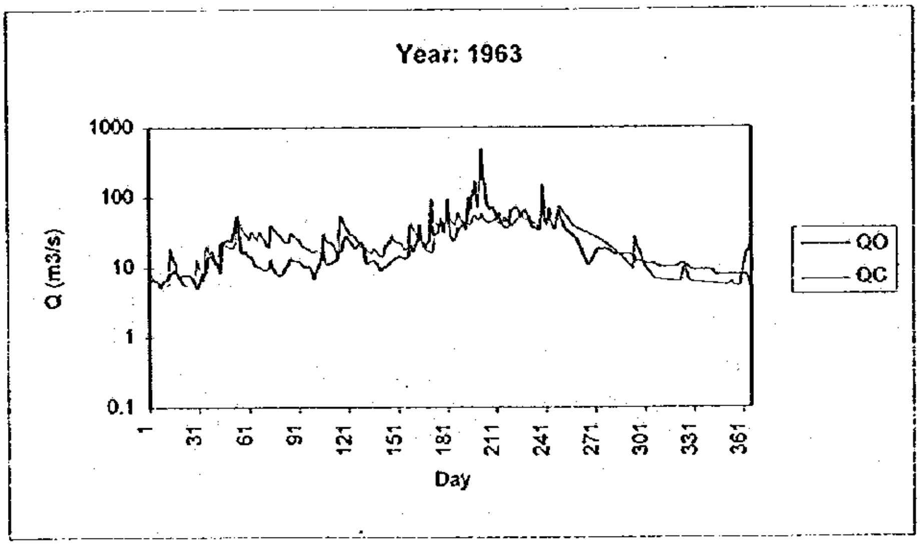


COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. I. 5.2.1 THIESSEN POLYGON NETWORK
JAPAN INTERNATIONAL COOPERATION AGENCY	

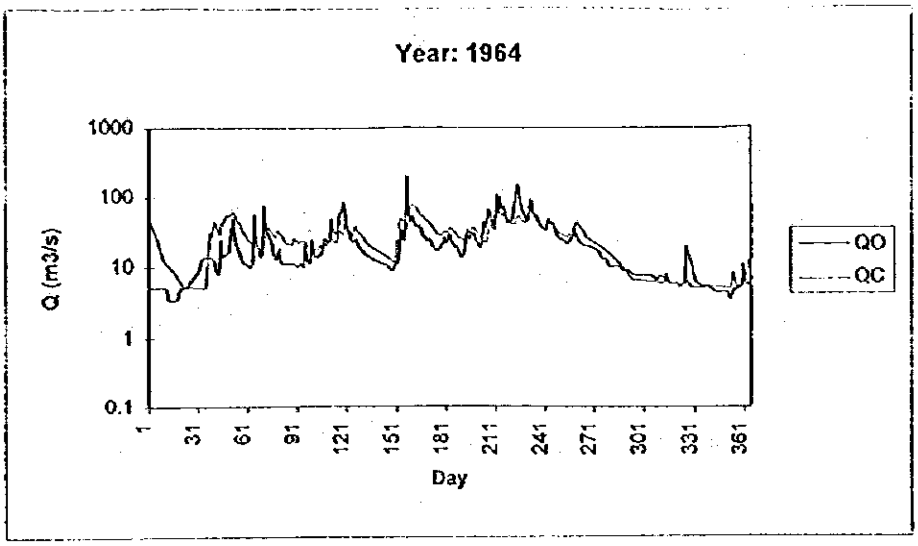


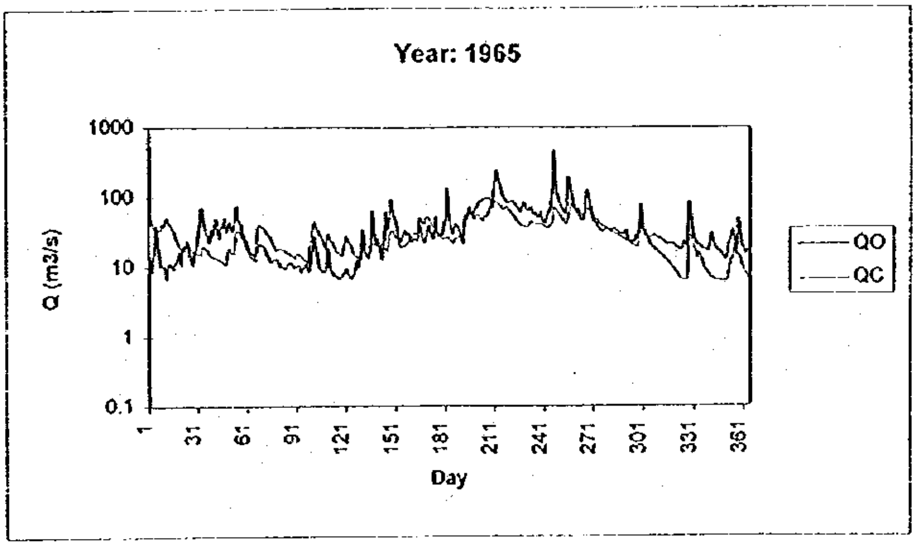
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. I. 5.2.2 HYETOGRAPH OF MONTHLY BASIN AVERAGE RAINFALL
JAPAN INTERNATIONAL COOPERATION AGENCY	



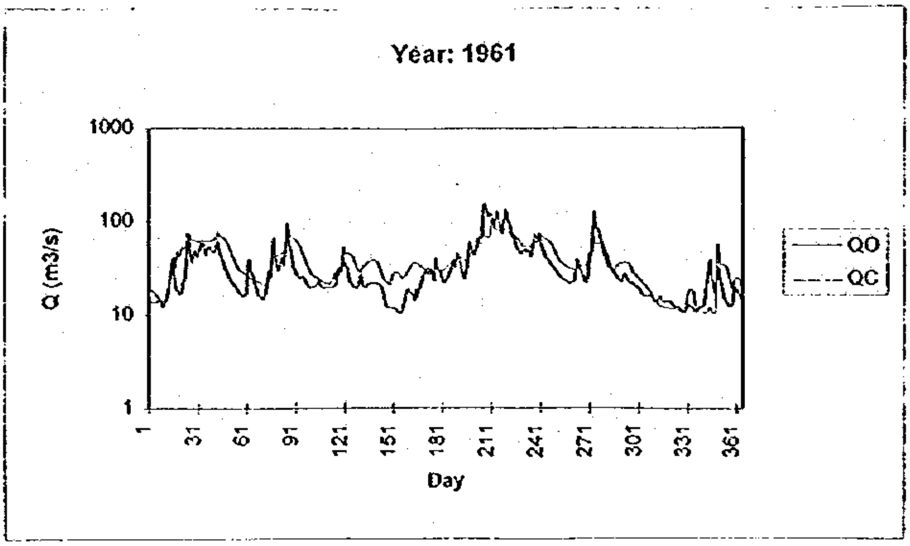


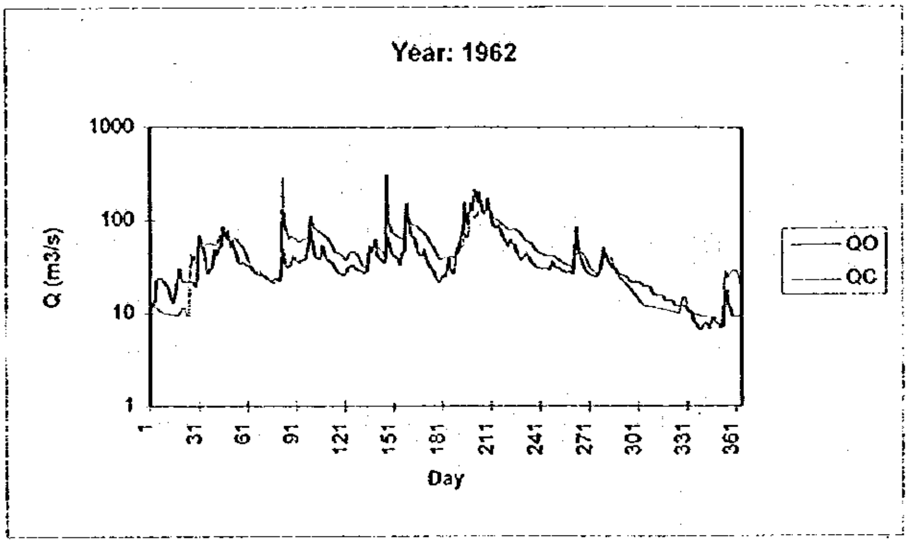
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. I. 5.3.1
JAPAN INTERNATIONAL COOPERATION AGENCY	DAILY RUNOFF DISCHARGE HYDROGRAPH (1/9) (NAMI STATION)



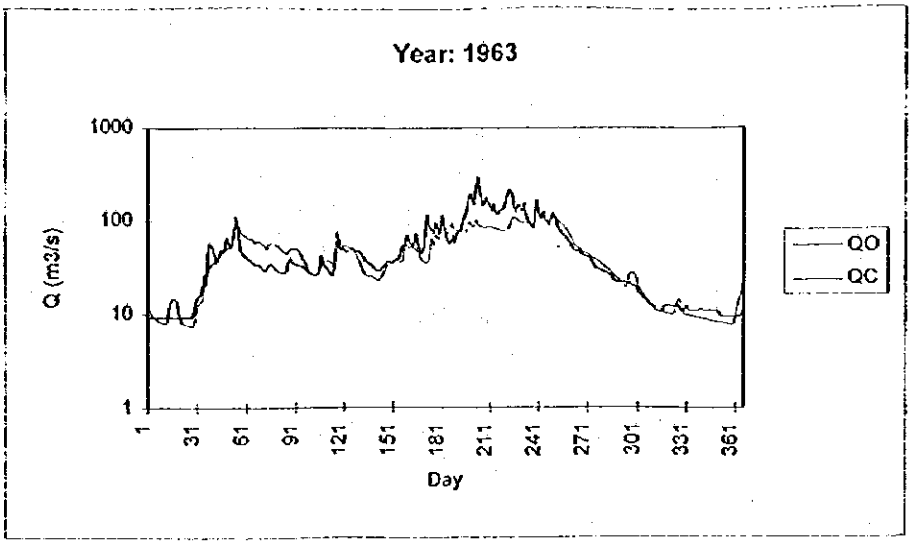


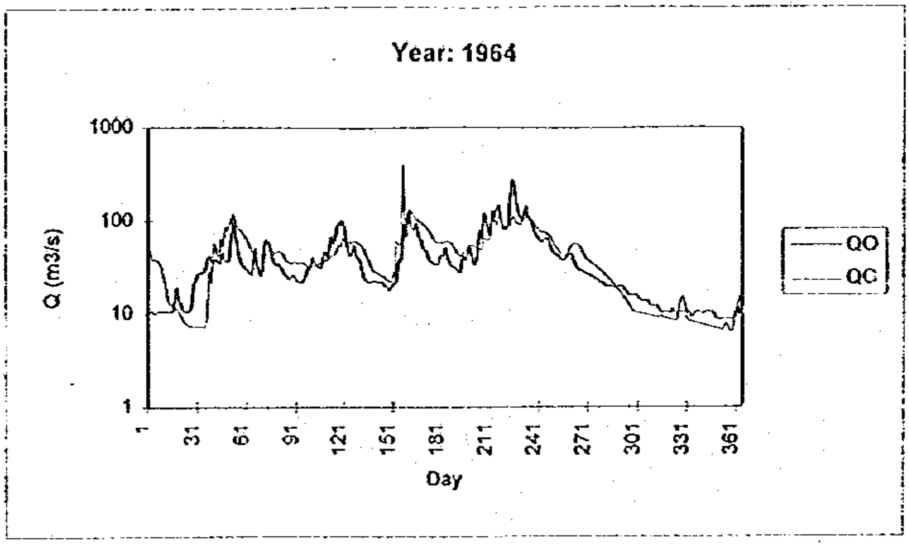
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY	FIG. I. 5.3.1 DAILY RUNOFF DISCHARGE HYDROGRAPH (2/9) (NAMI STATION)



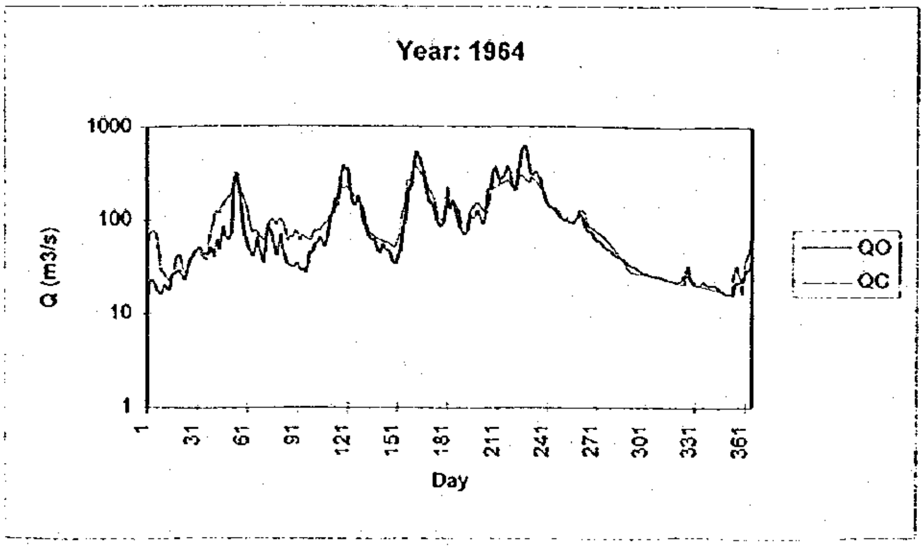


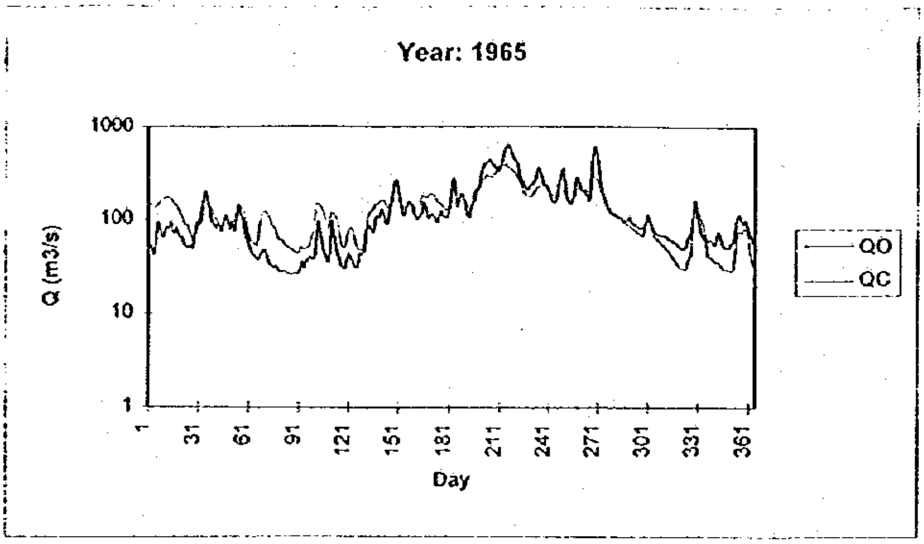
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY	FIG. I. 5.3.1 DAILY RUNOFF DISCHARGE HYDROGRAPH (3/9) (JENIANG STATION)

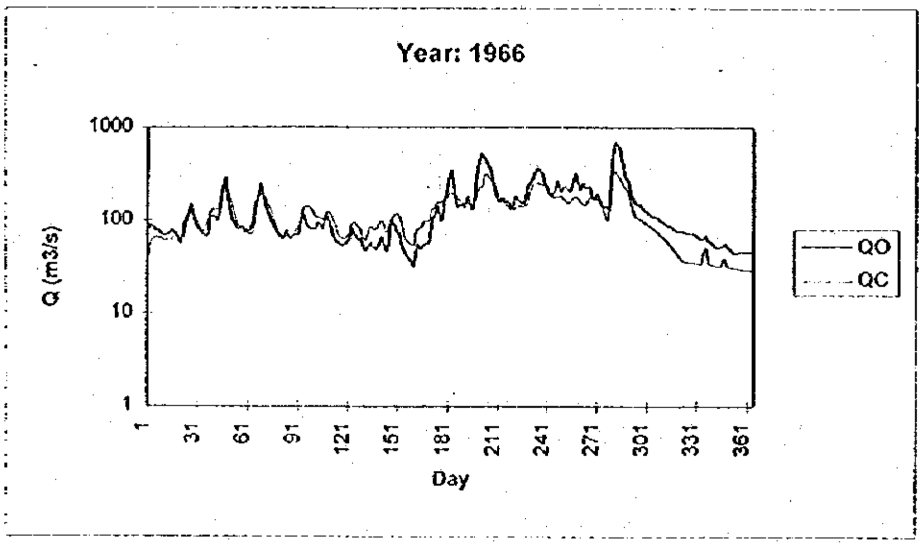




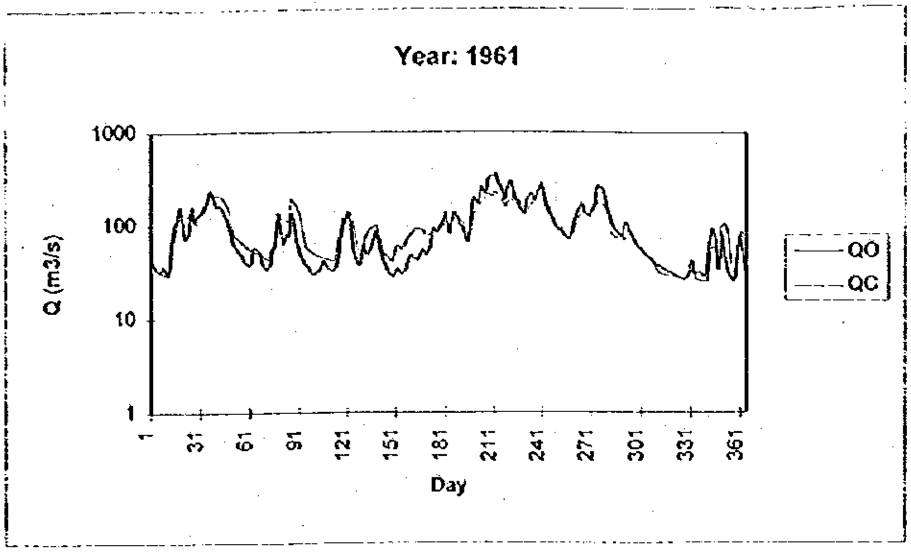
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. I. 5.3.1 DAILY RUNOFF DISCHARGE HYDROGRAPH (4/9) (JENIANG STATION)
JAPAN INTERNATIONAL COOPERATION AGENCY	

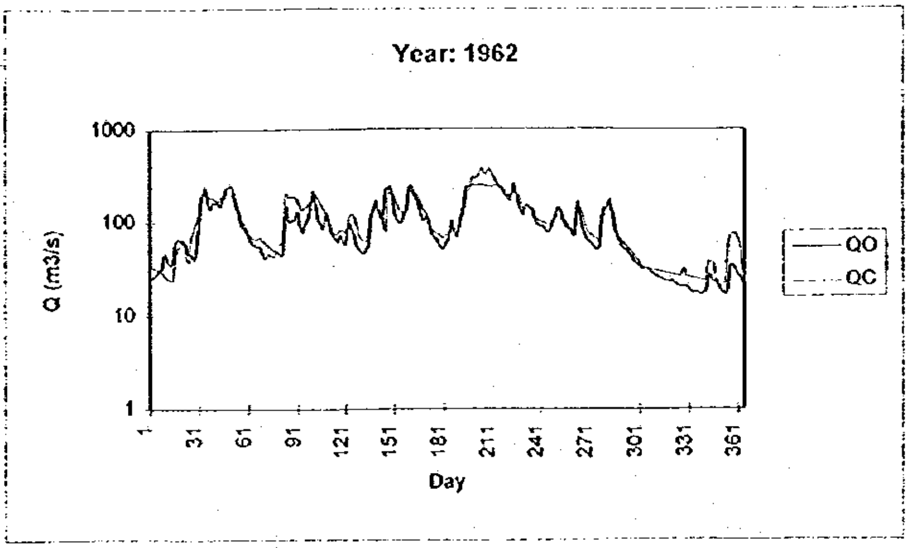


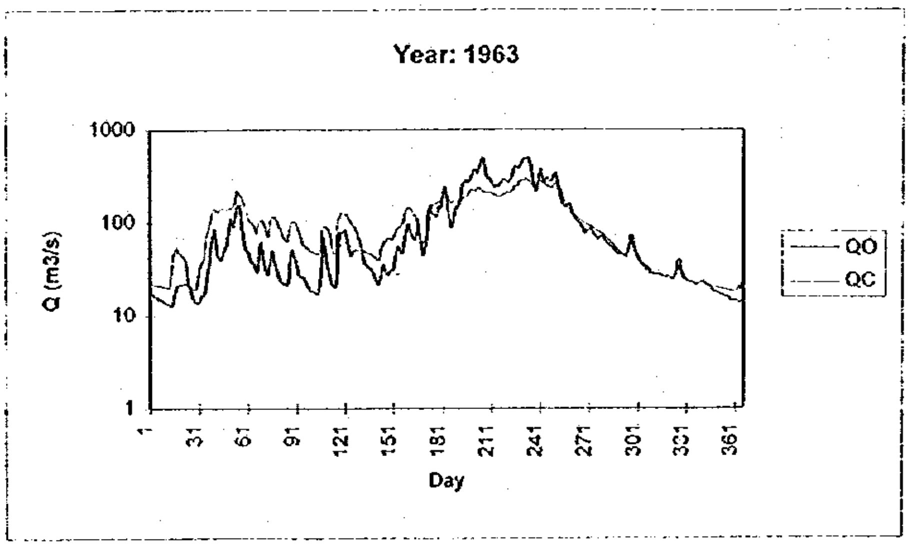




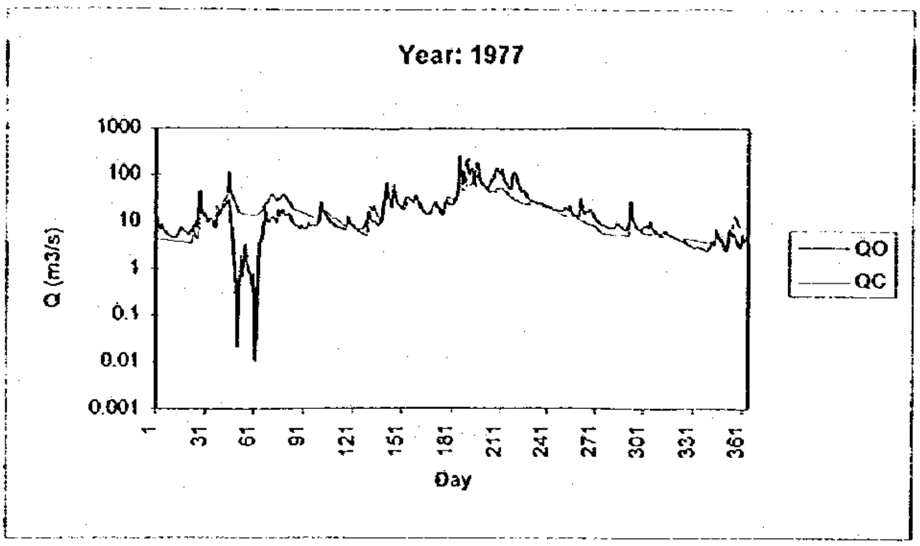
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY	FIG. I. 5.3.1 DAILY RUNOFF DISCHARGE HYDROGRAPH (5/9) (LDG. VICTORIA STATION)

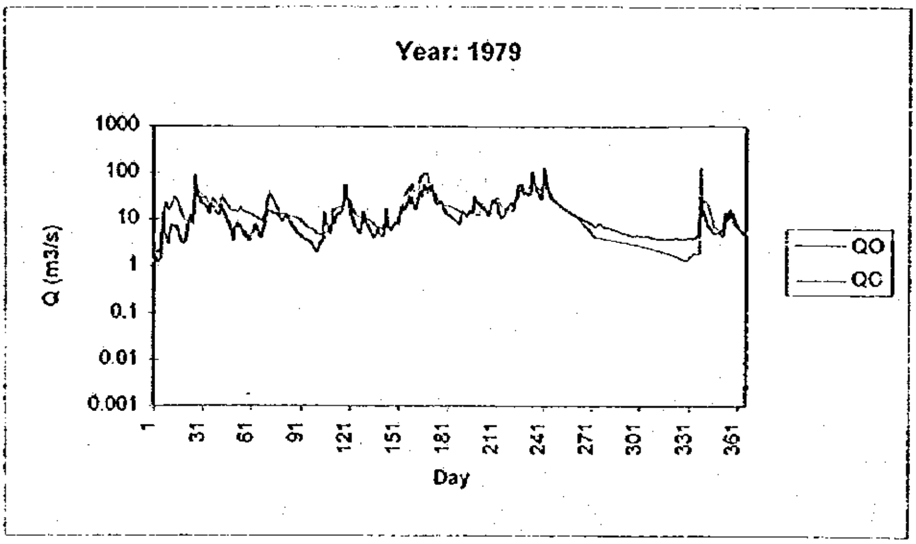




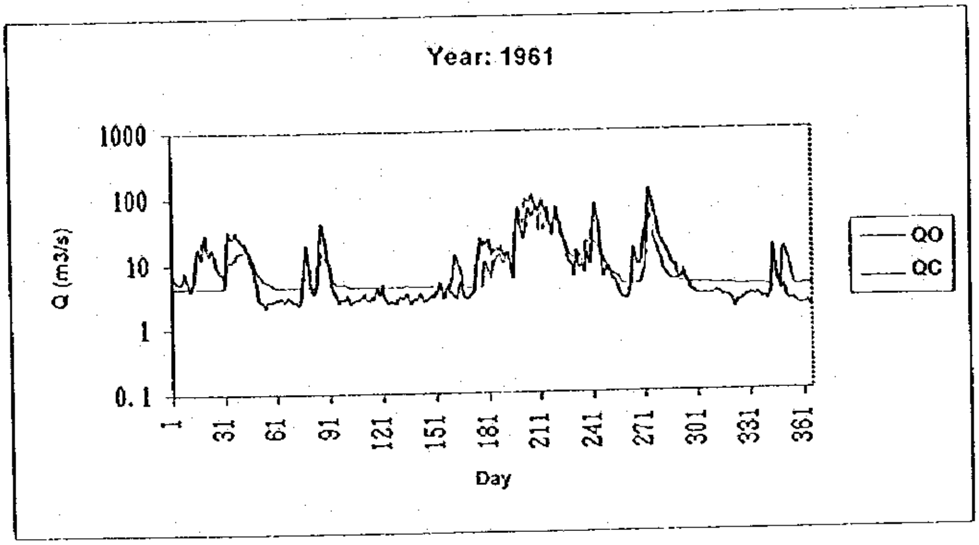


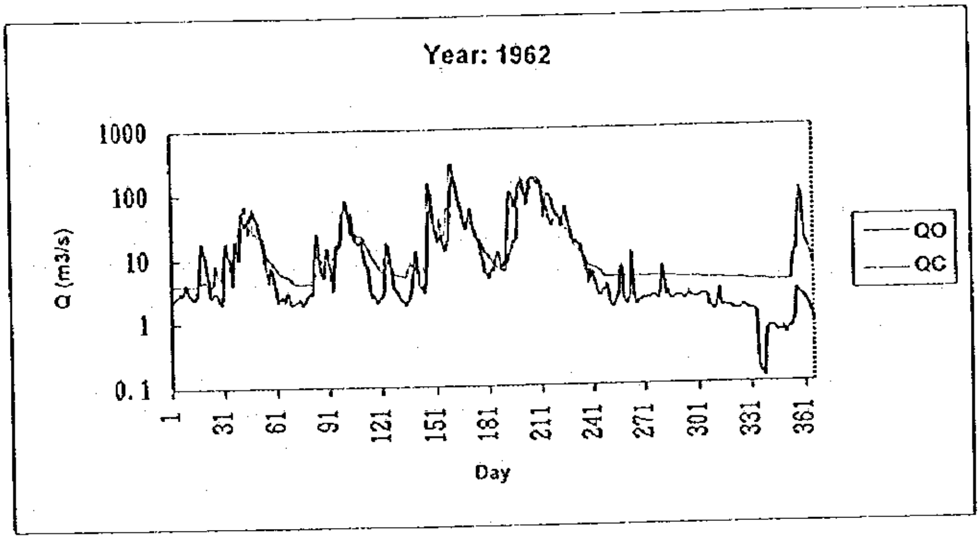
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY	FIG. I. 5.3.1 DAILY RUNOFF DISCHARGE HYDROGRAPH (6/9) (LDG. VICTORIA STATION)

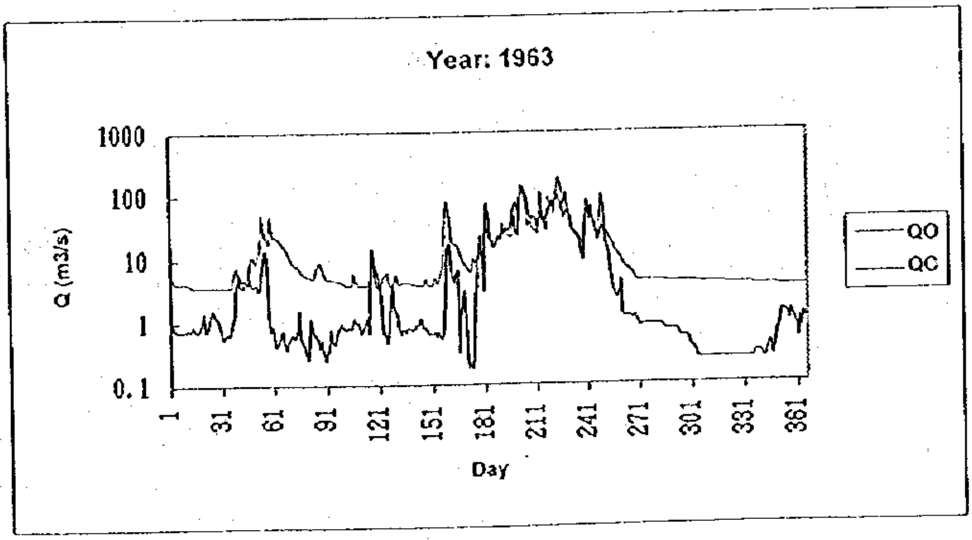




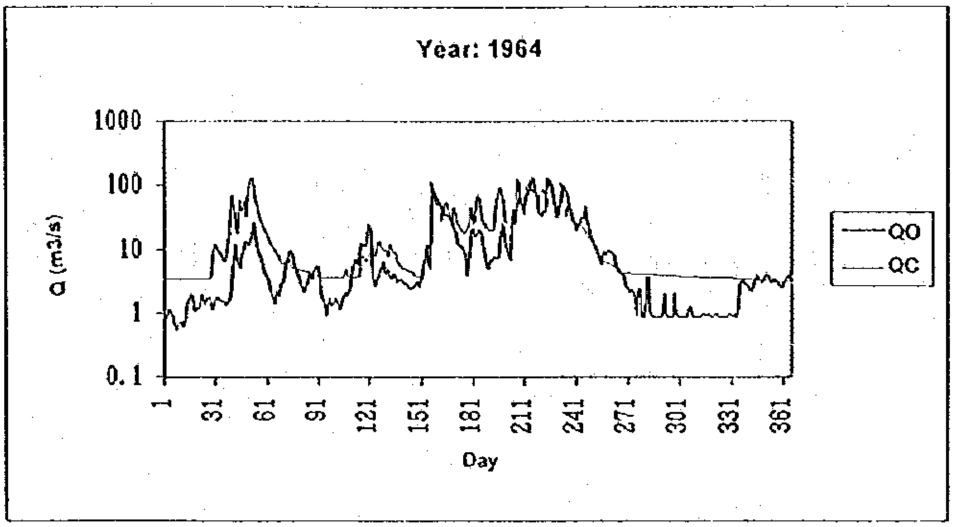
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY	FIG. I. 5.3.1 DAILY RUNOFF DISCHARGE HYDROGRAPH (7/9) (KUALA PEGANG STATION)

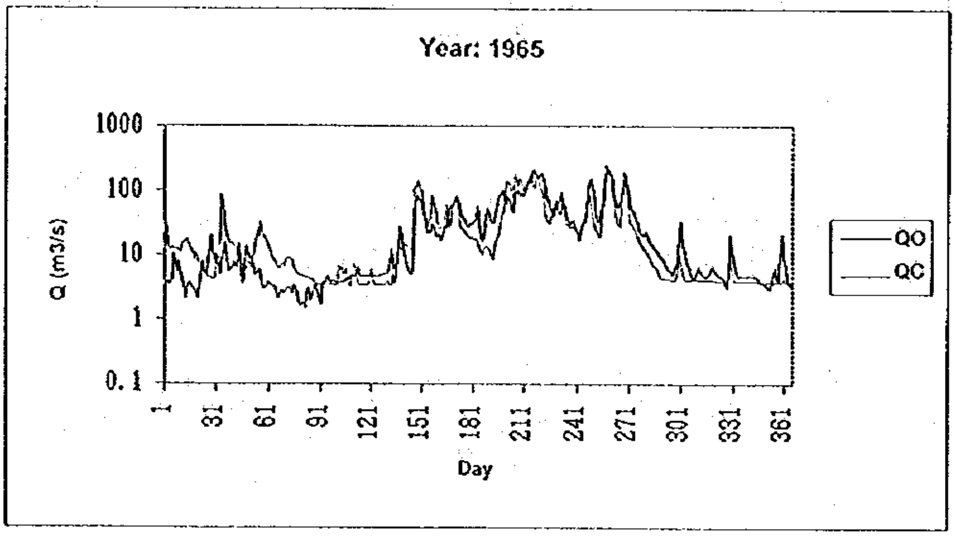


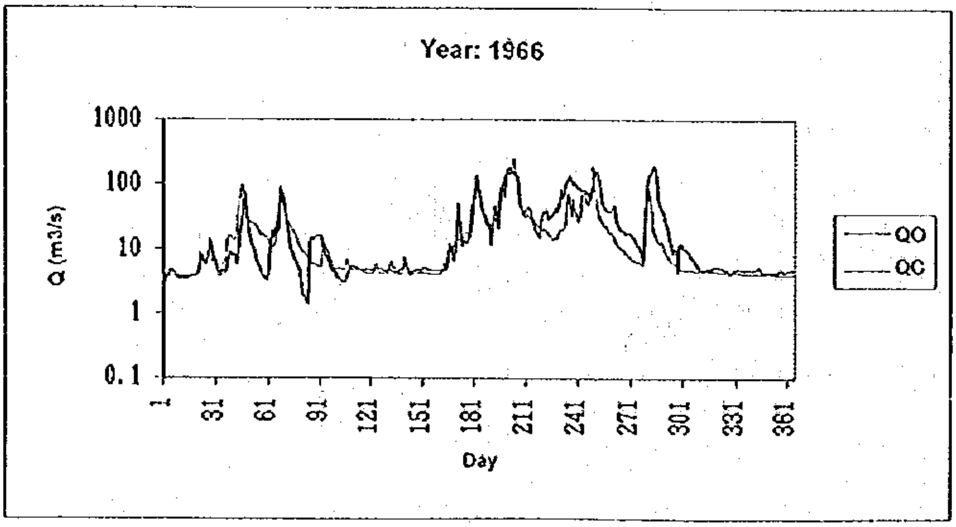




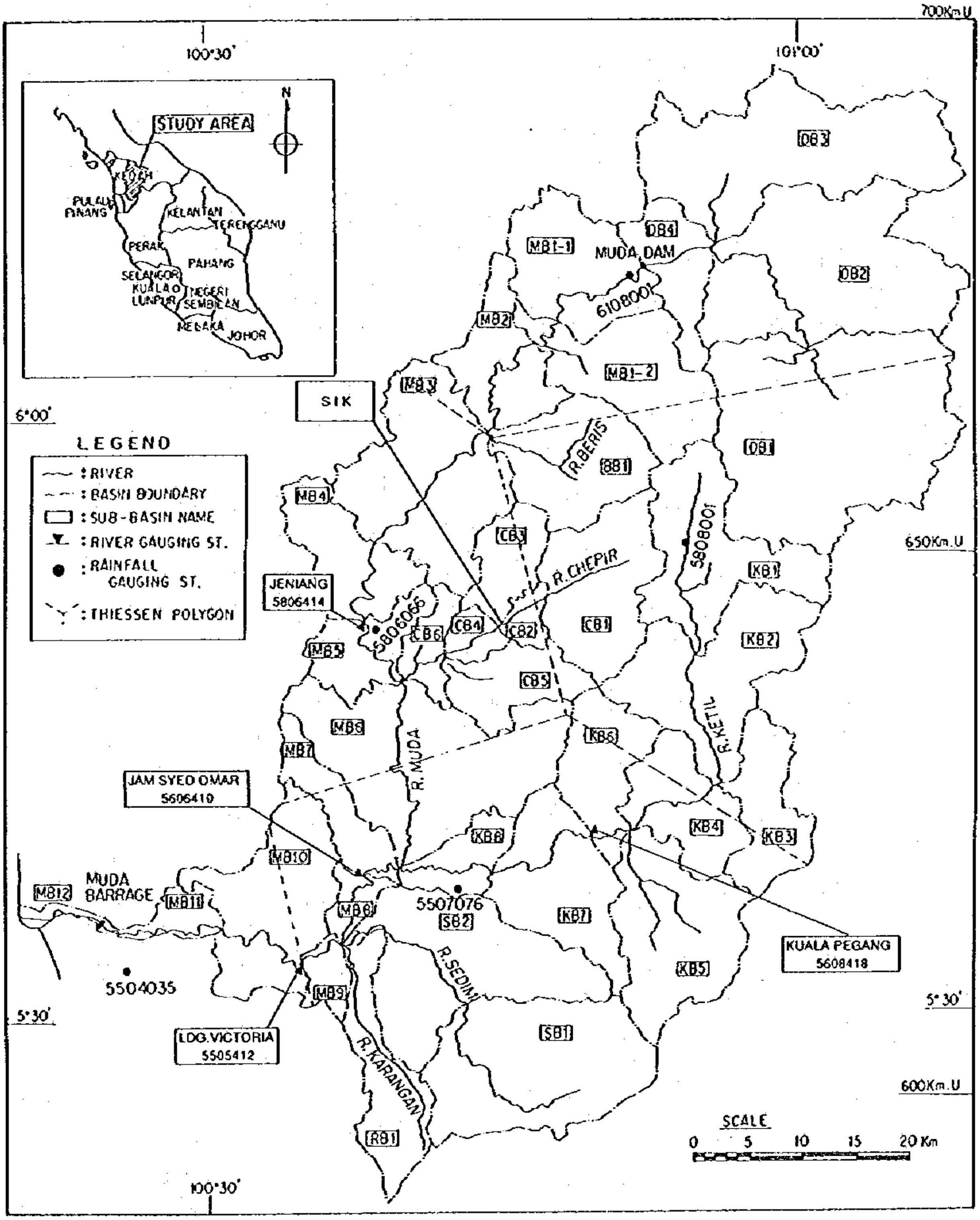
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY	FIG. I. 5.3.1 DAILY RUNOFF DISCHARGE HYDROGRAPH (8/9) (LENGKUAS STATION)



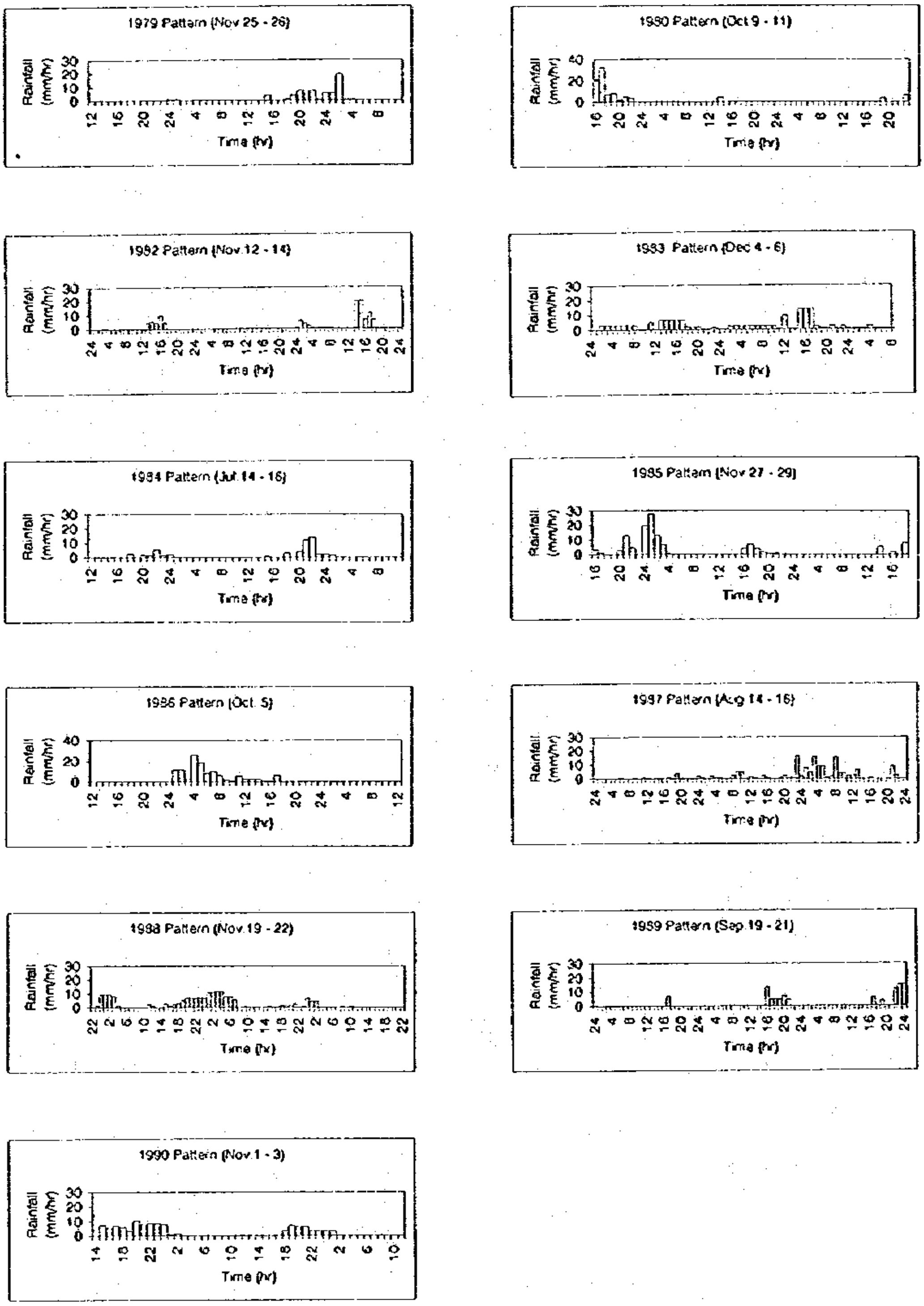




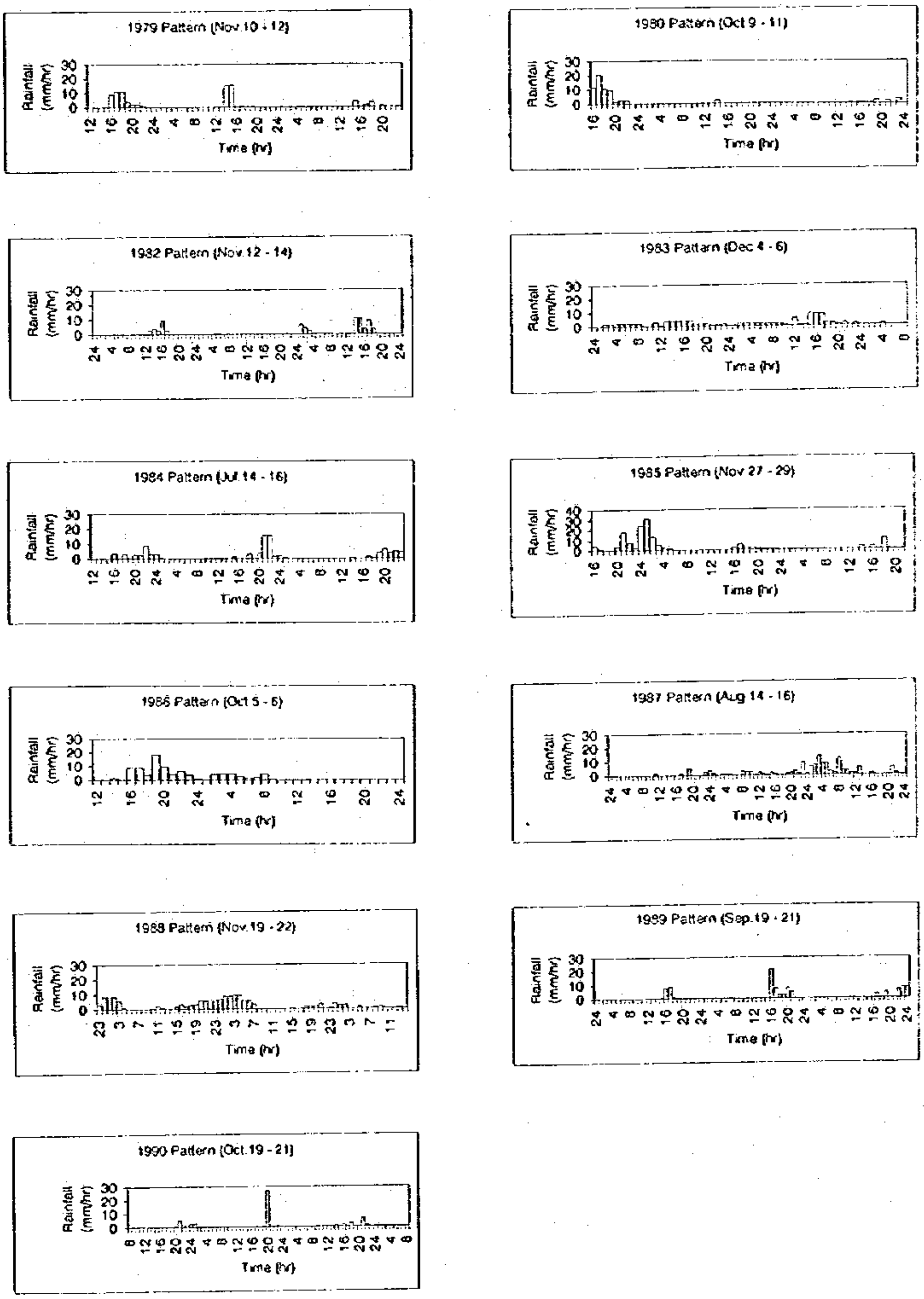
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. I. 5.3.1 DAILY RUNOFF DISCHARGE HYDROGRAPH (9/9) (LENGKUAS STATION)
JAPAN INTERNATIONAL COOPERATION AGENCY	



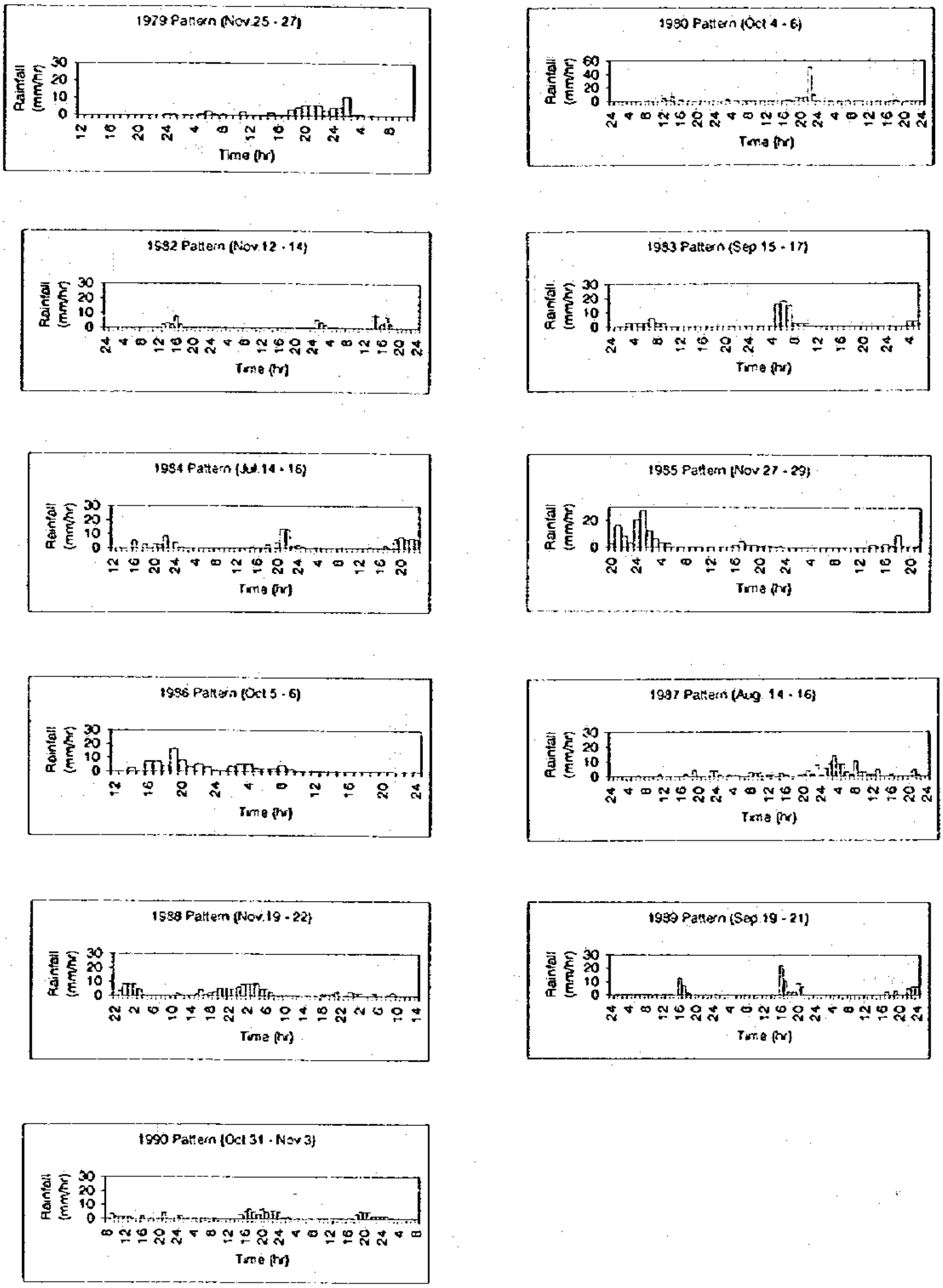
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY	FIG. I. 6.1.1 LOCATION MAP OF REFERENCE POINTS AND DIVISION OF MUDA RIVER BASIN FOR FLOOD RUNOFF ANALYSIS



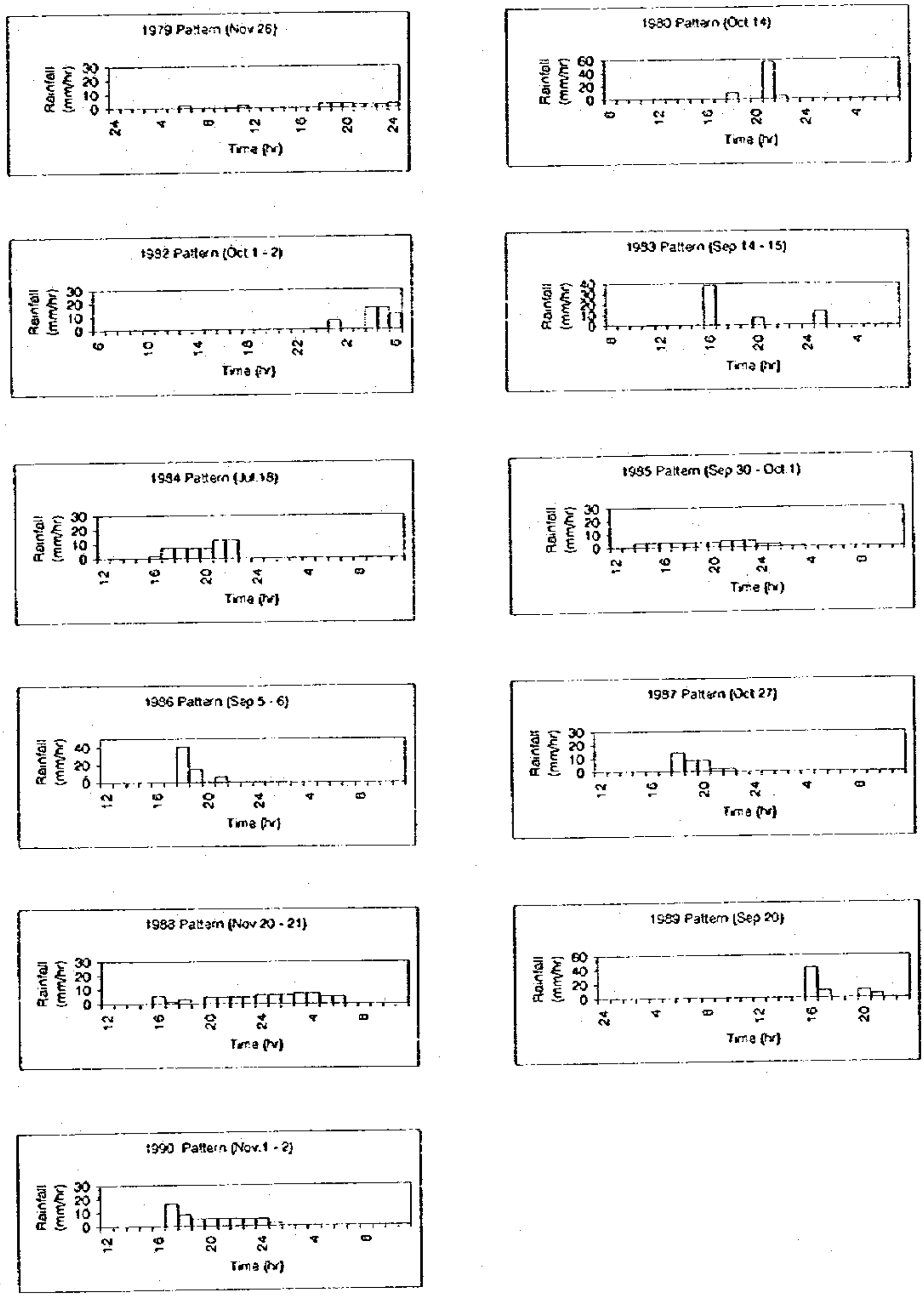
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY	FIG. I. 6.1.2 HOURLY BASIN AVERAGE HYETOGRAPH (1/5) (JENIANG)



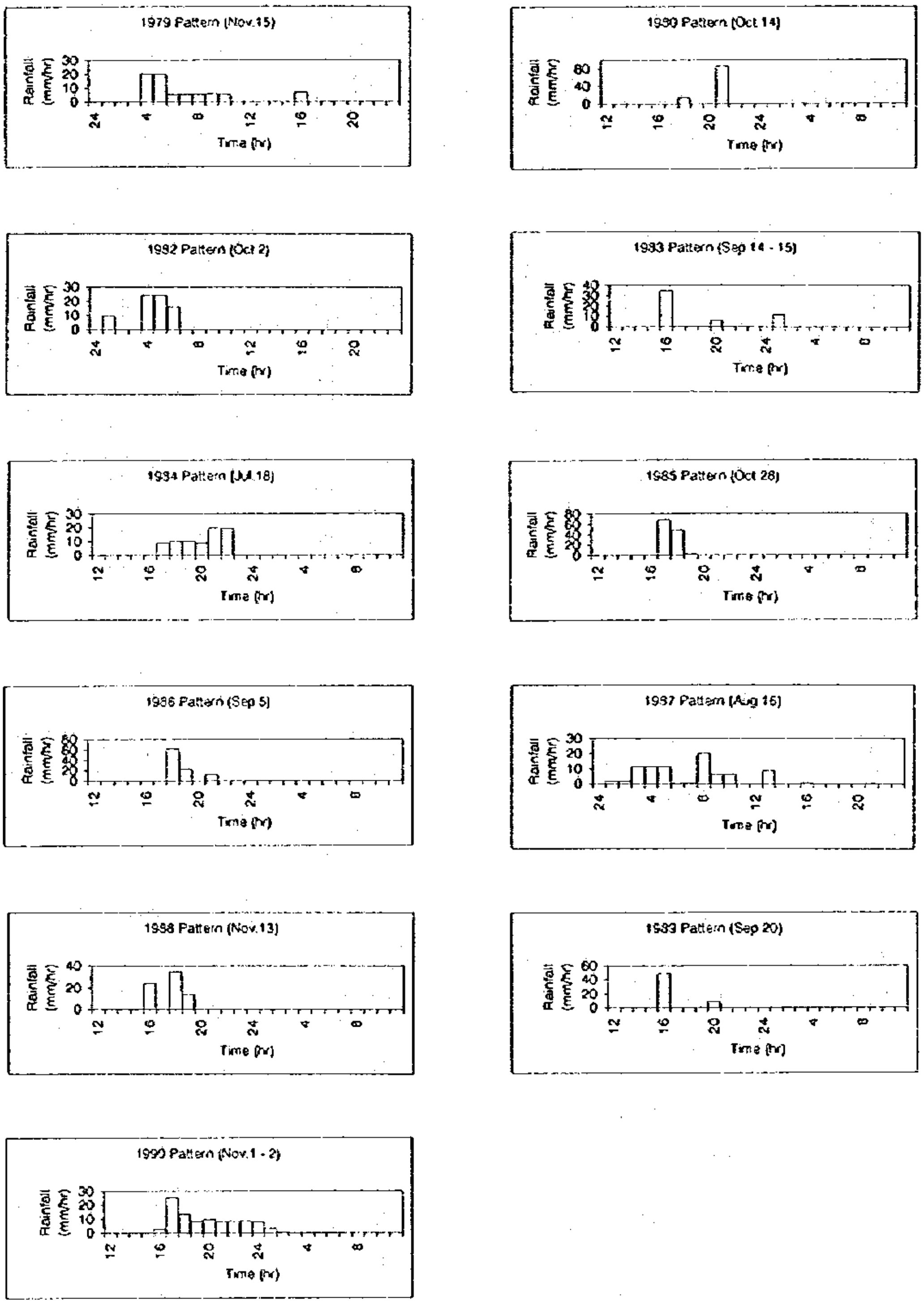
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. I. 6.1.2 HOURLY BASIN AVERAGE HYETOGRAPH (2/5) (JAM. SYED OMAR)
JAPAN INTERNATIONAL COOPERATION AGENCY	



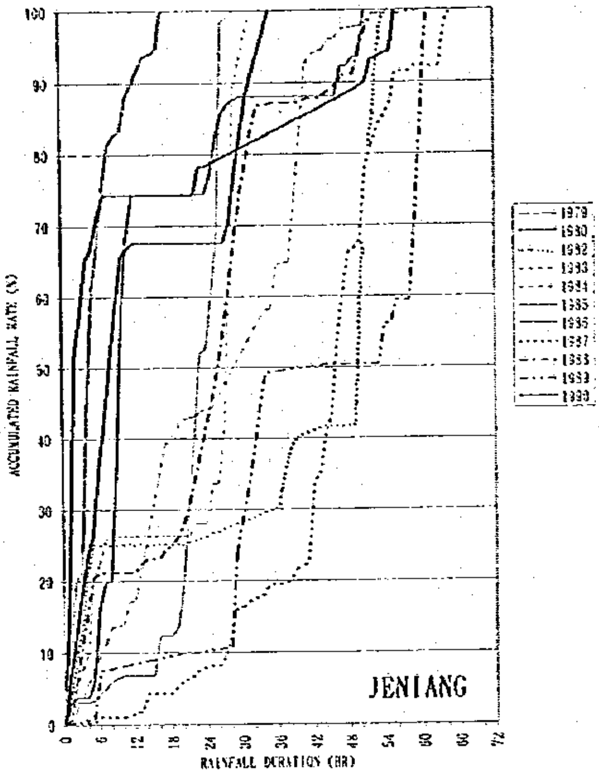
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY	FIG. I. 6.1.2 HOURLY BASIN AVERAGE HYETOGRAPH (3/5) (LDG. VICTORIA)

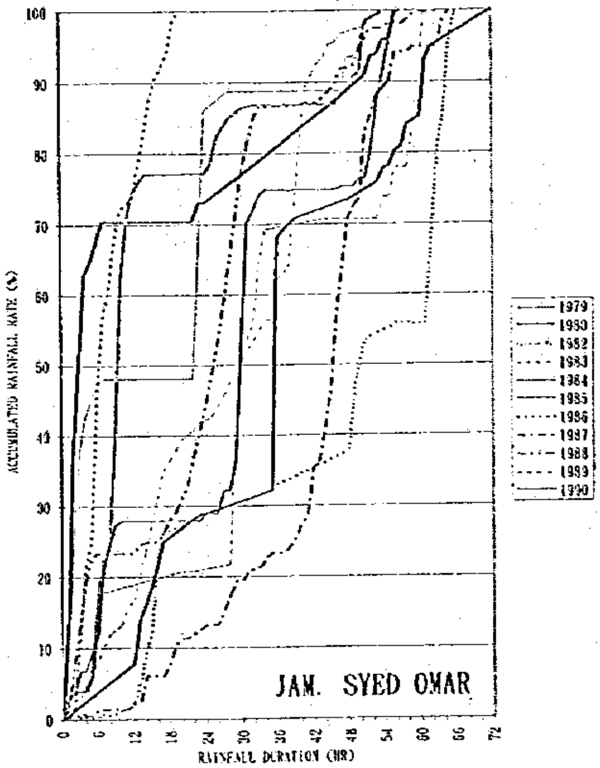


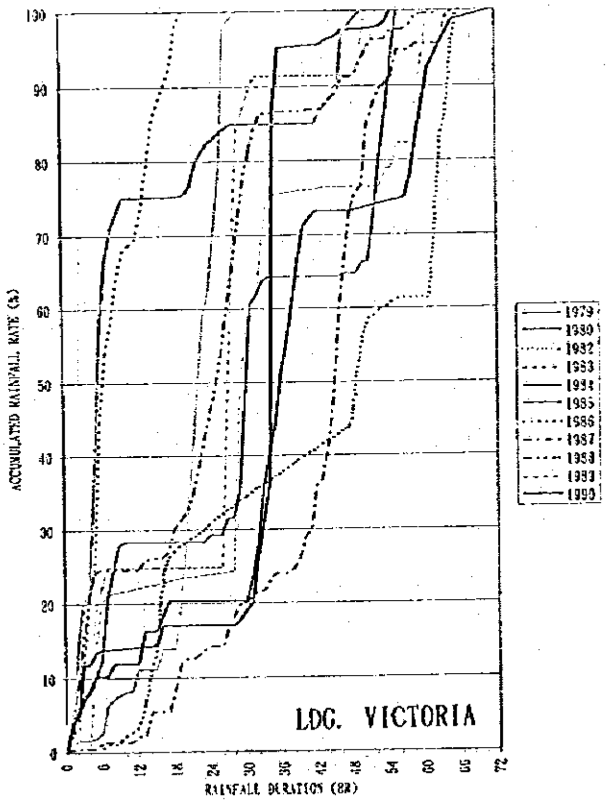
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. I. 6.1.2 HOURLY BASIN AVERAGE HYETOGRAPH (4/5) (KUALA PEGANG)
JAPAN INTERNATIONAL COOPERATION AGENCY	



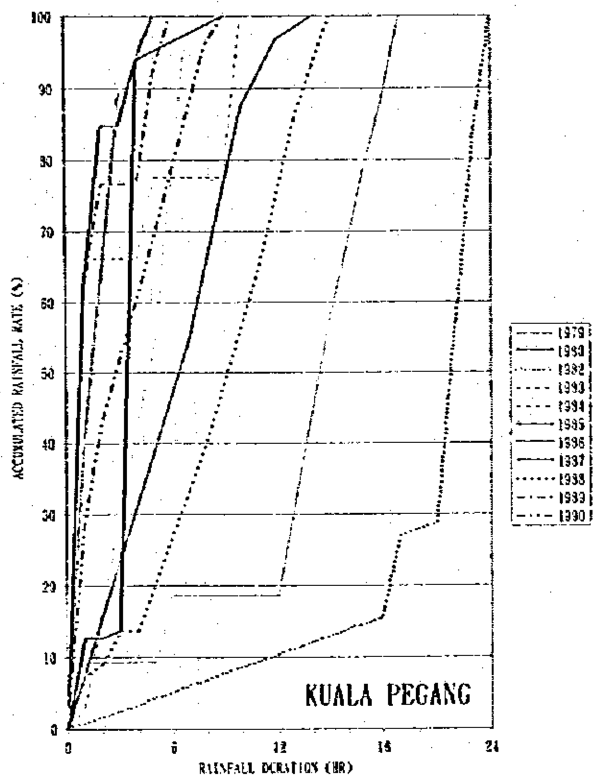
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY	FIG. I. 6.1.2 HOURLY BASIN AVERAGE HYETOGRAPH (5/5) (SIK)

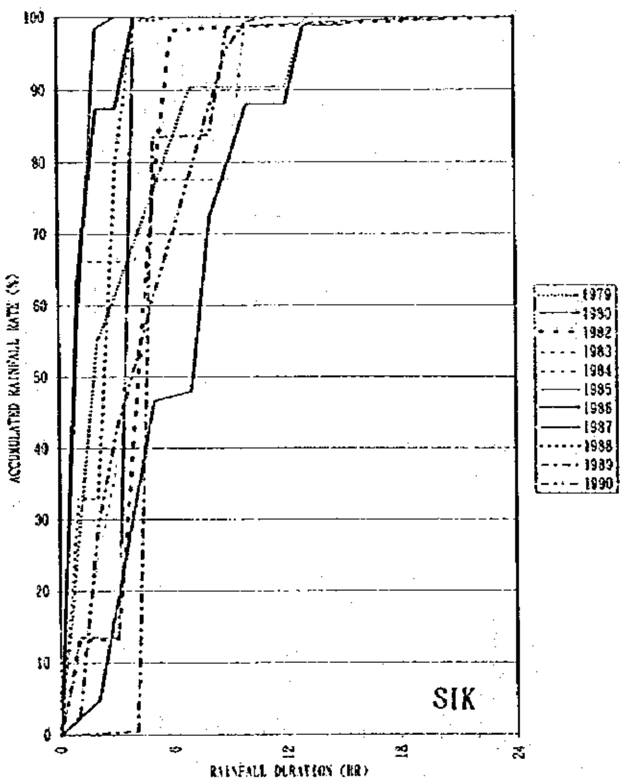






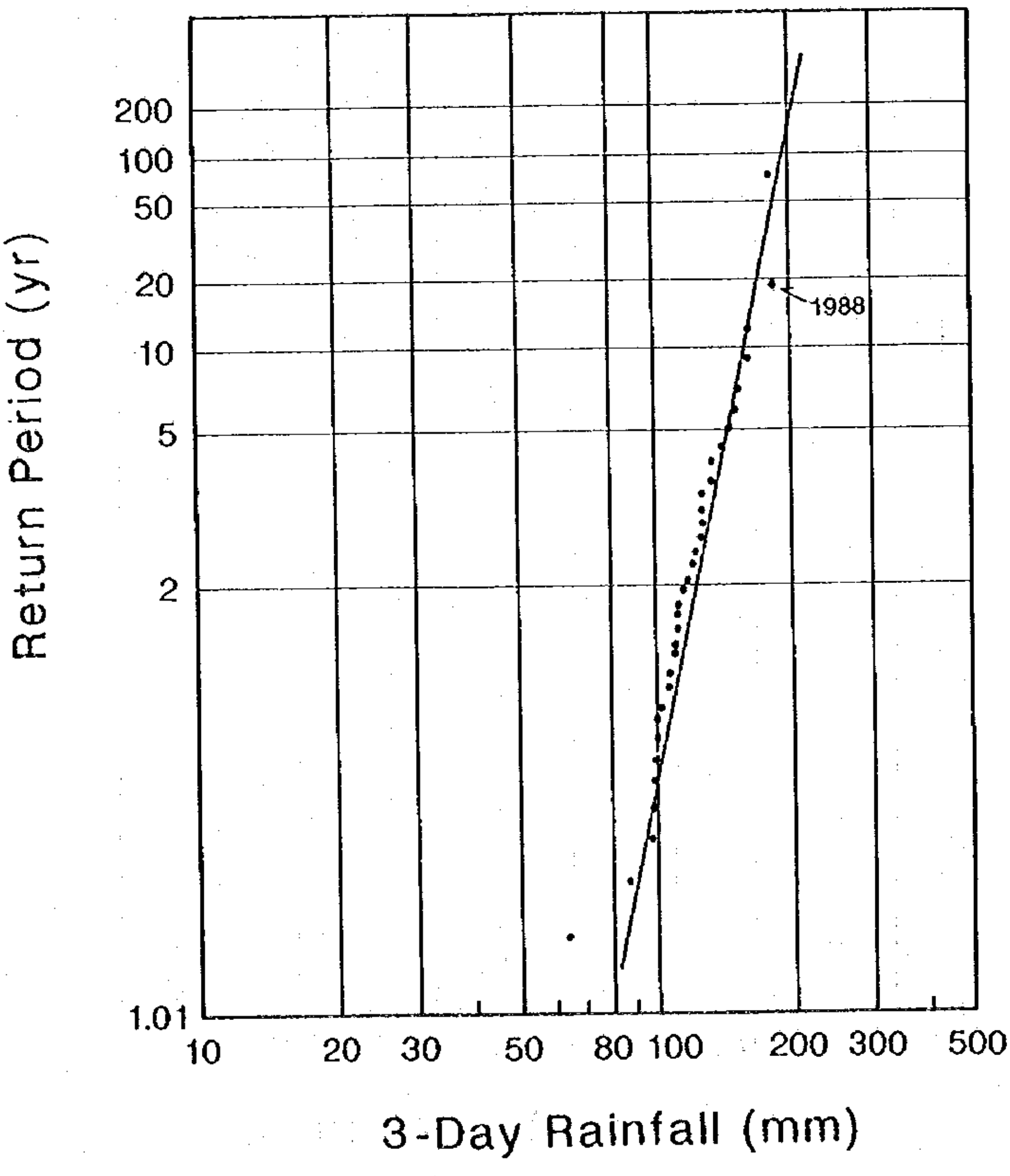
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY	FIG. I. 6.1.3 RAINFALL DURATION AND ACCUMULATED RAINFALL RATE (1/2)





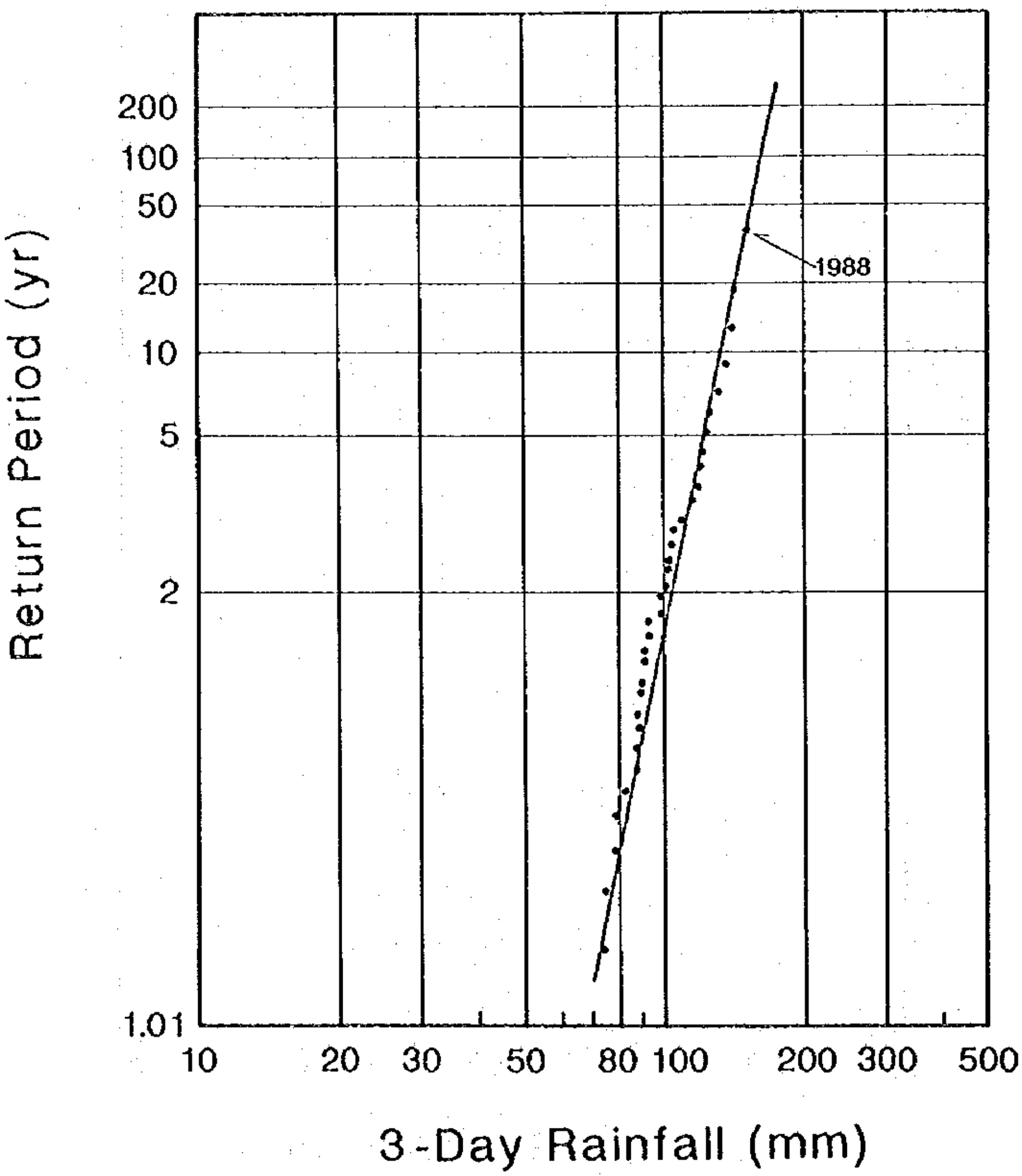
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY	FIG. I. 6.1.3 RAINFALL DURATION AND ACCUMULATED RAINFALL RATE (2/2)

Jeniang



COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY	FIG. I. 6.1.4 PROBABLE BASIN RAINFALL (1/5)

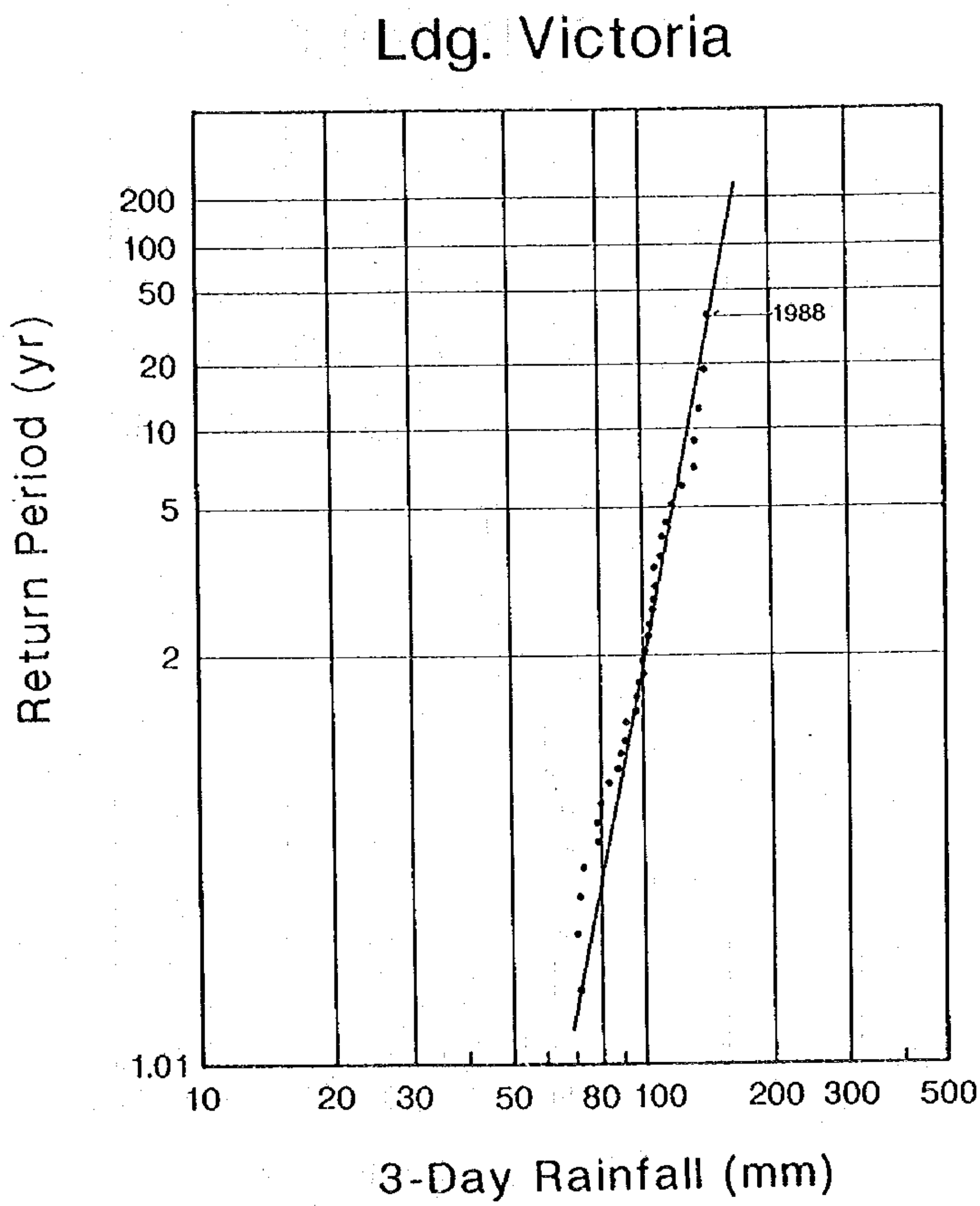
Jam. Syed Omar



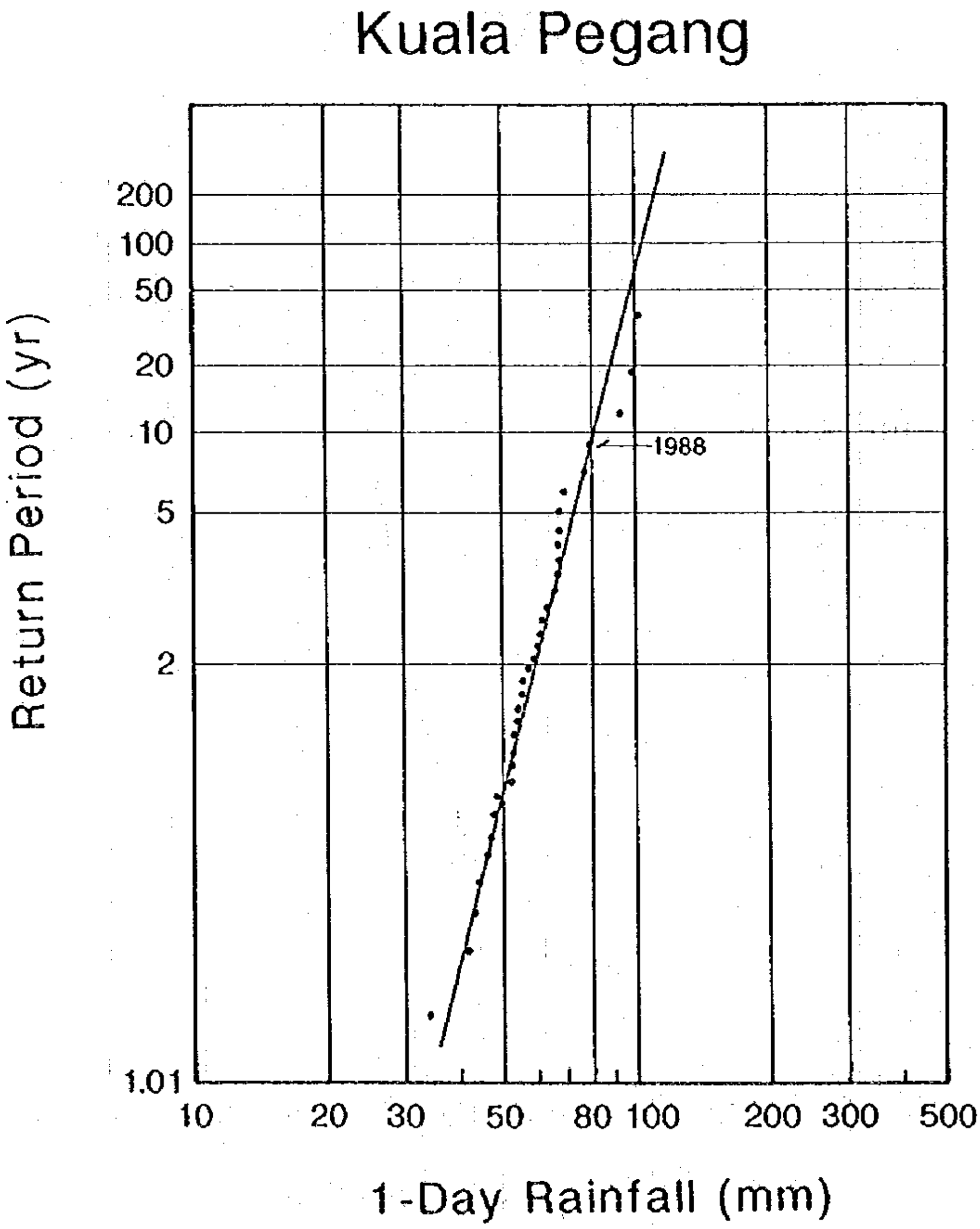
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

FIG. I. 6.1.4
PROBABLE BASIN RAINFALL (2/5)



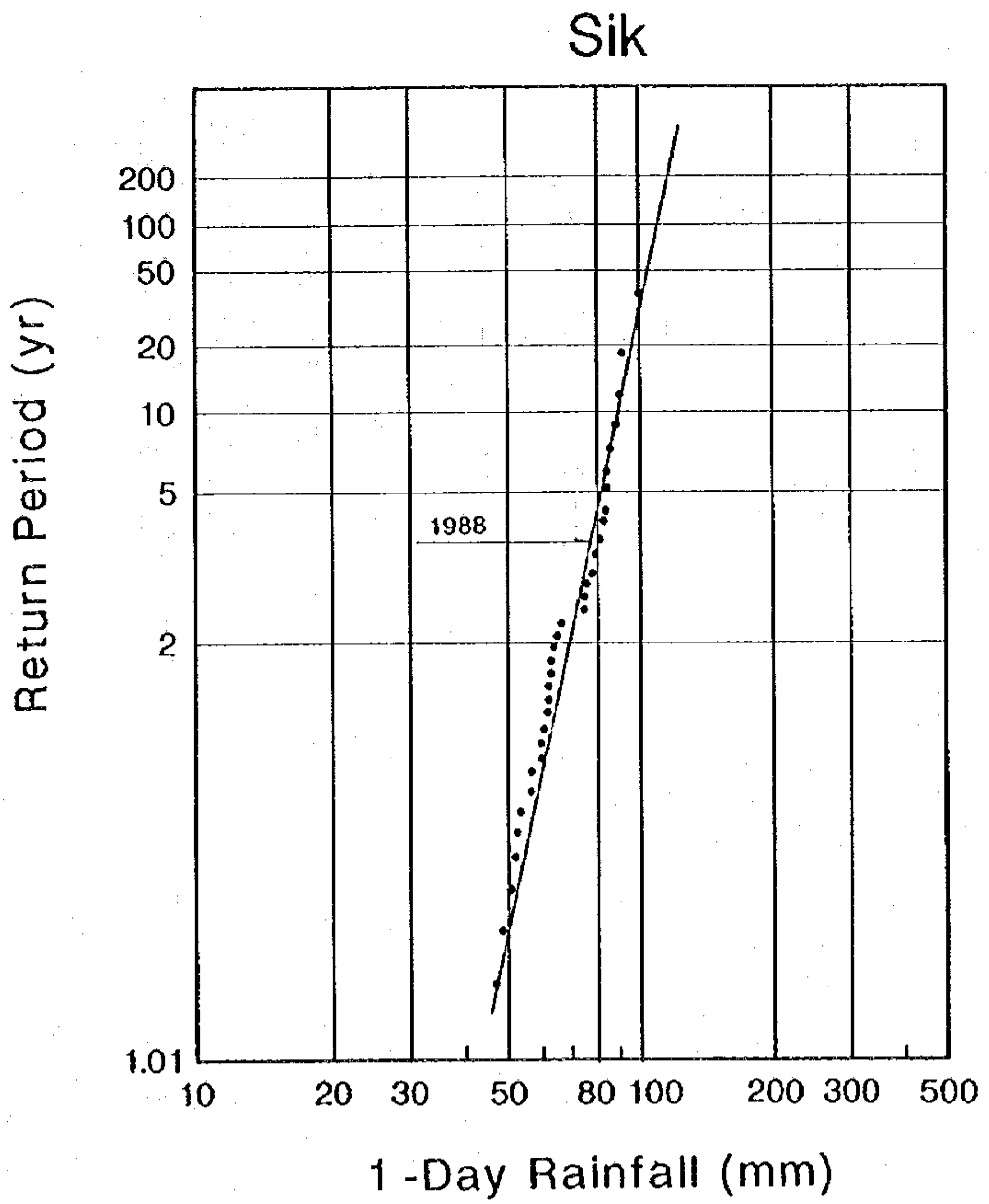
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. I. 6.1.4 PROBABLE BASIN RAINFALL (3/5)
JAPAN INTERNATIONAL COOPERATION AGENCY	



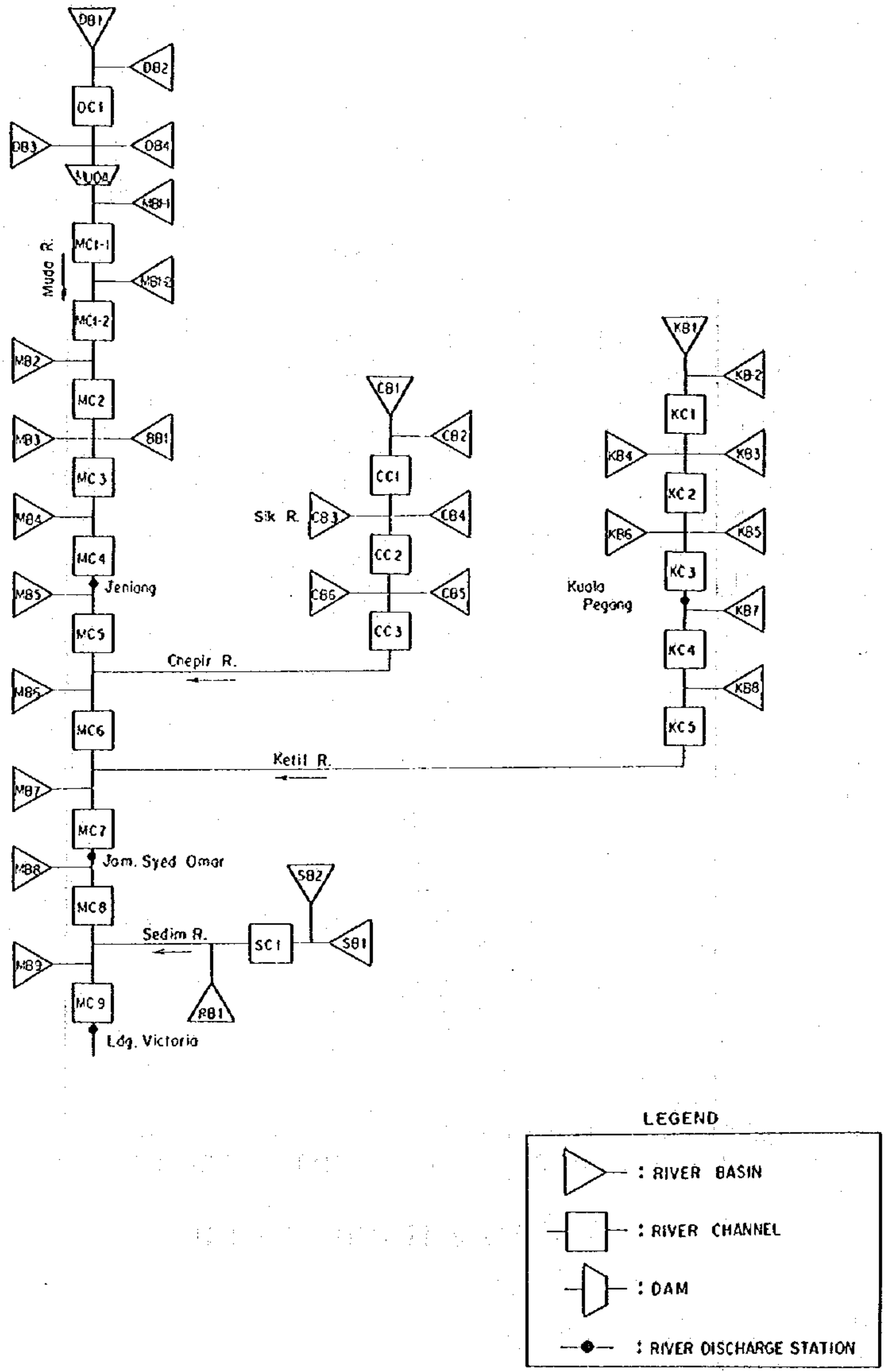
COMPREHENSIVE MANAGEMENT PLAN OF
MUDA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

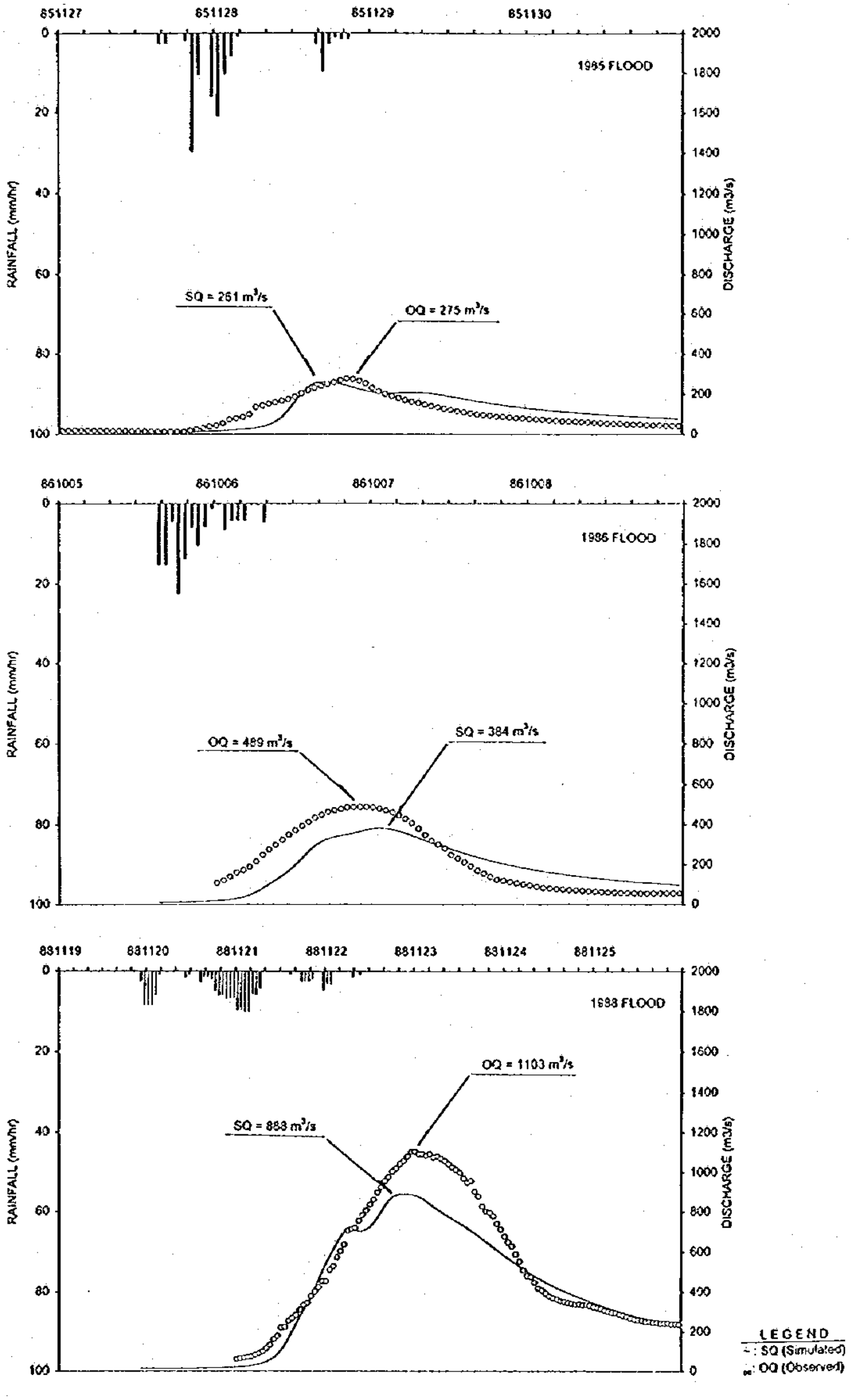
FIG. I. 6.1.4
PROBABLE BASIN RAINFALL (4/5)



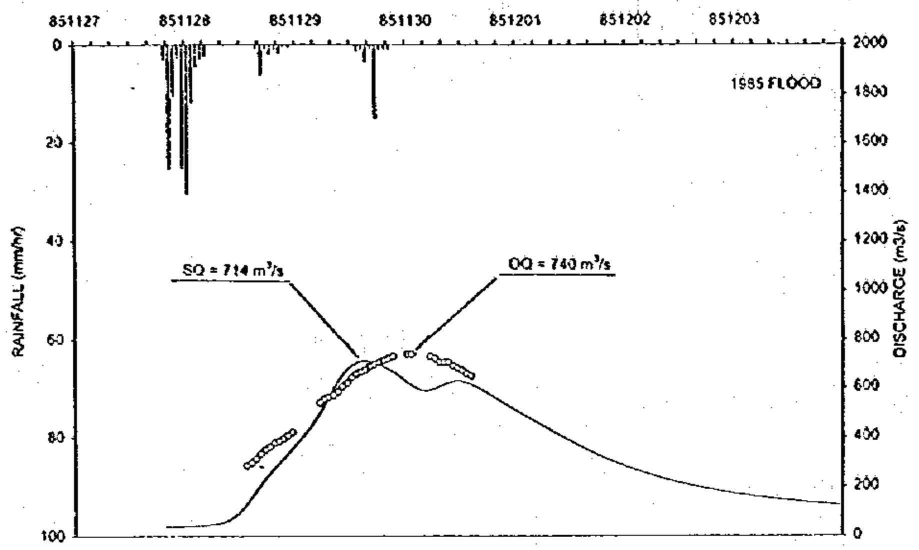
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY	FIG. I. 6.1.4 PROBABLE BASIN RAINFALL (5/5)

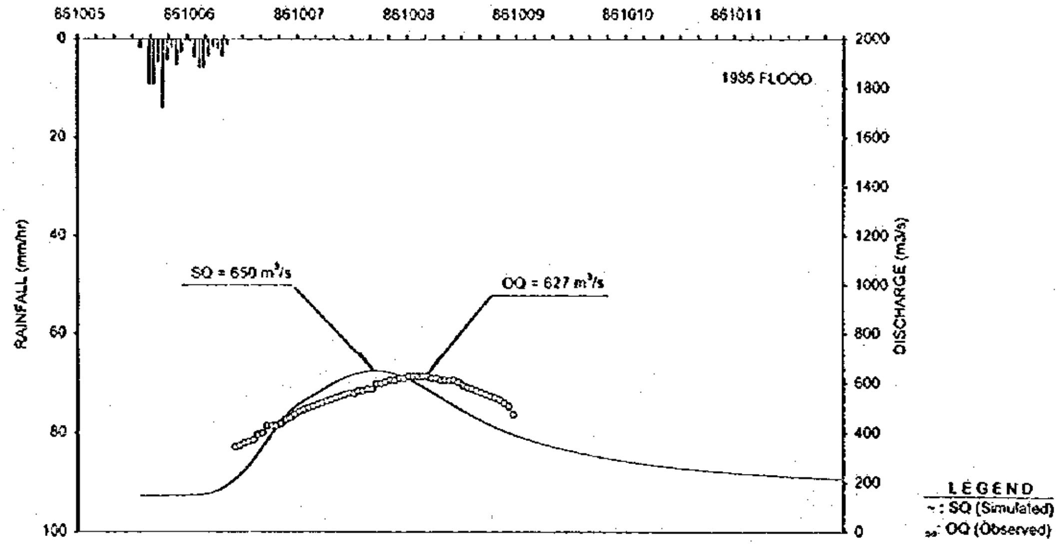


COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY	FIG. I. 6.2.1 FLOOD SIMULATION MODEL OF MUDA RIVER BASIN



COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. I. 6.3.1
JAPAN INTERNATIONAL COOPERATION AGENCY	OBSERVED AND SIMULATED FLOOD HYDROGRAPH (1/4) (JENIANG STATION)

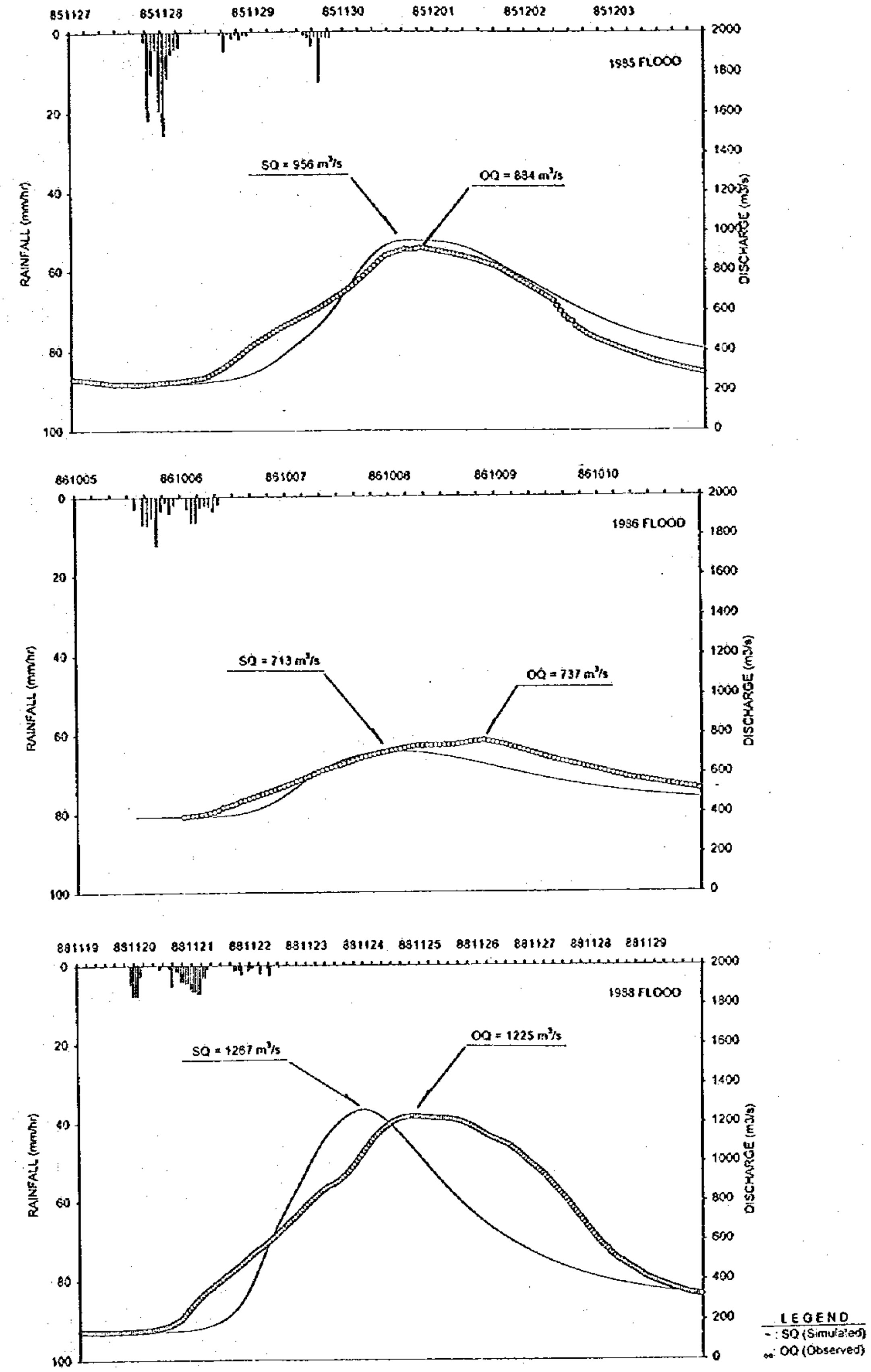




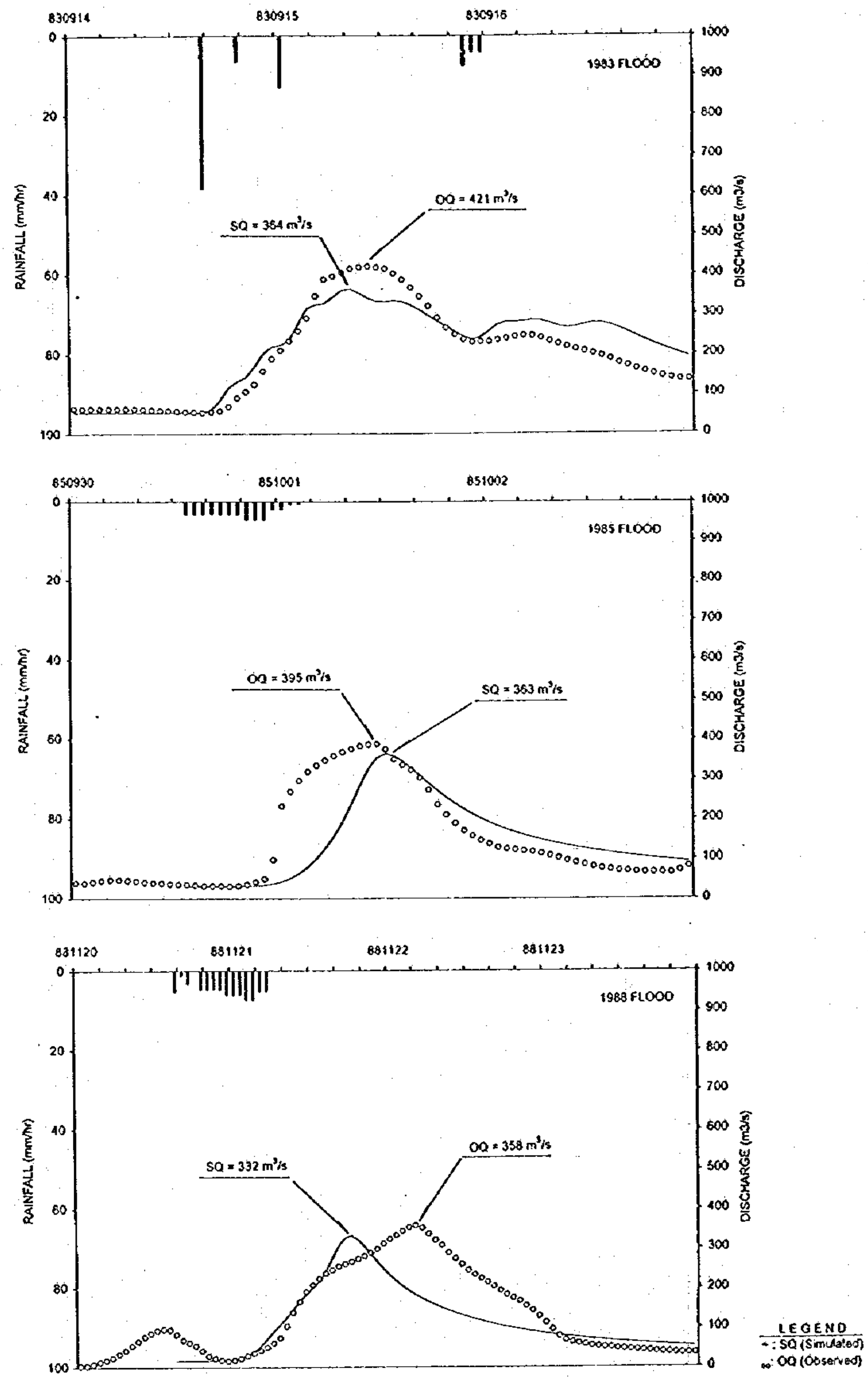
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

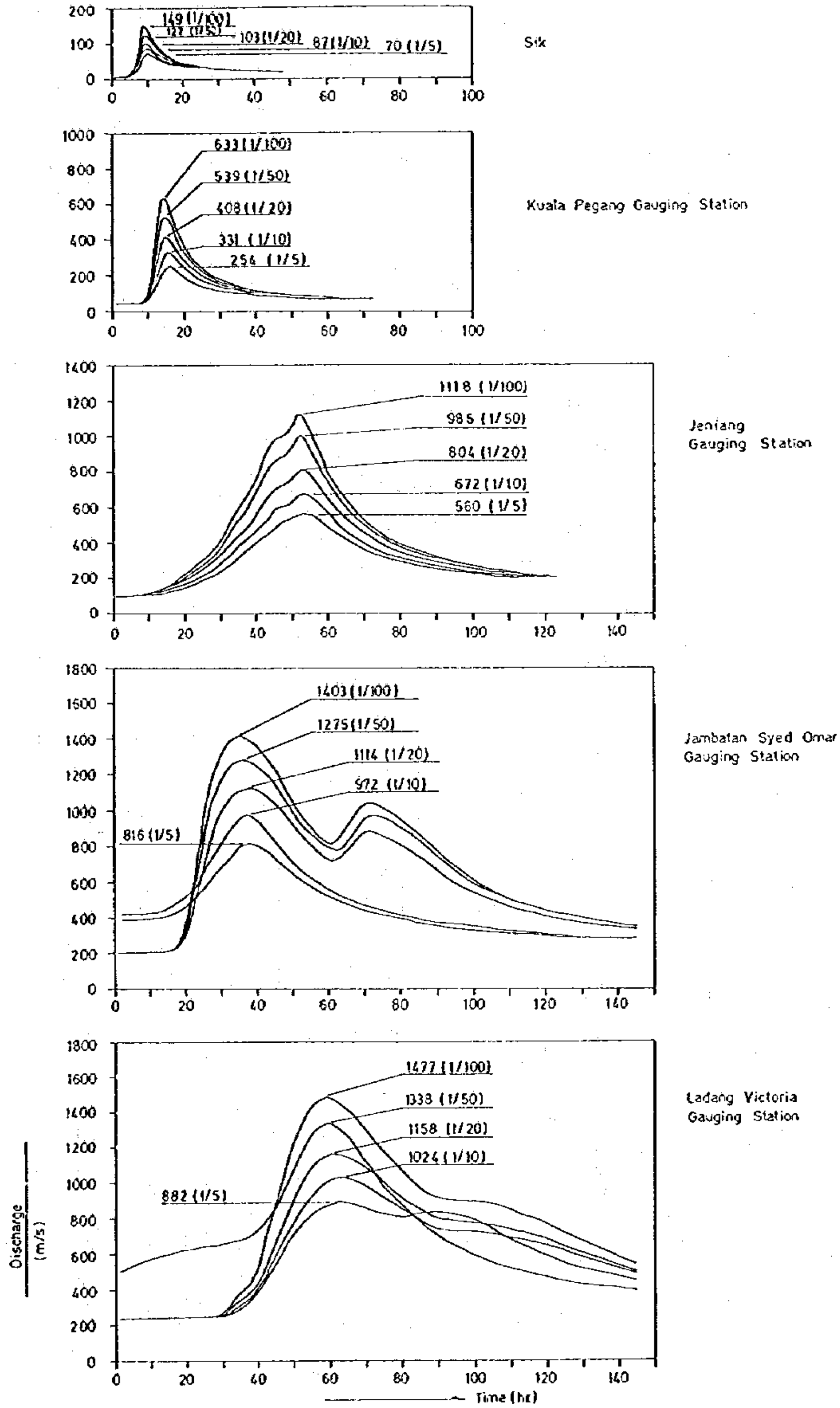
FIG. I. 6.3.1
OBSERVED AND SIMULATED FLOOD HYDROGRAPH (2/4)
(JAM. SYED OMAR STATION)



COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. I. 6.3.1 OBSERVED AND SIMULATED FLOOD HYDROGRAPH (3/4) (LDG. VICTORIA STATION)
JAPAN INTERNATIONAL COOPERATION AGENCY	



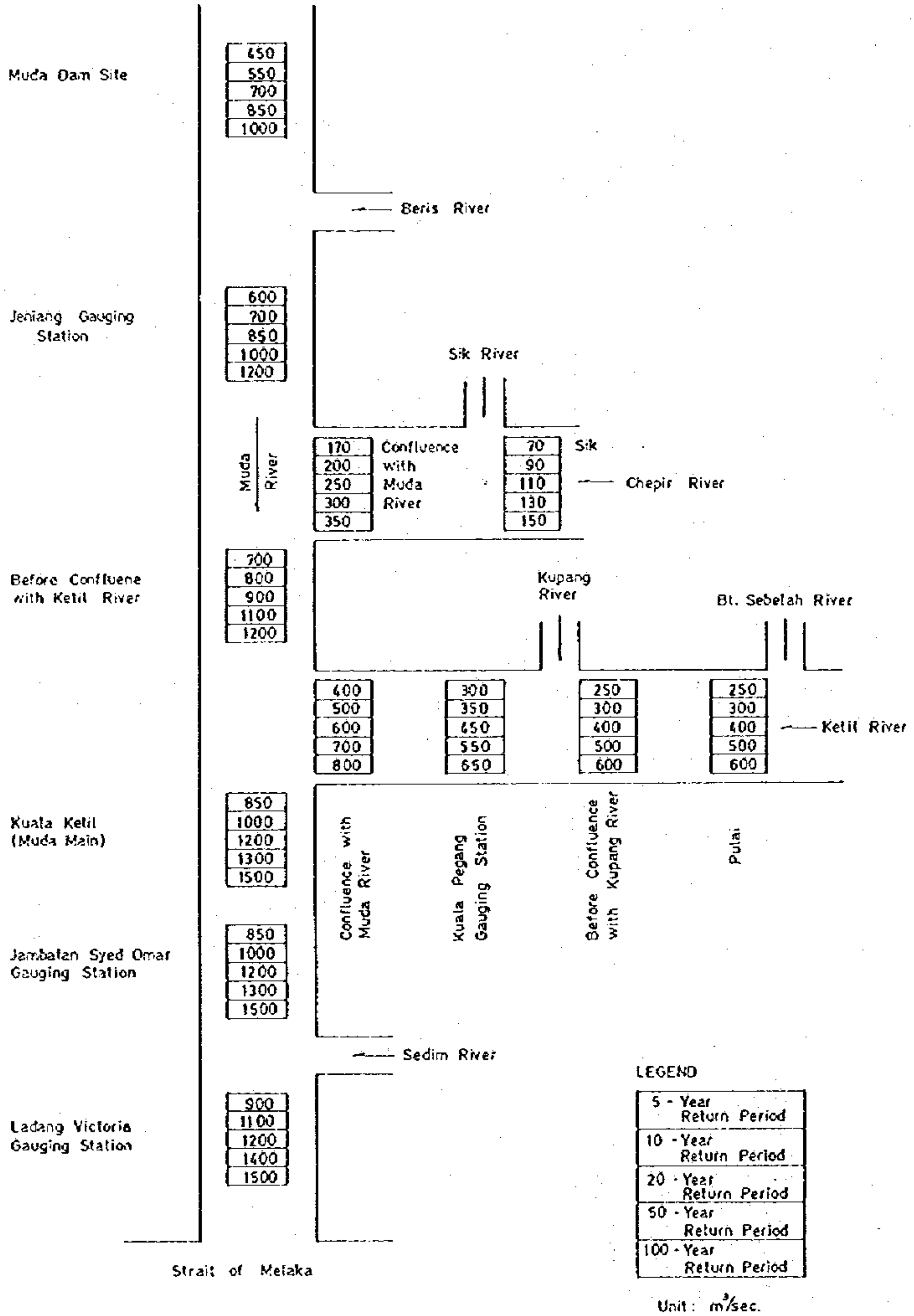
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. I. 6.3.1 OBSERVED AND SIMULATED FLOOD HYDROGRAPH (4/4) (KUALA PEGANG STATION)
JAPAN INTERNATIONAL COOPERATION AGENCY	



COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

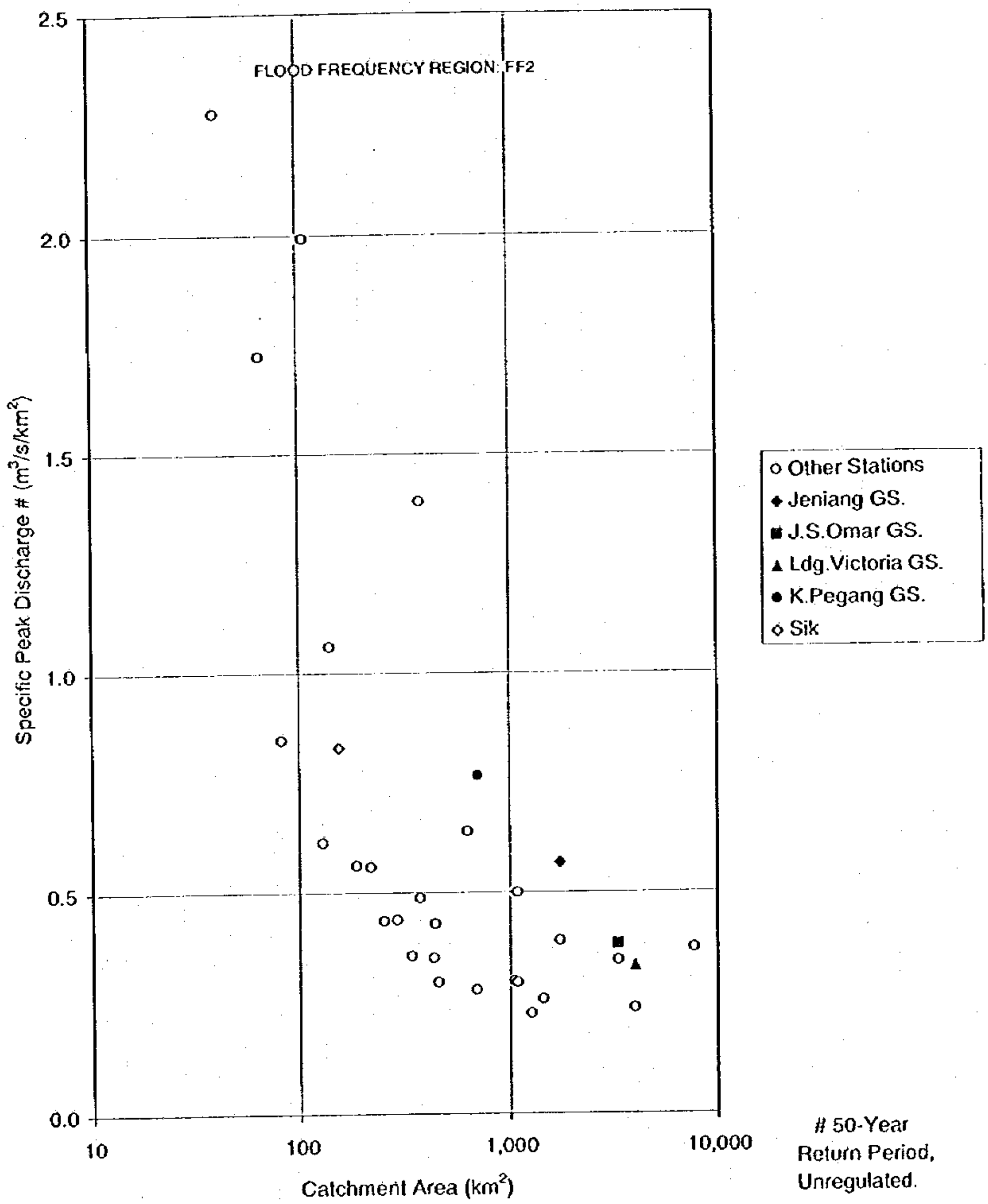
FIG. I. 6.4.1
HYDROGRAPH OF PROBABLE FLOOD DISCHARGE



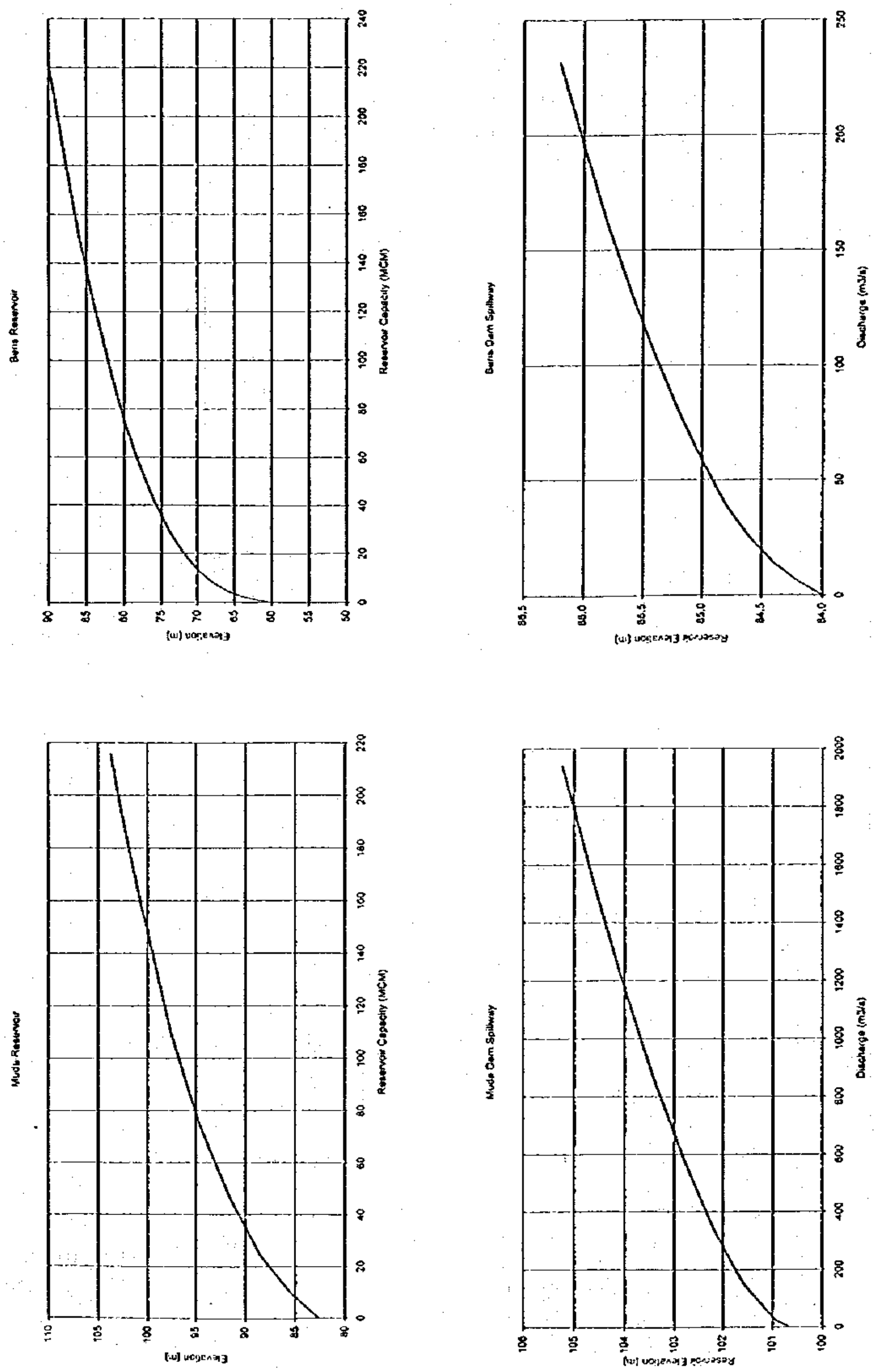
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

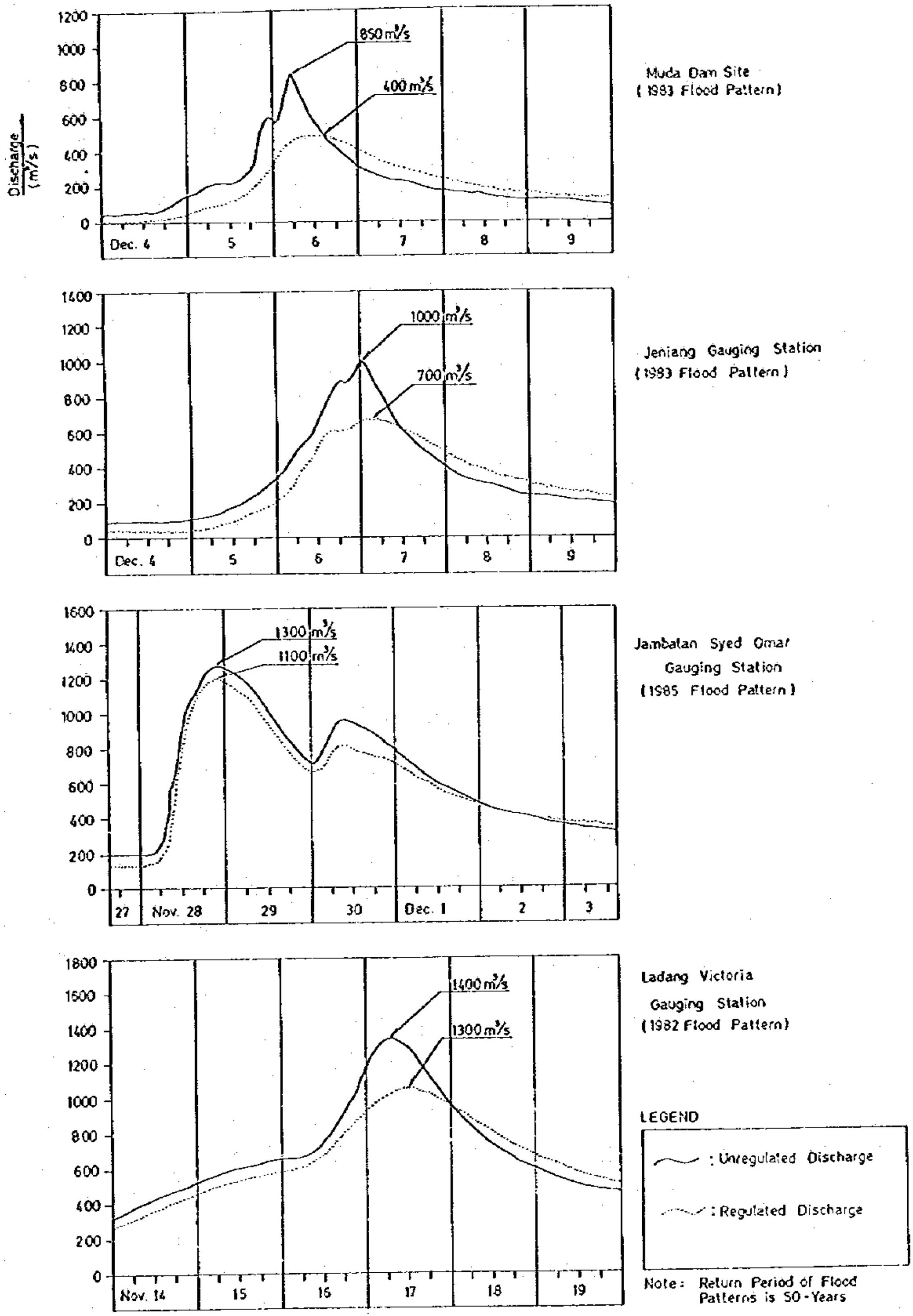
FIG. I. 6.4.2
PROBABLE FLOOD DISCHARGE DISTRIBUTION



COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY	FIG. I. 6.4.3 SPECIFIC PEAK DISCHARGE OF UNREGULATED FLOOD DISCHARGE FOR 50-YEAR RETURN PERIOD



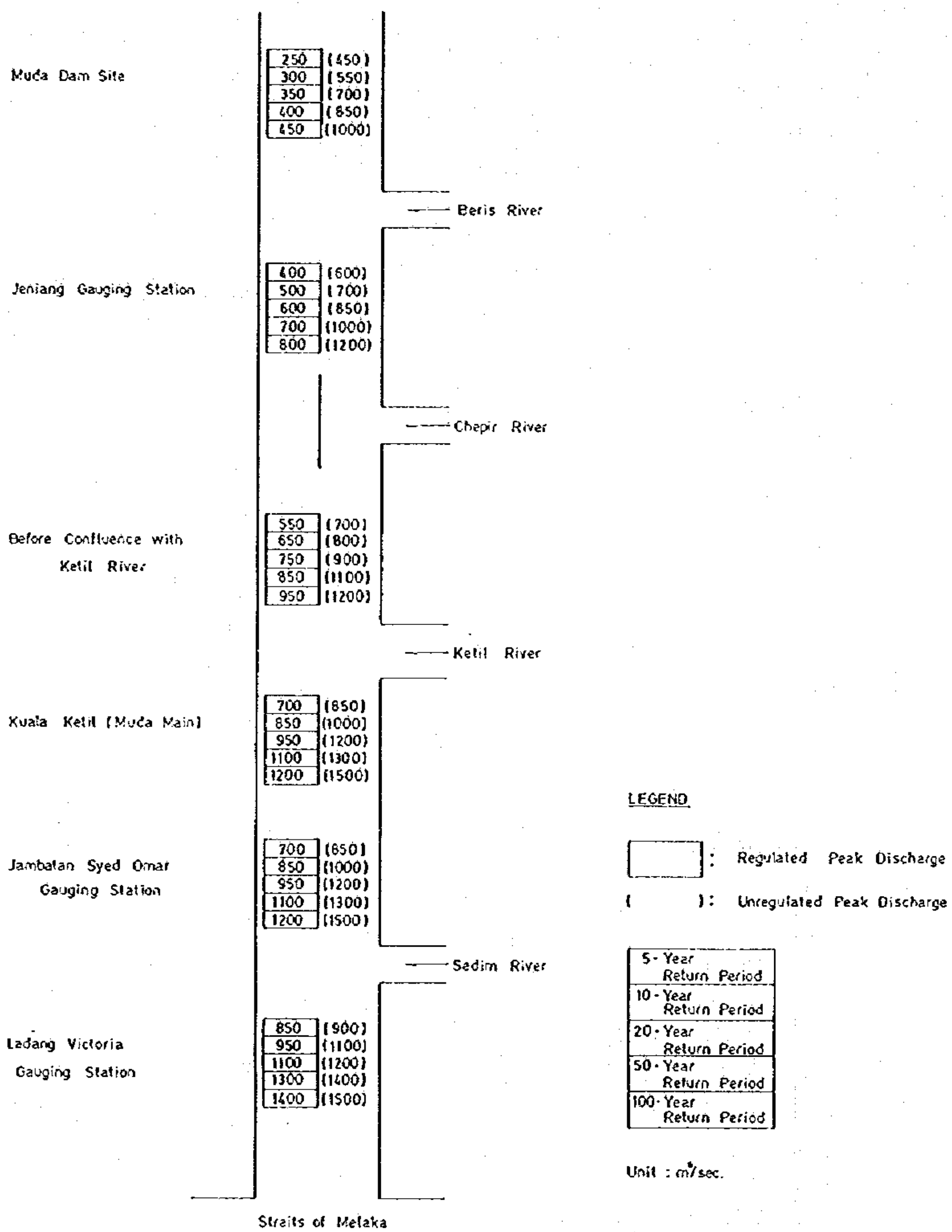
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. I. 7.1.1 RESERVOIR CAPACITY CURVES AND SPILLWAY DISCHARGE RATING CURVES OF MUDA AND BERIS DAMS
JAPAN INTERNATIONAL COOPERATION AGENCY	



COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

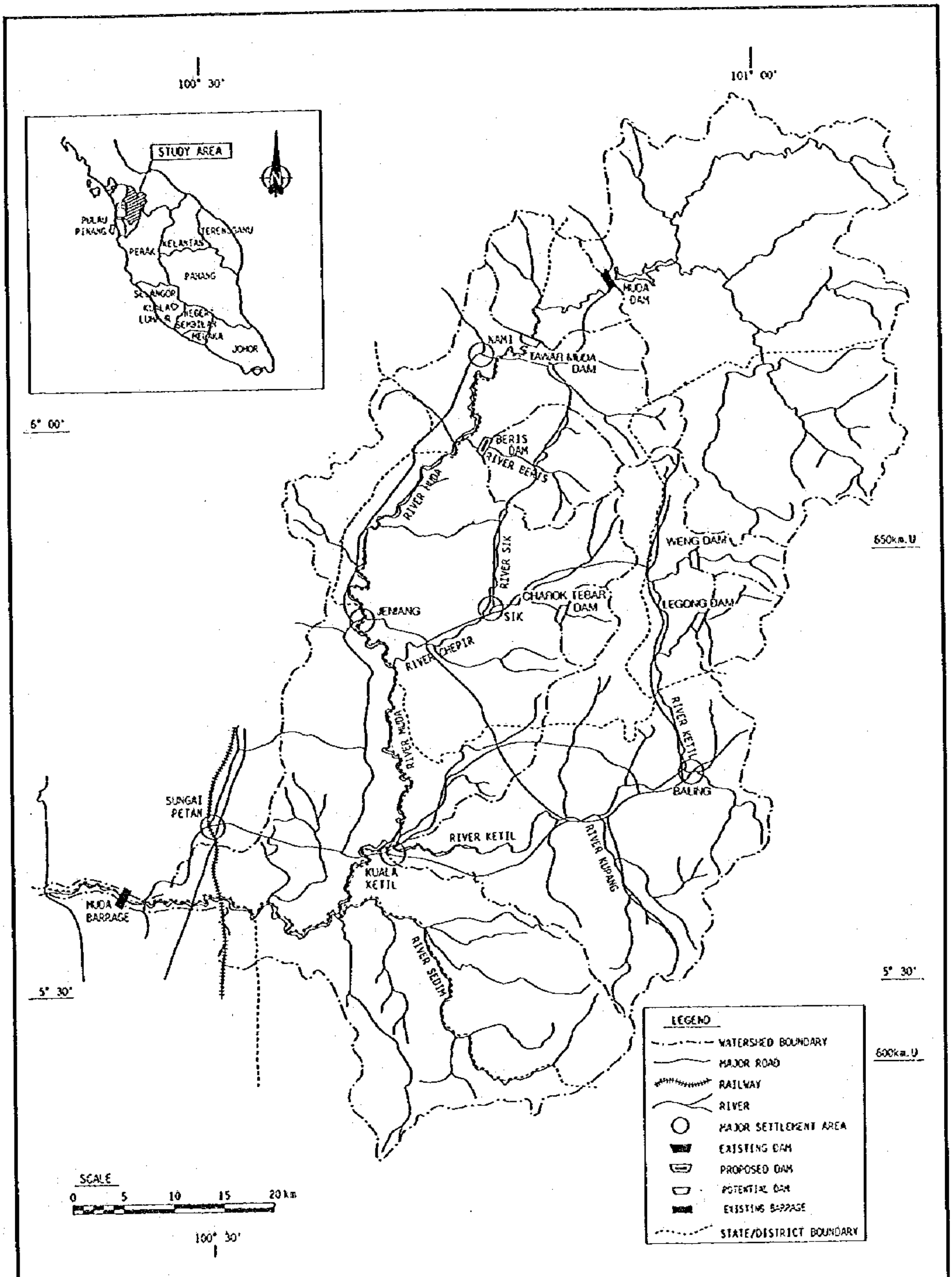
FIG. I. 7.2.1
HYDROGRAPH OF FLOOD MITIGATION EFFECT OF MUDA DAM



COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

FIG. I. 7.2.2
REGULATED PROBABLE FLOOD DISCHARGE DISTRIBUTION



COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. I. 8.1.1 LOCATION MAP OF DAMS FOR FLOOD MITIGATION EFFECT AND CALCULATION
JAPAN INTERNATIONAL COOPERATION AGENCY	

SECTOR II

FLOOD MITIGATION PLAN

SECTOR II
FLOOD MITIGATION PLAN

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1. PRESENT RIVER CONDITION

1.1 River Channel

The Muda River originates in the northern mountainous area of the State of Kedah and flows southward joining its major tributaries, the Chepir, Ketil and Sedim rivers. At the confluence with Sedim River, it changes its course westward to the Strait of Malacca.

1.1.1 Main Features

The main channel of the Muda River has a length of about 180 km with a gradient of 1/2,300 from the river mouth to Muda Dam. The Ketil River is the largest tributary with a channel length of 70 km. Longitudinal profiles of the Muda River and its major tributaries are given in Fig. II.1.1.1, and their main features are summarized as follows:

Name of River	Catchment Area (km^2)	Channel Length (km)	Average Channel Gradient
Muda River	4,210	180	1/2,300
Sedim River	626	30	1/550
Ketil River	868	70	1/750
Chepir River	335	25	1/800

1.1.2 River Channel and Meandering

The river channels of Muda River and the tributaries are U-shaped. The channel width is 300 m near the river mouth, and it gets narrower upstream.

Meandering is seen in all the stretches. At many remarkably meandering portions, bank erosion is also observed. Such bank erosion is being aggravated by sand mining operations. Significantly changed portions were identified by comparing old toposheets and aerial photographs newly taken, as shown in Fig. II.1.1.2 and summarized as follows:

Name of River	Course Location Change	Amplitude (m)	Remarks
Muda River	10 - 11 km	500	Manual diversion with. construction of Muda Barrage
	38 - 39 km	100	
	48 - 49 km	500	
	59 - 60 km	100	
	64 - 65 km	500	
Ketil River	4 - 5 km	100	
	8 - 9 km	300	

1.2 Riverbed Material

A riverbed material survey was done to know the particle size distribution and specific gravity of riverbed materials. Thirty (30) sampling sites were selected along the river channels of Muda River and its major tributaries and at the Muda river mouth, as shown in Fig. II.1.2.1. The bed material samples were put to a sieve test, hydrometer test (if necessary) and specific gravity test in a laboratory.

The specific gravity of all the samples ranges from 2.65 to 2.72. Particle size distribution of each sample is summarized as a gradation curve in Fig. II.1.2.2. Fig. II.1.2.3 shows the longitudinal distribution of 10%, 50% and 90% particles along the channels of the Muda and Ketil rivers.

1.2.1 River Channel

Sand (0.074 - 4.76 mm) and gravel (4.76 - 76.2 mm) are dominant along Muda River and the tributaries. It is observed that riverbed materials are coarser in the more upstream stretches.

A sample, M-7, taken just upstream of Merdeka Bridge (13.1 km) is exclusively fine compared with the neighboring samples. Considering that the sampling point was very deep, it seems that an upper sandy layer was already removed and exhausted by excessive sand mining.

1.2.2 River Mouth

An interesting distribution of bed materials is found at the Muda river mouth. In the north side of the mouth bed materials are very fine and muddy but coarse and sandy in the south side. A sandy beach is formed from the river mouth to Butterworth as shown in Fig. II.1.2.4, although the west coast of Peninsular Malaysia is generally covered with muddy material. This noteworthy fact shows that southward longshore transport is prevailing and carrying sandy materials supplied from Muda River to the south.

1.3 Bed Load

Sediment moved by flowing water may be generally divided into bed load, suspended load and wash load according to the physical process. Among them, bed load is the most influential in the change of sandy riverbed like the Muda River.

In this Study, bed load sampling was carried out at 5 locations: Pinang Tunggal, Jam. Syed Omar, Jeniang Bridge and Nami of Muda River and Kg. Tiban of Ketil River where discharge measurement data are available. The results are given in Table II.1.3.1, and the observed bed load data are plotted versus the corresponding water discharge in Fig. II.1.3.1.

The observed data are scattered and a distinct relationship is not seen between the observed bed load and water discharge in Fig. II.1.3.1. An empirical formula, Sato-Kikkawa-Ashida s Formula was used as bed load rating curves at the sampling sites to supplement the scattered records. The rating curves by the empirical formula are also drawn in the same figure.

1.3.1 Sato-Kikkawa-Ashida's Formula

Sato-Kikkawa-Ashida's Formula is widely applied in Japan to estimate bed load. The formula is expressed by the following equation:

$$Q_B = [U_*^3 / \{(W_s / W_w - 1) \cdot g\}] \cdot \varphi \cdot F(\tau_0 / \tau_c) \qquad (1.3.1)$$

$$\varphi = 0.623 \qquad \text{if } n > 0.025 \qquad (1.3.2)$$

$$\varphi = 0.623 \cdot (40 \cdot n)^{-3.5} \qquad \text{if } n \leq 0.025 \qquad (1.3.3)$$

Where,

Q_B	:	Bed load
U_*	:	Friction velocity $[U_* = (g \cdot R \cdot I_e)^{0.5}]$
R	:	Hydraulic radius
I_e	:	Energy gradient
W_s	:	Density of sand
W_w	:	Density of water
g	:	Acceleration of gravity
n	:	Manning s roughness coefficient
F	:	Function of τ_0 / τ_c
τ_0	:	Tractive force
τ_c	:	Critical tractive force

The rating curves were made, based on the particle size distribution and the cross section survey data at the sampling sites. Fig. II.1.3.1 shows that the calculated bed load is in the range of the observed data, and that the curves are applicable for the Muda and Ketil rivers.

1.3.2 Annual Bed Load

By combining the bed load rating curves and discharge duration curves, annual bed load was estimated at the sampling sites. The estimation results are presented in Table II.1.3.2 and summarized as follows:

River	Location	Catchment Area (km^2)	Annual Bed Load (m^3)
Muda River	Pinang Tunggal	4,172	6,800
	Jam. Syed Omar	3,330	3,500
	Jeniang Bridge	1,740	1,800
	Nami	1,220	4,400
Ketil River	Kg. Tiban	825	10,600

1.4 Sand Mining

1.4.1 Mining Operation

As of September 1993, there were 95 permit holders for mining operations on the Muda river channel in the State of Kedah. As for the State of Pulau Pinang, a total of 9 mining sites have been designated. These mining sites are concentrated between Muda Barrage and the proposed Jeniang Barrage, as shown in Fig. II.1.4.1.

The annual sand mining volume in 1993 was estimated at more than 1.0 million m^3, excluding an unknown volume in the State of Pulau Pinang. Mining production depends upon the demand. For the last three years, 1991 to 1993, of which records are available, the volume has doubled. According to officials concerned, much more volume was extracted from Muda River around 1990 when the construction work of the North-South Expressway was at its peak. The annual mining volumes are tabulated below.

State	District	Annual Mining Volume (m^3)		
		1991	1992	1993
Kedah	Kuala Muda	355,400	602,800	734,600
	Kulim	42,900	114,300	85,600
	Baling	113,200	186,200	304,100
	Sik	No Data	No Data	123,200
	Padang Terap	No Data	No Data	No Data
Pulau Pinang	Seberang Perai Utara	No Data	No Data	No Data
Total		511,500	903,300	1,247,500

Data Source: District Land and Mining Office

Taking the available records and the interview survey with officials concerned into account, it seems that a big volume of sand as much as 0.5 to 1.0 million m^3 has been removed annually from the Muda river channel for the last 10 or more years. This quantity which is much greater than the sand supply from the upstream, namely the bed load of 1 to 10 thousand m^3 is causing subsidence of the riverbed.

1.4.2 Problems Caused by Sand Mining

The sand mining operations have caused many problems in the surrounding river environment. Among all the problems reported so far, the following three items are related to flood mitigation:

(a) Riverbank erosion;

(b) Riverbed subsidence; and

(c) Obstruction to flood flow by sand stockpile, embankment and abandoned machines.

Among them, riverbed subsidence is the most difficult and serious problem. Riverbank erosion is attributed much to the deepened riverbed by the sand mining. The riverbed subsidence is a threat to the stability of river structures like bridges and water intake facilities. In fact, foundation piles of Sidam Bridge are exposed by 2 to 3 m above the eroded riverbed, as shown in Fig. II.1.4.2. If the condition becomes worse, they will collapse during a big flood. Moreover, water level is also becoming lower together with the riverbed. This results in an increase of load to pumps of many intake facilities for irrigation and domestic/industrial purposes.

1.4.3 Riverbed Subsidence

Riverbed subsidence is proven by comparing river channel cross sections surveyed in different years. Fig. II.1.4.3 shows cross sections at four river discharge stations: Ldg. Victoria, Jam. Syed Omar and Jeniang Cable of Muda River and Kuala Pegang of Ketil River. Fig. II.1.4.4 compares longitudinal profiles of the downstream stretch of Muda River surveyed in 1983, 1988 and 1994.

At all the three stations of Muda River, the riverbeds have obviously become lower, especially at Jam. Syed Omar where the riverbed has dropped by 2 m for the last three years. Fig. II.1.4.4 shows that the average riverbed became lower by 2 to 5 m from 1983 to 1994 in the stretch upstream of Muda Barrage where sand mining is active.

Water level is also becoming lower. Fig. II.1.4.5 shows changes of annual minimum water levels at the four discharge stations. The minimum water levels became lower by 1 to 2 m for 20 to 30 years.

At Kuala Pegang of Ketil River, the riverbed has been stable for the last three years. However, the annual minimum water level has on a long-term been on a downward trend like the stations along Muda River. Even in Ketil River where mining operations are minimal, the riverbed might gradually become lower due to an influence of the declining Muda River channel bed. Unfortunately, the available data are too insufficient to make it clear.

1.4.4 DID Guidelines

Agencies concerned such as the Land and Mining Office, DID and PWD have been making efforts to control illegal and violent mining by imposing technical and administrative mining conditions. For example, DID stipulated an allowable location of sand mining as shown in Fig. II.1.4.6. According to the conditions, sand is allowed to be extracted from the middle third section of the river channel. The allowable extraction depth is decided according to the channel width. Sand mining is prohibited within a certain radius from a river structure.

The current conditions seem to be effective to protect riverbanks and river structures locally for a short period. As shown in Fig. II.1.4.4, however, in a long time the riverbed subsided longitudinally in a long stretch. The sand supply from the upstream is negligible compared with the mining quantity, and, therefore, the riverbed becomes lower as much as sand is removed. The problem is how deep the riverbed is allowed to be lowered.

1.5 River Mouth Siltation

The Muda river mouth, which was placed as one of the target river mouths by the "National River Mouths Study by JICA in 1994" (hereinafter referred to as NRMS), is too shallow for fishing boats to navigate during low tide.

1.5.1 Physical Conditions

The Muda river mouth protrudes straight to the Malacca Strait. The mouth width is about 200 m and a sand bar has developed from the Kedah side. The tide is semi-diurnal with a spring tide range of about 2 m. Due to short fetches in Malacca Strait, waves are comparatively low. As described in Section 1.2, the bed materials are muddy in the Kedah side but sandy in the Pulau Pinang side.

The inner channel is relatively maintained deep enough by tidal flow and river discharge but a shallow convex portion, namely a problem portion exists in the outer channel as shown in Fig. II.1.5.1. The shallowest point of the 1994 sounding survey is 2 m below LSD at 0.5 km off the river mouth.

For preventing beach erosion, DID constructed rock bunds towards the north and the south from the mouth along the shorelines in 1992 and 1994, respectively.

1.5.2 Problems and Measures Taken

The Muda river mouth has been used as a port by about 200 fishing boats. There are landing and mooring facilities at both the Kedah and Pulau Pinang sides. All of the boats are smaller than 10 GRT with draft of 1.0 m. They cannot navigate while the tide depth is smaller than their draft.

DID dredged the outer channel of 1.2 km in length in August 1986. The channel bed was deepened to the elevation of 4 m below LSD, but silted up by 2 to 3 meters within 76 mouths after dredging as shown in Fig. II.1.5.1.

2. FLOODING CONDITION

Due to poor flow capacities of the river channels, flooding occurs almost every year and affects low-lying residential and agricultural areas.

2.1 Flood-Prone Area

DID had identified the flood-prone areas and classified them into the following three types of flood:

(a) Flash flood;

(b) Flood associated with extensive inundation; and

(c) Tidal flood.

Fig. II 2.1.1 shows the three types of flooding areas in the Muda river basin.

2.1.1 Flash Flood

Flash floods occur along the middle and upper stretches of the tributaries usually due to a short but very intensive localized rainfall. When such flash floods occur, flood water levels tend to suddenly rise but subside within a short duration after rainfall stops. The towns of Baling and Sik suffer almost every year from flash floods of the Ketil and Chepir rivers, respectively. It is feared that future urbanized areas along the river channels will be seriously damaged particularly by this type of flood.

2.1.2 Flood Associated with Extensive Inundation

Floods associated with extensive inundation occur along the downstream and midstream stretches of the Muda River due to widespread and prolonged heavy rainfall. The flood discharge spills out from the riverbanks to the adjoining low-lying areas, resulting in extensive inundation which often lasts for a week.

2.1.3 Tidal Flood

The lowest stretch is threatened with flooding by a combination of high tide and flood runoff discharge flowing from the upstream. When flood runoff discharge flows down during high tide, the flood runoff water is raised by the backwater effect of the high tide and may spill over the banks.

2.2 1988 Flood

Vast low-lying areas along the Muda River were submerged in flood water in November 1988. Interview surveys to local people and officials concerned show that the 1988 flood was the worst since a flood in 1967 which is regarded as the biggest after the second world war.

2.2.1 Rainfall

Rainfall from November 20 to 23, 1988 caused flooding everywhere along the river channels of Muda River and its tributaries. The heavy rainfall was biased to the northern mountainous areas. The daily rainfall at Pedu Dam exceeded 200 mm on November 20. The isohyetal map of 48-hour rainfall is given in Fig. II.2.2.1.

2.2.2 Discharge

The flood hydrographs at the river discharge stations in Fig. II.2.2.1 were estimated in this Study. Since rating curves currently used by DID except Kuala Pegang were regarded not applicable to big flood discharge, rating curves were newly prepared by non-uniform flow calculation.

The most important parameter of the non-uniform flow calculation, Manning's roughness coefficient *n* was calibrated to discharge measurement records, as shown in

Fig. II.2.2.2. The river channel cross sections of the year 1988 were made by modifying the cross sections surveyed in 1994, assuming that the riverbed has subsided at a rate of 0.2 m/year. If the sand mining width and length are assumed to be 25 m and 100 km, respectively, the rate of 0.2 m/year is equivalent to a sand mining volume of 500,000 m^3/year. The rating curves are as drawn in Fig. II.2.2.3.

The heavy intensive downpour in the northern area generated flash runoff, which spilled over the Muda dam crest to the downstream. The dam reservoir water level marked 8.8 inches over the crest, the highest record since the dam operation started. The flood water traveled down the river channel, collecting runoff water from the tributaries, spilling over the river banks and retarded in the lower basins. At the lower station, Ldg. Victoria, the flood hydrograph was very big and gentle, and high flood exceeding 1,000 m^3/s lasted for three days from November 24 to 26.

2.2.3 Return Period

A statistical analysis was conducted to estimate the return period of the 1988 flood discharge. The annual maximum water level records were converted to discharge by using the non-uniform flow rating curves. The rating curves of 1983 were applied for the previous years too when no cross section data were available. The estimated annual maximum discharge at the three discharge stations of Ldg. Victoria, Jeniang Cable and Kuala Pegang is given in Table II.2.2.1.

Normal log distribution was employed to estimate return period, as shown in Fig. II.2.2.4 and summarized as follows:

River	Discharge Station	Return Period of 1988 Flood Discharge	Return Period of 1988 Flood Rainfall
Muda	Ldg. Victoria	45 years	30 years*
	Jeniang Cable	140 years	40 years*
Ketil	Kuala Pegang	5.5 years	10 years**

* 3 day rainfall
** 1 day rainfall

During the 1988 Flood, heavy rainfall was biased to the northern areas. The return period is as long as 140 years at Jeniang and 45 years at Ldg. Victoria, while that of Kuala Pegang is 5.5 years because of less rainfall in the Ketil river basin. In the above table, return period of the basin mean rainfall estimated in SECTOR I., HYDROLOGY, is also added for reference.

2.2.4 Flood Damage

In most of the river stretches, the flood water spilled over the river banks. The towns of Sik and Baling were affected by flash floods from the Chepir and Ketil rivers, respectively. At the Jeniang Gauging Station which is located midstream of Muda River, the water level continued to exceed the danger level for 6 days from November 21 to 26. Due to the high flood water level, inundation occurred along the midstream and downstream of Muda River affecting Kuala Ketil and the villages of Sidam Kanan, Sidam Kiri, Pinang Tunggal, Bumbung Lima and Kota Kuala Muda.

The inundation areas along Muda, Ketil and Chepir Rivers were identified on 1 : 10,000 toposheets newly prepared in 1994 through a series of field investigation and interview surveys, as shown in Figs. II.2.2.5, II.2.2.6 and II.2.2.7. The total area of the inundation areas and the number of houses and buildings affected are as follows:

River	Survey Area	Inundation Area (km^2)	No. of Houses and Buildings Affected
Muda	River Mouth to Jeniang Barrage	65	5,300
Ketil	Muda River to Baling Town	9	600
Chepir	Muda River to Sik Town	4	200
Total		78	6,100

In "The Annual Flood Report, 1988", the flood damage to riverbanks in the Muda river system was estimated at RM 1,224,000.

2.3 Flood in 1995

In mid-September 1995, Tropical Storm Ryan hit the three northern states, Kedah, Pulau Pinang and Perak. The heavy rainfall from September 17 to 18 which exceeded 300 mm caused inundation in many areas of these states. Newspapers had reported that water level rose over danger levels at the downstream and middle stretches of the Muda and Ketil rivers and many people living along these rivers had evacuated to relief centers.

Some water level and rainfall records have been obtained but they are not enough to assess the return period of the September 1995 flood. At the lowest station, Bumbung Lima Pump Station, the water level nearly reached the maximum water level in 1988; however, those of the other stations were considerably lower than the 1988 level, as shown in the table below. Hence, it seems that the September 1995 flood was a little smaller than the 1988 flood.

Flood	Maximum Water Level (m LSD)		
	Bumbung Lima P/S	Pinang Tunggal P/S *	Jeniang Cable
1988 Flood	4.39	6.93	25.60
1995 Flood	4.34	5.95	29.90

P/S : Pump Station
* : Pulau Pinang

3. EXISTING FLOOD MITIGATION WORKS

3.1 Structural Measures

The Muda river system where flooding has been bothering people living near Muda River and its tributaries has hardly been provided with flood mitigation works other than the existing Muda river bund constructed downstream (refer to Fig. II.3.1.1).

3.1.1 Muda River Bund

According to the DID annual report in 1935, Muda River Bund was constructed by a private enterprise about a century ago. It has been maintained and rehabilitated by DID. The purpose of the bund is to protect the low-lying Pulau Pinang area from flooding. The latest rehabilitation of the bund was carried out in 1987. In the 1988 flood, the bund was able to get rid of overflow with a freeboard of 9 inches.

3.1.2 Dam Reservoir

Muda Dam is located 170 km upstream from the river mouth. It has a catchment area of 984 km^2 and a reservoir of 160 million m^3. Muda Dam Reservoir has no specific storage capacity for flood mitigation but some flood mitigation effect may be expected from it, because of its large storage capacity and the diversion to Pedu Dam through the diversion tunnel.

The proposed Beris Dam Reservoir will also regulate flood discharge to some extent for the same reason as Muda Dam. The proposed dam site is located in the downstream stretch of Beris River, a tributary of Muda River. The dam has a catchment area of 116 km^2 and a reservoir of 114 million m^3.

3.2 Flood Forecasting and Warning System (FFWS)

FFWS is an important, practical low cost measure to minimize flood damage. The purpose of the system is to enable people living in flood-prone areas to be forewarned and take the necessary action to evacuate themselves and their belongings through dissemination of flood information. In Muda River System where flood mitigation structures are hardly provided, DID has established a flood forecasting and warning system.

3.2.1 Water Level Monitoring Stations

DID Kedah and DID Pulau Pinang have established ten and two water level monitoring stations, respectively, in the Muda river system, as shown in Fig. II.3.2.1. For each of the monitoring stations, three critical water levels are designated, namely alert, warning and danger levels.

The water level readings are to be reported to the state flood operation room once in three hours when the water level exceeds the alert level, and every hour when it exceeds the danger level. The water level readings of Jeniang and Jam. Syed Omar are also to be sent to DID Pulau Pinang.

At the six water level stations of Jeniang, Jam. Syed Omar, Pinang Tunggal and Bumbung along Muda River and Kg. Baru and Rumah Pam Pulai along Ketil River, a telemeter is scheduled to be installed.

3.2.2 Warning Station with Siren

The warning stations with siren are located in the upstream areas which are subject to flash flooding. The sirens are automatically triggered when the river stage reaches the warning level, thus giving immediate warning to the surrounding population.

3.2.3 Flood Operation Room

The state and district flood operation rooms play a key role for the flood forecasting and warning system. They are set up in DID state and district offices from the 1st of August to 15th of January.

The rooms are equipped with communication equipment such as a VHF set, telephones and facsimile machines to receive or send information such as rainfall, water level, warnings, flood damage and evacuation. Flood forecasting is also conducted in the operation rooms simply based on the flood traveling time from an upper water level station. The flow chart of the aforesaid flood forecasting and warning system is as shown in Fig. II.3.2.2.

4. STUDY AND ANALYSIS

4.1 Flow Capacity and Flood Inundation Analysis

Non-uniform flow calculation was carried out to estimate flow capacities of Muda, Ketil and Chepir River channels and to identify probable inundation areas.

4.1.1 Non-Uniform Flow Calculation

In order to estimate flood water profiles, non-uniform flow calculation by Ida Method was applied under the following conditions:

River	Calculation Stretch	Cross Section Data	Water Level at Downstream End
Muda	177 km (River Mouth to Muda Dam)	Surveyed in 1994	HHWS (1.1 m LSD)
Ketil	55 km (Muda River to)	- ditto -	Water Level of Muda River
Chepir	25 km (Muda River to)	Surveyed in 1987 and 1994	- ditto -

Manning's roughness coefficient *n* was calibrated to discharge measurement records as shown in Fig. II.2.2.2 and given in Table II.4.1.1. Fig. II.4.1.1 shows the longitudinal flood water profiles of the three rivers.

4.1.2 Flow Capacity

Based on the calculated flood water levels with different return periods, a bankfull flow capacity was also estimated as shown in Fig. II.4.1.1. The flow capacity is small in lower stretches of Muda River but comparatively large in upper stretches. At many points downstream of the confluence with Sedim River the flow capacity is lower than the 2-year flood discharge. In the upper stretches upstream of the confluence with Chepir River where the river forms a valley, the river banks are high enough against the 10-year flood. Along the Ketil and Chepir rivers there are scattered low-lying areas submerged even by the 2-year flood water.

4.1.3 Probable Flood Inundation Area

From the flood water profiles and available topographic information, probable flood inundation area maps were prepared for the Muda and Ketil rivers as shown in Fig. II.4.1.2 to indicate the extent of the 100-year flood water. Fig. II.4.1.3 shows probable inundation areas along the three short stretches which are proposed as target of the structural flood mitigation plan as discussed in the next section.

Belt-shaped areas along Muda and Ketil Rivers are submerged under the flood water. The width is as wide as 1 to 5 km in the lower stretches of Muda River downstream of the confluence with Ketil River, while narrower and 1 km at the maximum in the upstream valley. Such definite tendency is not found for Ketil River, and it varies from 0.5 m to 2 km due to local topographic conditions. The total inundation areas and number of houses and buildings located there are as follows:

River	Stretch	Length (km)	Inundation Area (km^2)	No. of Houses & Buildings
Muda River	River Mouth to Ldg. Victoria (Lower Muda River)	40.3	45.0	5,640
	Kuala Ketil Town Stretch *1	5.4	1.4	610
	Ldg. Victoria to Prop. Jeniang Barrage *2	72.9	33.1	560
Ketil River	Muda River to Kg. Tg. Merbau *2	39.2	16.9	1,200
	Baling Town Stretch	0.8	0.3	200
Chepir River	Sik Town Stretch	0.8	0.2	160
Total		159.4	96.9	8,370

*1 : Left side of the stretch from Cross Section No. 60 of Muda River to Cross Section No. 1 of Ketil River.
*2 : Excluding Kuala Ketil Town Stretch.

4.2 Study on Design Riverbed Profile

As disclosed in Section 1.4, Muda River has been affected by excessive mining activities. In particular, the riverbed subsidence of 2 to 5 m in the recent 10 years caused by the sand extraction has damaged some river structures such as bridges and pump stations.

To stabilize the riverbed and protect the river structures, an ideal longitudinal riverbed profile, namely the design riverbed profile shall be set up from the river mouth to the upstream end. Any activity affecting the river channel including river channel improvement and sand mining shall be led or regulated towards realization and maintenance of the design profile.

4.2.1 Determination of Design Riverbed Profile

The design riverbed profile of Muda River was proposed as shown in Fig. II.4.2.1 for the 154 km length from the river mouth to Nami Bridge where sand mining sites are located. The design profile was adjusted to the existing average riverbed profile as discussed below.

(1) Stability of Existing River Bed Profile

The existing riverbed profile was produced as a result of both long term natural phenomena and recent human activities, mainly sand mining. Sediment transport is the natural force to the riverbed change. In this context, annual bed load was estimated by Sato-Kikkawa-Ashida's Formula at 10 sampling sites of bed material along Muda River. The estimation result is added in Fig. II.4.2.1 to compare with the longitudinal profile.

The bed load fluctuates from 2,000 to 8,000 m^3/yr along the Muda River. Erosion occurs at locations where bed load is bigger, while sedimentation occurs where the bed load is smaller. However, this value of bed load is negligible compared with the sand extraction volume of 500,000 to 1,000,000 m^3/yr. This means that the gentle Muda riverbed will probably become stable if sand mining is suspended, although some small local scouring and sedimentation will still be inevitable.

(2) Existing River Structures

Some of the existing river structures have been affected by riverbed subsidence. The river bed at Sidam Bridge which is located 40 km upstream of the river mouth is so seriously eroded that the foundation piles of the bridge piers are exposed by 2 to 3 m above the riverbed and are threatened to be washed out by a big flood. Sidam Kanan Pump Station near the bridge experienced difficulty of water extraction during the dry season of February and March this year because of lowering of the river water due to the river bed subsidence.

Such problems will be solved if the existing lowered riverbed can naturally recover to the original elevation when the structures were constructed. Unfortunately, this is very difficult to expect because of the small sediment transport capacity even if the sand mining is completely banned in Muda River, and will take a long time to happen.

What is important now for minimizing damages to the structures is to stop the riverbed subsidence and to maintain the present bed elevation. Therefore, the design riverbed profile is proposed to follow the existing profile which can probably be stable if the mining is controlled adequately. Damaged structures shall be rehabilitated or reconstructed so as to fully perform their required functions.

Among the existing structures, Sidam Kanan Pump Station and Sidam Bridge are so far found seriously affected by the riverbed subsidence. They shall be urgently reinforced or reconstructed. The other structures also seem to be affected to some extent, and periodical monitoring is necessary to avoid fatal damage. Table II.4.2.1 is a list of the existing pumping stations, and the operational minimum water level of each pump station is compared with the design riverbed elevation.

4.2.2 Proposed Sand Mining Area

The proposed sand mining area is as described below.

(1) Sand Deposit

Sand deposit above the design riverbed profile was estimated to contribute to the development of management on the mining operations. Sand was assumed to be extracted from the middle third section of the river channel in accordance with the current DID guidelines as shown in Fig. II.4.2.2. The cross sections newly surveyed in 1994 were used for this estimation.

The total sand deposit volume from the river mouth to Nami Bridge was estimated at only 2 million m^3, which will be exhausted in a few years if the current active mining of half to one million m^3/yr is continued. As for the longitudinal distribution, stretches downstream of Merdeka Bridge (14 km) and near the confluence with Sedim River (47 km) and a short stretch upstream of the confluence with Ketil River (64 km) are comparatively rich in sand deposit (Refer to Fig. II.4.2.1).

(2) Proposed Sand Mining Area

Since the present deposit volume is very small and the sand supply from the upstream cannot be expected, the total ban on sand mining seems to be the solution to the problem. However, it is anticipated to be administratively difficult to completely prohibit such active sand mining at this time. On the contrary, a deeper river channel is desirable for the purpose of flood mitigation, and the sand deposit which hinders flood flow shall be removed. Sand mining may decrease future dredging work for river channel improvement.

In this Study, therefore, the sand mining operation is proposed to be reduced gradually and banned totally in the future. As the first step, mining operations shall be urgently suspended out of allowable areas where sand deposit is still rich. When the sand deposit is exhausted even in the allowable areas, the mining shall be immediately banned totally.

The allowable mining areas are proposed as shown in Fig. II.4.2.3, and summarized as follows:

Stretch	Length (km)	Estimated Sand Deposit (m^3)	Remarks
River Mouth to Muda Barrage	10.4	620,000	affected by saline water
Muda Barrage to Merdeka Bridge	2.7	160,000	
Near Sedim River (No. 43 to No. 50)	6.7	310,000	
Upstream of Ketil River (No. 65 to No. 68)	2.0	130,000	
Total	21.8	1,220,000	

The total sand deposit is estimated at 1,220,000 m^3 in the proposed allowable areas. It includes 620,000 m^3 downstream of Muda Barrage which is under the sea water. Although sand mining has not been conducted there yet, utilization of such saline sand is worthy of being examined, taking it into account that river sand is being exhausted. Moreover, the sea also may be an alternative source of sand as in Japan, where one-third of the total sand mining volume is obtained from the sea and the sea sand is used also as concrete material after a simple washing.

5. STRUCTURAL FLOOD MITIGATION PLAN

5.1 Basic Conditions of Structural Flood Mitigation Plan

5.1.1 Return Period

The design return period is proposed to be 50 years, which is approximately equal to that of the 1988 Flood. The return period seems to be long enough to ease the local people and satisfy the DID practice as discussed below.

(1) 1988 Flood

This flood event is so recent that the local people vividly remember the disaster. To ease the affected people, it might be an alternative that the design scale will be proposed to be as large as the past flood. In other words, the proposed flood mitigation plan will target and cope with the actual flood. As discussed in Section 2.2, the return period of the 1988 Flood is estimated at some 50 years along the downstream stretches of Muda River, which are proposed to be protected by structural measures as discussed in the next subsection.

(2) DID Guideline and Practice

DID has prepared guidelines for designing gas pipelines, bridges and culverts crossing rivers. According to DID, the return period for design flood computation shall be based on catchment land use as follows:

Structure	Catchment Land Use	Design Return Period
Gas Pipeline	Urban	100 years
	Agriculture	25 years
	Forest	5 years
Bridge and Culvert	Urban	100 years
	Agriculture	50 years

Note: The guideline for bridges and culverts is still in draft form and has not been authorized yet.

As for the other river structures, DID has no specific guidelines to determine design return period. Actually, however, a return period of 50 to 100 years has been applied for recent flood mitigation plans of strategic rivers flowing in densely populated and developed areas, and a shorter period of 10 to 30 years in less developed river basins.

The Muda river basin is regarded as an agricultural basin rather than an urban one. If the DID practice is directly followed, a shorter period shall be applied. As described in the next subsection, however, structural flood mitigation measures are proposed to be concentrated to more developed and densely populated areas only. The proposed return period, 50 years, seems not too long for the priority areas.

5.1.2 Target Stretch for Structural Flood Mitigation Plan

As shown in Fig. II.2.1.1, the flood-prone areas widely spread over Muda River and its tributaries. It is, however, economically unfeasible to provide all the stretches with structural measures. Structural measures shall be concentrated to high priority stretches to be selected considering their land use, population, assets, future development and severity of flood damage. For the other low priority stretches, non-structural measures shall be considered to minimize flood damage, preserving the existing retarding effect.

Consequently, the following four stretches are selected as target stretches for the structural flood mitigation plan, and their locations are given in Fig. II.5.1.1:

River	Stretch	Length (km)	Reference Point	Design Discharge (m^3/s)
Muda River	Lower Muda River	40.3	Ldg. Victoria	1,300 *
	Kuala Ketil Town	3.5	Jam. Syed Omar	1,100 *
Ketil River	Kuala Ketil Town	1.9	Confluence with Muda River	700
	Baling Town	0.8	Pulai	500
Chepir River	Sik Town	0.8	Sik Town	130

* Regulated discharge by Muda Dam Reservoir

5.1.3 Menu of Structural Measures

Structural measures generally include river channel improvement and construction of a bypass floodway, a retarding basin and a flood mitigation dam reservoir. Among them, a bypass floodway is topographically difficult for Muda river basin. A suitable area for a retarding basin is not found along the rivers, either. Consequently, river channel improvement and construction of a flood mitigation dam reservoir are the possible structural measures for the Muda river basin.

(1) River Channel Improvement

This work is to increase flow capacity of channel by deepening, widening and canalizing the existing river channel and constructing dikes on the banks. For Lower Muda River which have a 40 km long stretch, long continuous dikes are necessary to confine the design discharge in a design channel. The short target stretches such as Kuala Ketil Town, Baling Town and Sik Town shall be protected by short dikes, which will hardly decrease the existing retarding effect.

(2) Flood Mitigation Dam Reservoir

A flood mitigation dam reservoir is very effective if its catchment area and storage capacity is large enough. The existing Muda and the proposed Beris dam reservoirs have no specific capacity for flood mitigation purpose but some flood regulation effect can be expected because of their large storage reservoirs. If effective, they will be incorporated in the proposed flood mitigation plan.

In addition to the two dam reservoirs, many potential dam sites have been identified by the previous studies, as shown in Fig. II.5.1.2. Among them, four dam sites, Tawar Muda, Charok Tebar, Weng and Legong were found more probable for flood mitigation purpose through a preliminary screening as shown in Table II.5.1.1. Storage capacity curves of the four dam reservoirs are given in Fig. II.5.1.3.

5.2 Effectiveness of Dam Reservoir

Effectiveness of the dam reservoirs was examined from the viewpoint of flood regulation and economic viability. In conclusion, the existing Muda Dam Reservoir was solely found effective, and proposed to be incorporated in the flood mitigation plan as discussed below.

5.2.1 Muda and Beris Dam Reservoirs

According to SECTOR I, HYDROLOGY, the existing Muda Dam Reservoir possesses a natural flood regulation effect large enough to reduce flood runoff discharge significantly in the lower stretches. It is, therefore, concluded that the Muda Dam Reservoir shall be incorporated in the flood mitigation plan of the Muda river basin. On the other hand, the effect of the proposed Beris Dam Reservoir was found to be negligibly small due to its small catchment area.

5.2.2 Potential Dam Reservoirs

All the four potential dam reservoirs, Tawar Muda, Charok Tebar, Weng and Legong are not so effective for reducing flood discharge in the downstream target stretches. What is worse is that the dam construction costs of RM 25 to 191 million will be too expensive to adopt them as structural measures to protect the short target stretches.

Target Stretch	Potential Dam Reservoir			Construction Cost of River Improvement (RM mil.)
	Name	Reduction of Discharge *1	Construction Cost (RM mil.) *2	
Kuala Ketil Town	Tawar Muda	0 m^3/s	191	17
Sik Town	Charok Tebar	26 m^3/s	70	7
Baling Town	Weng	64 m^3/s	65	9
	Legong	33 m^3/s	25	

*1 : Reduction of discharge with topographically maximum development of dam reservoir.
*2 : Compensation cost is not included (refer to Table II.5.2.1).

5.3 Lower Muda River Improvement

Lower Muda River is the most downstream target stretch from the river mouth to Ldg. Victoria (Sidam Bridge). Along this 40.3 km stretch there are located Muda Barrage and many pump stations for irrigation, domestic and industrial purposes. The vast low-lying areas on both the right and left banks have been often submerged by flood water. Navigation of fishing boats has to be suspended during low tide due to siltation of the river mouth.

5.3.1 Design Criteria

The design criteria are as discussed below.

(1) Design Discharge

The design discharge is 1,300 m^3/s which is the 50-year discharge with flood regulation by Muda Dam Reservoir.

(2) River Alignment

To minimize construction cost, land acquisition, house evacuation and relocation of the existing structures, the existing alignment is adopted.

(3) Longitudinal Profile

The design riverbed profile determined in Subsection 4.2.1 is adopted. The design H.W.L. is setup as low as possible to minimize flood damage potential to the adjacent areas.

(4) Cross Section

Compound cross section composed of a low water channel and a high water channel is adopted. The cross section of the low water channel is determined to confine the existing flow capacity of 600 m^3/s.

(5) Design Criteria for River Mouth Improvement

The design criteria applied in NRMS are adopted in this Study to design alternative plans. They are:

(a) Design Boat Size

GRT	Length	Beam	Depth	Draft
40	14 m	4.2 m	2.4 m	1.7 m

(b) Siltation Rate

Description	Inner Channel	Outer Channel
Without Submerged Jetty	negligible	1 m/yr
With Submerged Jetty	negligible	45% of volume without submerged jetty

5.3.2 Preliminary Design of River Improvement Plan

Ordinary river improvement method consisting of dike construction and deepening and widening of a river channel is applied to the preliminary design of this long stretch. The proposed design plan and typical cross sections are as shown in Fig. II.5.3.1, and the proposed longitudinal profile in Fig. II.5.3.2. The main features of the river improvement plan are summarized below.

Stretch Length	40.3 km
Design Discharge	1,300 m^3/s
River Width	180 to 1,000 m
Low Water Channel Width	110 to 600 m
Excavation/Dredging	10,400,000 m^3
Embankment	1,100,000 m^3
Revetment	83,000 m^2
Sluices to be Constructed	28 units
Barrage to be Reconstructed	Muda Barrage
Pump Stations to be Relocated	Terat Batu, Sidam Kiri and Sidam Kanan
Bridges to be Reconstructed	Railway and water pipe & pedestrian bridges
Bridges to be Reinforced	Merdeka, Expressway, Sidam ridges
Land Acquisition	510 ha
House Evacuation	189 houses

Special attention was paid to the following points:

(1) River Mouth Improvement

In the "National River Mouths Study by JICA in 1994" (NRMS), Muda river mouth was studied as one of the objective river mouths, and the following two alternative works were proposed as countermeasure against the river mouth siltation:

Case 1	Capital and Maintenance Dredging
Case 2	Capital Dredging and Combination of Submerged Jetty and Maintenance Dredging

In this Study, a review study of the alternatives was carried out by using the hydrographic data newly surveyed in 1994. Fig. II.5.3.3 shows the plans of the two alternatives. As a result, Case 1, Capital and Maintenance Dredging, is proposed as the optimum measure through a cost comparison of the two alternatives. The total costs in a manner of net present value are summarized below, assuming that the project life is 30 years and the discount rate is 8% (refer to Table II.5.3.1).

Unit: RM 1,000

Alternatives	Initial Cost	Maintenance Cost	Total Cost
Case 1	681	6,682	7,363
Case 2	3,569	5,095	8,664

(2) Reconstruction of Muda Barrage

Muda Barrage has been helping the upstream pump stations to abstract river water by stopping saline water from the sea and keeping water level above at a certain level since it was constructed in 1972. However, the existing cross section at the barrage is too small to confine the design discharge as shown in Fig. II.5.3.4. The existing flow capacity at the barrage is estimated at only 250 m^3/s, less than 20% of the design discharge of 1,300 m^3/s. It will be an obstacle in future if it is left untouched. In this Study, Muda Barrage is proposed to be reconstructed in the proposed Lower Muda River Improvement Works.

The new barrage is proposed to be constructed in the right bank, 300 m upstream of the existing one as shown in Fig. II.5.3.4. In addition, a 1,300 m long cut-off channel is proposed to be excavated instead of the existing channel. The location of the new barrage was determined for the following engineering reasons:

(a) A barrage shall be constructed in a straight channel to minimize its disturbance to flood flow. In this sense, the proposed site is the best.

(b) The construction work in the dry bank is easier and more economical because it does not require coffering and diversion works of the existing channel.

(c) According to cadastral maps, most of the construction area for the proposed new barrage and cut-off channel is owned by the State of Kedah. The construction work can then be implemented with small land acquisition.

An argument may arise between the states of Kedah and Pulau Pinang because the course change of the river channel with the construction of the new barrage will result in a change of the state boundary. The state boundary which has been drawn along the center line of the channel will move towards the Kedah side by 350 m at the maximum, and some 30 ha of land will be transferred from Kedah to Pulau Pinang if the current rule is followed. In this Study, however, such political issue is not considered, but the optimum plan from the engineering viewpoint is proposed as discussed above.

(3) River Environment Development

As discussed in SECTOR IV, RIVER ENVIRONMENTAL MANAGEMENT PLAN, both banks at the proposed Muda Barrage and the left bank at the Expressway Bridge are attractive areas for river environment development. In order to utilize the areas more effectively, the dike alignments are designed intentionally far from the river to generate wide spaces on the high water channels. There are proposed recreational parks on the two spaces as shown in Fig. II.5.3.1.

5.4 Kuala Ketil Town Stretch Improvement

The Kuala Ketil Stretch extends from the bridge at Cross Section No. 60 of Muda River to the bridge at Cross Section No. 1 of Ketil River. This stretch has a total length of 5.4 km, 3.5 km for Muda River and 1.9 km for Ketil River, and is selected as a target stretch for the structural flood mitigation plan to protect Kuala Ketil Town which was badly damaged by the 1988 flood.

5.4.1 Design Criteria

The design criteria is as discussed below.

(1) Design Discharge

The design discharge for Muda River is 1,100 m^3/s which is the 50-year discharge with a flood regulation by Muda Dam Reservoir, while that of Ketil River is 700 m^3/s.

(2) River Alignment

An excessive meandering stretch is generally inferior in flow capacity and liable to cause bank erosion, resulting in breaking of a dike. Moreover, river improvement for a long meandering channel may be costlier than a short-cut channel. For the above-said reason, a cut-off channel is proposed for the Muda and Ketil rivers, respectively.

(3) Longitudinal Profile

Shortening of the stretch by applying the cut-off channels results in steepening of the channel. In order to keep the existing riverbed gradient, drop structures are proposed respectively in the two cut-off channels. The design H.W.L. was set up as low as possible to minimize flood damage potential to the adjacent areas.

(4) Cross Section

Single cross section is adopted so as to follow the existing shape. A ring dike is proposed on the left bank to protect Kuala Ketil Town.

5.4.2 Preliminary Design of River Improvement Plan

The proposed design plan and typical cross sections are shown in Fig. II.5.4.1, and the proposed longitudinal profile in Fig. II.5.4.2. The channel length is shortened by 1,630 m of Muda River and by 980 m of Ketil River by the construction of the cut-off channels. The ring dike on the left dike will protect Kuala Ketil Town from flood inundation. The main features of the river improvement plan are summarized below.

Stretch Length	1,870 m (Muda River), 920 m (Ketil River)
Design Discharge	1,100 m^3/s (Muda River), 700 m^3/s (Ketil River)
River Width	100 m (Muda River),70 m (Ketil River)
Cut-off Channel	900 m (Muda River), 250 m (Ketil River)
Excavation/Dredging	522,000 m^3
Embankment	22,400 m^3
Revetment	23,100 m^2
Sluices to be Constructed	3 units
Drops to be Reconstructed	(Muda River), 1 (Ketil River)
New bridge to be Constructed	1 bridge
Land Acquisition	11.8 ha
House Evacuation	9 houses

5.5 Baling Town Stretch Improvement

Baling Town Stretch of Ketil River is located about 45 km upstream from the confluence with Muda River and extends from Pulai Pump Station to the confluence with Bt. Sebelah River. This 750 m long stretch is selected as a target for the structural flood mitigation plan to protect Baling Town which is the administration center of Baling District and has been suffering from habitual flood inundation.

5.5.1 Design Criteria

The design criteria is as discussed below.

(1) Design Discharge

The design discharge of this stretch is 500 m^3/s which corresponds to a 50-year discharge.

(2) River Alignment

In order to minimize construction cost, land acquisition, house evacuation and relocation of the existing structures, the existing alignment is adopted.

(3) Longitudinal Profile

The design riverbed profile is determined to follow the existing profile. The design H.W.L. is set up as low as possible to minimize flood damage potential to the adjacent areas.

(4) Cross Section

Single cross section is adopted to follow the existing shape.

5.5.2 Preliminary Design of River Improvement Plan

The proposed design plan and typical cross sections are shown in Fig. II.5.5.1, and the proposed longitudinal profile in Fig. II.5.5.2. The main features of the river improvement plan are summarized below.

Stretch Length:	750 m
Design Discharge	500 m^3/s
River Width	53 m
Excavation/Dredging	37,500 m^3
Embankment	12,800 m^3
Revetment	12,100 m^2
Sluices to be Constructed	2 units
Bridges to be Reconstructed	3 bridges
Land Acquisition	2.3 ha
House Evacuation	28 houses

5.6 Sik Town Stretch Improvement

Sik Town Stretch of Chepir River is located about 17 km upstream from the confluence with Muda River and extends from Kg. Kuala Bridge to Chepir Bridge. This 800 m long stretch is selected as a target for the structural flood mitigation plan to protect Sik Town which is the administration center of Sik District and has been suffering from habitual flood inundation.

5.6.1 Design Criteria

The design criteria is as discussed below.

(1) Design Discharge

The design discharge of this stretch is 130 m^3/s which corresponds to a 50-year discharge.

(2) River Alignment

In order to minimize construction cost, house evacuation, land acquisition and relocation of the existing structures, the existing alignment is adopted.

(3) Longitudinal Profile

The design riverbed profile is determined to follow the existing profile. The design H.W.L. is set up as low as possible to minimize flood damage potential to the adjacent areas.

(4) Cross Section

Single cross section is adopted to follow the existing shape.

5.6.2 Preliminary Design of River Improvement Plan

The proposed design plan and typical cross sections are shown in Fig. II.5.6.1, and the proposed longitudinal profile in Fig. II.5.6.2. The main features of the river improvement plan are summarized below:

Stretch Length	800 m
Design Discharge	130 m^3/s
River Width	30 m
Excavation/Dredging	6,200 m^3
Embankment	14,400 m^3
Revetment	13,600 m^2
Sluices to be Constructed	2 units
Land Acquisition	1.5 ha
House Evacuation	12 houses

6. NON-STRUCTURAL FLOOD MITIGATION PLAN

6.1 River Reserve and Controlled Area

A "River reserve area" and a "River controlled area" is defined as a buffer area between a river and its adjacent area to protect it from undesirable activities. Its importance has been fully acknowledged among officials concerned. A certain width of river bank is recommended by DID to be delineated as a river reserve area. However, delineating of river reserve areas has not been progressing very far.

The riverside areas of Muda and Ketil rivers, which have not been delineated yet are being affected by recent sprawling land developments. They are exclusively used as private land and are far from management. For realizing orderly and harmonized development of the river environment, the delineation of adequate areas as river reserve areas and river controlled area is urgently required.

6.1.1 Required Function of River Reserve Area and River Controlled Area

The required land acquisition and functions of these areas are summarized as below.

(1) River Reserved Area

Entire land in this area is subject to land acquisition by the government, and any private land development works are frozen under jurisdiction of the river management body. The river reserved area shall be used as the space for the river improvement works as well as the space for operation and maintenance as described below:

(a) Space for River Improvement Works

Resettlement/relocation is one of the difficult problems encountered in the implementation of construction work. Many works have encountered this problem and some of them have been suspended because of it. To minimize resettlement/relocation, probable areas for future river improvement works is desirable to be protected from any development, and to be acquired as soon as possible.

(b) Space for Operation and Maintenance Work

For operation and maintenance work, a road is desirable to be constructed on riverbanks.

(2) River Controlled Area

The present private land located in this area is not subject to land acquisition by the government, but all land development therein is to be controlled through evaluation and approval by the river management body so as to fulfill the following functions:

(a) Function as Natural Retarding Basin

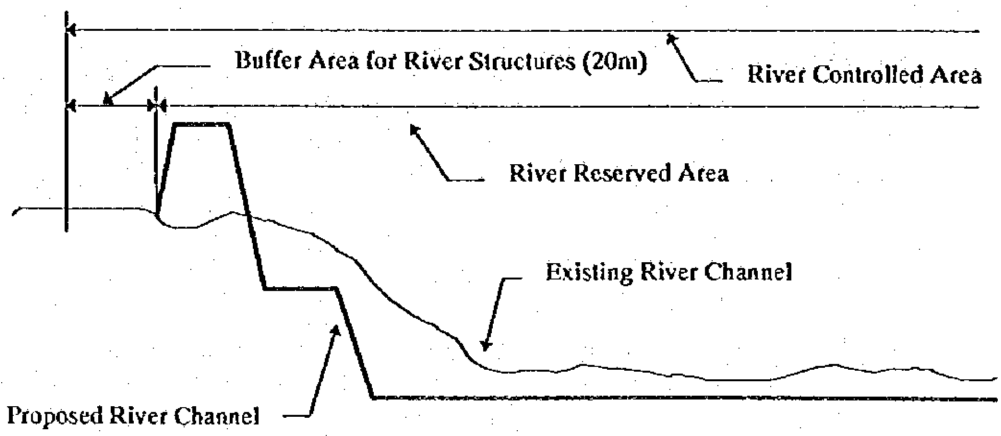
Flood inundation areas function as natural retarding basin to reduce flood discharge to the downstream stretches. A decrease of such inundation areas by development may result in the increase of burden to the downstream areas. In addition, the increase of assets in these areas may lead to the increase of flood damage potential. Therefore, disorderly development in the inundation areas shall have to be avoided.

(b) Space for Bank Erosion and Meandering

A meandering river like the Muda River needs a buffer area for possible bank erosion/meandering, if no protection works such as revetment and groin are provided.

(c) Buffer Area for River Structures

A river structure such as dike shall be protected from undesirable activities which may affect it. In Japan, a buffer/belt area with a width of 20 m along a dike is designated as a river controlled area as shown below:



6.1.2 River Reserve Area and River Controlled Area for Muda and Ketil Rivers

The DID Manual proposes a standard minimum width of a river reserve area according to the river width. For example, the minimum width of a river reserve area proposed as the extent of the possible flood inundation area of 100-year return period, the possible extent of the river erosion and meandering and a belt area of 20 m in width along the proposed river dike. The proposed river reserve area and river controlled area cover an area of about 57 km^2 in total along a stretch of 113 km of the main stream from the river mouth to the proposed Jeniang Barrage and a stretch of 41 km long of Ketil River from the confluence with the main stream to Kg. Tg. Merbau, as shown in Figs. II.6.1.1 to II.6.2.2, and in 1/20,000 topo-sheets in the Data Book. The average width of river reserve area and river controlled area is about 69 m and 167 m, respectively both for right and left banks, as listed below:

Proposed River Reserve Area and River Controlled Area

River	Stretch	Stretch Length (km)	River Reserve Area		River Controlled Area	
			Area (km^2)	Width* (m)	Area (km^2)	Width* (m)
Muda	Lower Muda River (River Mouth to Ldg. Victoria	40.3	5.6	69	1.6	20
	Ldg. Victoria to Proposed Jeniang Barrage	72.9	Nil	Nil	33.1	227
Ketil	Muda River to Kg. Tg. Merbau	41.0	Nil	Nil	16.9	206
	Total (or Average)	154.2	5.6	69 (Ave.)	51.6	167 (Ave.)

* Average width on one side.

According to Fig. II.1.1.2, the river channels have changed their courses at some portions at a maximum of 500 m for the last 28 years. Floodwaters may possibly erode the riverbanks along the boundary of the proposed reserve areas, but it is difficult to identify such probable erosion portions at present. Periodical monitoring is, therefore, very important and, if such portions are found by monitoring, a structural countermeasure such as revetment shall be provided, or the river reserve areas shall be extended to cover the probable erosion areas.

6.2 Recommendation for Improvement of Flood Forecasting and Warning System (FFWS)

DID has been making great efforts to improve the existing FFWS, which include installation of warning stations with a siren and telemetric rainfall and water level gauges. It is noteworthy that no loss of life was reported even during the 1988 flood mainly owing to adequate warning and evacuation activities of agencies concerned However, areas that could be improved still remain, and some recommendations are made as follows:

(1) Improvement of Rainfall Monitoring Network

Rainfall data are essential for flood forecasting. However, the existing rainfall stations are concentrated in the mid and downstream stretches of the basin, and the upstream mountainous areas are regarded as hydrologically blind areas. In particular, the fact that there is no rainfall gauge existing in the catchments of Muda and the proposed Beris Dams is a serious problem for the dam operation during a flood.

As discussed in SECTOR V, WATERSHED MANAGEMENT AND MONITORING PLAN, several rainfall gauges, which are desired to be equipped with a telemeter, shall be newly installed in the upstream areas to attain even distribution of rainfall gauges in the river basin.

(2) Integration of FFWS

Hydrological information such as water level and rainfall is monitored by three organizations, DID Kedah, DID Pulau Pinang and MADA in Muda River Basin. Data monitored individually by the three organizations are seldom exchanged among them although they have a system to transmit a few water level data of DID Kedah to DID Pulau Pinang. Flood forecasting and warning activities are also done individually by the states of Kedah and Pulau Pinang.

For taking a prompt action during a flood and avoiding duplication of facilities and activities, a basin-wide integrated organization shall be established. The organization shall have integrated and centralized function on all the FFWS works in the river basin. The Technical Secretariat which is proposed as an implementation organization of river management in SECTOR VIII, INSTITUTIONAL SETUP PLAN, can be the integrated organization for FFWS.

(3) Establishment of Warning System to Downstream of Dam and Barrage

Dams and barrages release water downstream for the purposes of irrigation or industrial/domestic water or emergency release during a flood. If people are in a river channel for fishing, swimming or playing when an upstream dam or barrage starts to release water, they may possibly be killed by the released surge water from the structure. In order to avoid such man-made flood disaster, a warning system to the downstream stretches of dams and barrages shall be established.

TABLES

SECTOR II

FLOOD MITIGATION PLAN

TABLE II.1.3.1 RESULT OF BED LOAD MEASUREMENT

River	Site	Sample No.	Date	Time	Water Level (m LSD)	Discharge (m3/s)	Bed Load (kg/day)
Muda	Pinang Tunggal	PT-1	19/11/94	10:00	1.93	68	47
		PT-2	26/11/94	7:12	2.06	94	5,756
		PT-3	4/12/94	5:45	2.50	214	22,846
		PT-4	11/12/94	5:40	1.88	59	4,671
	Jam. Syed Omar	JSO-1	19/11/94	15:55	7.83	52	16
		JSO-2	26/11/94	10:50	8.30	85	9,367
		JSO-3	4/12/94	8:30	9.40	197	2,761
		JSO-4	11/12/94	9:12	9.20	173	6,893
	Jeniang Bridge	JN-1	20/11/94	11:50	21.84	14	42
		JN-2	26/11/94	15:25	22.50	40	84
		JN-3	4/12/94	11:10	22.80	57	361
		JN-4	11/12/94	12:00	21.80	13	348
	Nami	NM-1	20/11/94	15:15	49.37	7	1,505
		NM-2	26/11/94	18:35	49.59	10	9,739
		NM-3	4/12/94	13:50	49.77	14	28,692
		NM-4	11/12/94	15:30	49.20	4	39,409
Ketil	Kg. Tiban	KT-1	20/11/94	9:05	17.46	18	49,912
		KT-2	26/11/94	13:26	17.86	37	56,740
		KT-3	4/12/94	10:10	18.08	49	86,783
		KT-4	11/12/94	10:50	17.40	16	41,381

TABLE II.1.3.2 ESTIMATION OF ANNUAL BED LOAD AT RIVER DISCHARGE STATION

% of Time	Pinang Tunggal (4,172 km2)		Ldg. Victoria (4,010 km2)	Jam. Syed Omar (3,330 km2)		Jeniang Bridge (1,740 km2)		N a m i (1,220 km2)		Kg. Tiban (825 km2)	
	Discharge* (m3/s)	Bed Load (M3)	Discharge (m3/s)	Discharge* (m3/s)	Bed Load (M3)	Discharge (m3/s)	Bed Load (M3)	Discharge** (m3/s)	Bed Load (M3)	Discharge** (m3/s)	Bed Load (M3)
5	375	2,195	356	276	1,524	78	760	24	730	85	2,567
10	288	1,401	273	212	804	58	423	18	584	63	1,837
15	241	908	229	177	433	46	232	14	464	51	1,304
20	201	643	191	148	265	38	143	12	386	41	988
25	160	437	152	118	153	31	90	10	324	34	761
30	136	298	129	100	89	25	58	8	273	28	589
35	119	223	113	88	59	22	39	7	235	24	472
40	104	172	99	76	41	19	27	6	206	20	386
45	91	133	86	67	28	16	20	5	181	18	319
50	79	102	75	58	19	15	15	5	164	16	274
55	70	80	67	52	14	13	11	4	147	14	234
60	62	63	58	45	10	11	8	3	131	12	196
65	53	48	50	39	7	9	6	3	114	10	161
70	45	35	42	33	4	8	4	3	101	9	133
75	36	25	34	27	3	7	3	2	89	8	111
80	29	16	27	21	1	6	2	2	78	7	90
85	21	10	20	15	1	5	1	2	66	5	70
90	14	5	13	10	0	4	1	1	53	4	51
95	7	2	7	5	0	3	0	1	41	3	34
100	0	0	0	0	0	1	0	0	27	1	19
Total		6,797			3,454		1,844		4,393		10,596

Data Source : Discharge data of Ldg. Victoria and Jeniang are from "Hydrological Data, Streamflow and River Suspended Sediment Records 1975-1980"

Note * : Discharge of Ldg. Victoria was modified based on catchment area considering influence of Muda dam.

** : Discharge of Jeniang was modified based on catchment area considering influence of Muda dam.

TABLE II.2.2.1 (1/3) ANNUAL MAXIMUM WATER LEVEL AND DISCHARGE (LDG. VICTORIA)

Serial No.	Year	Day	Annual Maximum Water Level (m LSD)	Annual Maximum Discharge (m3/s)	Remarks
1	1960	22/11	8.60	900	
2	1961	29/10	7.74	602	
3	1962	03/01	7.19	443	
4	1963	22/10	8.31	792	
5	1964	14/11	8.81	934	
6	1965	02/11	9.19	1.142	
7	1966	18/10	8.82	990	
8	1967	08/01	9.30	1.189	
9	1968	31/10	8.53	877	
10	1969	18/10	8.44	843	Completion of Muda Dam
11	1970	17/11	8.69	938	
12	1971	22/09	9.00	1.064	
13	1972	23/11	8.91	1.025	
14	1973	12/12	9.05	1.083	
15	1974	01/10	7.19	442	
16	1975	24/12	8.56	885	
17	1976	15/10	8.23	766	
18	1977	05/10	8.31	795	
19	1978	08/09	7.31	476	
20	1979	29/11	7.47	520	
21	1980	08/10	7.77	612	
22	1981	31/05	7.58	554	
23	1982	18/11	7.32	478	
24	1983	18/09	7.81	624	
25	1984	18/07	8.18	769	
26	1985	01/12	8.44	884	
27	1986	08/10	7.94	737	
28	1987	11/11	8.32	883	
29	1988	25/11	9.21	1.225	
30	1989	05/10	8.21	886	
31	1990	04/11	9.01	1.180	
32	1991	04/06	8.27	946	
33	1992	28/08	7.46	724	

TABLE II.2.2.1 (2/3) ANNUAL MAXIMUM WATER LEVEL AND DISCHARGE (JENIANG CABLE)

Serial No.	Year	Day	Annual Maximum Water Level (m LSD)	Annual Maximum Discharge (m3/s)	Remarks
1	1960	20/11	27.13	347	
2	1961	30/12	25.57	118	
3	1962	18/10	26.30	211	
4	1963	20/10	26.88	303	
5	1964	10/11	26.82	293	
6	1965	04/12	27.74	471	
7	1966	16/10	26.85	298	
8	1967	06/01	28.74	715	
9	1969	01/12	25.63	124	Completion of Muda Dam
10	1970	15/11	26.14	188	
11	1971	19/09	25.92	158	
12	1972	20/11	26.73	276	
13	1973	10/12	28.59	673	
14	1975	22/12	27.47	413	
15	1976	14/10	25.91	157	
16	1977	11/10	25.64	125	
17	1978	06/09	25.63	124	
18	1979	27/11	25.64	125	
19	1980	10/10	27.25	370	
20	1981	29/05	26.54	247	
21	1982	19/05	25.68	129	
22	1983	06/12	26.59	254	
23	1984	16/07	25.43	121	
24	1985	28/11	26.46	275	
25	1986	06/10	27.52	489	
26	1987	17/08	27.43	493	
27	1988	23/11	29.90	1.103	
28	1989	29/10	25.45	215	
29	1990	02/11	26.03	311	
30	1991	24/07	26.51	399	
31	1992	29/08	24.69	176	

TABLE II.2.2.1 (3/3) ANNUAL MAXIMUM WATER LEVEL AND DISCHARGE (KUALA PEGANG)

Serial No.	Year	Day	Annual Maximum Water Level (m LSD)	Annual Maximum Discharge (m3/s)
1	1974	23/11	30.99	103
2	1975	19/11	31.18	120
3	1976	01/01	30.40	61
4	1977	03/10	32.64	256
5	1978	08/11	31.70	167
6	1979	27/11	32.22	216
7	1980	16/10	32.72	264
8	1981	24/09	31.47	145
9	1982	01/10	31.73	169
10	1983	15/09	34.23	421
11	1984	28/04	33.21	313
12	1985	28/11	33.99	395
13	1986	17/11	32.62	254
14	1987	28/10	33.71	365
15	1988	22/11	33.65	358
16	1989	29/10	32.81	273
17	1990	26/10	32.78	270
18	1991	21/05	33.21	313
19	1992	27/08	33.43	336

Data Source : DID

TABLE II.4.1.1 PROPOSED MANNING'S ROUGHNESS COEFFICIENT

River	Stretch	Length (km)	Roughness Coefficient L.W.C.	H.W.C.
Muda River	River Mouth to Sidam Br.(Ldg. Victoria)	40	0.030	0.050
	Sidam Br. to Muda Dam	137	0.035	0.050
Ketil River	Confluence with Muda River to Kg. Bongor	49	0.035	0.050
Chepir River	Confluence with Muda River to Kg. Chepir	25	0.035	0.050

L.W.C. : Low Water Channel
H.W.C. : High Water Channel

TABLE II.4.2.1 LIST OF INTAKE PUMP STATIONS ALONG MUDA RIVER

Serial No.	Name of Pump Station	Location: Cross Sec No.	Location: Distance (km)	Location: Right / Left	Pump Capacity (m3/day)	Purpose	Completion Year	Managing Office	i) Operational Min. Water Level (m LSD)	ii) Prop. Design River Bed (m LSD)	Difference = i) - ii) (m)	Remarks
1	Kola-2	No. 12 + 850	11.5	R	599,000	Irrigation	1988	DID Kedah	-2.00	-2.68	0.68	
2	Pelula	No. 14 + 500	13.8	R	329,000	Irrigation	1998	DID Kedah	No Data	-2.51		
3	Bumbung Lima	No. 15 + 200	14.3	L	1,223,000	Irrigation	1957/1997	DID P. Pinang	1.52	-2.45	3.97	
4	Lahar Tiang	No. 23 + 200	22.1	L	315,000	Domestic	1972/1987	PWA	1.37	-1.79	3.16	
5	Pinang Tunggal	No. 24 + 750	24.6	R	88,000	Irrigation	1988	DID Kedah	No Data	-1.54		
6	Sungai Patani	No. 25 + 350	25.2	R	68,300	Domestic	1991	PWD Kedah	No Data	-1.49		
7	Pinang Tunggal	No. 25 + 800	25.4	R	27,300	Domestic	1979	PWD Kedah	1.52	-1.45	2.98	
8	Kelim	No. 26 + 150	25.0	R	160,000	Domestic		PWD Kedah	1.70	-1.39	3.09	Under Const.
9	Pinang Tunggal	No. 27 + 50	25.8	L	990,000	Irrigation	1970	DID P. Pinang	1.52	-1.35	2.87	
10	Terat Batu	No. 31 + 750	31.2	L	14,000	Irrigation	1987	DID Kedah	No Data	-0.77		
11	Pantai Perai	No. 32 + 150	31.6	R	132,000	Irrigation	1961	DID Kedah	No Data	-0.68		
12	Sidam Kiri	No. 39 + 450	39.0	R	88,000	Irrigation	1957	DID Kedah	3.17	0.80	2.37	
13	Sidam Kanan	No. 40	39.5	L	60,000	Irrigation	1957	DID Kedah	No Data	0.92		
14	Kg Kemumbong	No. 45 + 950	45.5	R	18,000	Irrigation	1988	DID Kedah	No Data	2.47		
15	Lubok Kiab	No. 50 + 850	50.9	R	12,000	Irrigation	1989	DID Kedah	No Data	4.02		
16	Pantai Cicak	No. 55 + 900	56.1	L	14,000	Irrigation	1985	DID Kedah	6.41	5.45	0.99	
17	Kuala Ketil	No. 57 + 250	58.0	R	15,000	Domestic	1991	PWD Kedah	7.60	6.03	1.57	
18	Teloi	No. 79 + 350	83.5	L	21,400	Domestic	1988	PWD Kedah	16.89	14.18	2.71	
19	Jeniang	No. 98 + 800	103.5	R	14,600	Domestic	1990	PWD Kedah	22.40	20.88	1.52	
20	Jeneri	No.109 +1500	117.0	R	8,700	Domestic	1992	PWD Kedah	27.55	27.14	0.41	
21	Padang Cicak	No.112 +2100	124.0	R	24,000	Irrigation	1984	DID Kedah	No Data	31.26		
22	Lubuk Merbau	No.120 +2400	140.5	R	1,400	Domestic	1968	PWD Kedah	No Data	40.95		
23	Nami	No.129 +1800	152.7	R	4,000	Domestic	1990	PWD Kedah	43.10	45.12		

[ ] : These pump stations are located within the back water stretch of Muda Barrage which keeps raising water level above 1.75 m (5.75) LSD.

Data Source : DID, PWD and PWA

TABLE II.5.1.1 FLOOD REGULATION EFFECT OF PROPOSED AND POTENTIAL DAM RESERVOIRS (PRELIMINARY SCREENING)

No	Dam Reservoir	Catchment Area (km^2)	Flood Regulation Effect at Downstream Point									Screening*4
			D/S Point	Catchment Area(km^2)	Reduction Ratio K*1	D/S Point	Catchment Area(km^2)	Reduction Ratio K*1	D/S Point	Catchment Area(km^2)	Reduction Ratio K*1	
1	Charok Sama Gajah	23	Jeniang	1,740	0.99	Kuala Ketil*2	2,401	1.00	Ldg Victoria	4,010	1.00	Abandoned
2	Tawar Muda	1,113	Jeniang	1,740	0.63	Kuala Ketil*2	2,401	0.75	Ldg Victoria	4,010	0.86	Selected
3	Sungai Ma	40	Jeniang	1,740	0.99	Kuala Ketil*2	2,401	0.99	Ldg Victoria	4,010	1.00	Abandoned
4	Kerik	20	Jeniang	1,740	0.99	Kuala Ketil*2	2,401	1.00	Ldg Victoria	4,010	1.00	Abandoned
5	Charok Kasai	10	Jeniang	1,740	1.00	Kuala Ketil*2	2,401	1.00	Ldg Victoria	4,010	1.00	Abandoned
6	Reman	32	Jeniang	1,740	0.99	Kuala Ketil*2	2,401	0.99	Ldg Victoria	4,010	1.00	Abandoned
7	Charok Tebar	38	Sik	210.7	0.91	Kuala Ketil*2	2,401	0.99	Ldg Victoria	4,010	1.00	Selected
8	Weng	37	Baling	310	0.94	Kuala Pegang	704	0.98	Kuala Ketil*3	868	0.93	Selected
9	Legong	44	Baling	310	0.93	Kuala Pegang	704	0.97	Kuala Ketil*3	868	0.93	Selected
10	Kupang	24	Kuala Pegang	704	0.98	Kuala Ketil*3	868	0.99				Abandoned

Note : *1 : Flood Reduction Ratio $K = \text{sq root} \{ 1 - (1 - m^2) \times a / A \}$

where K : Flood reduction ratio at downstream point = Regulated flow / Natural flow without dam reservoir

This formula is from "National Water Resources Study, Sectorial Report Vol.5 River Conditions, JICA 1982"

A : Catchment area of downstream point

a : Catchment area of dam

m : Flood reduction ratio at dam (m = Outflow / Inflow, assumed to be 0.25)

*2 : Upstream of confluence point with Ketil River

*3 : Upstream of confluence point with Muda River

*4 : Screen criteria : selected if K < 0.95, abandoned if K > or = 0.95

TABLE II.5.2.1 PRELIMINARY COST ESTIMATE FOR FLOOD CONTROL DAMS

Name of Dam	C.A (km^2)	Required Vol. (mil m^3)			Equivalent W.L. (m LSD)	Dam			Construction cost *** (10^6 RM)	Remarks
		Flood control	Sedime-ntation	Total		Crest length (m)	Height * (m)	Volume (10^3m^3)		
Tawar - Muda	129	54	7.6	61.6	77	*4 1,377.5	33	*5 1,194	191	Fill type dam
Charok Tebar	38	0.76	0.9	1.66	68	249	38	430.7	70	Fill type dam
Weng	37	1.07	0.9	1.97	206	309	32	394.0	65	Fill type dam
Legong	44	1.46	1.1	2.56	141	139	28	140.8	25	Fill type dam

* 3m freeboard and river bed excavation are included
** Compensation cost is not included
*** Dead vol. = $7.6 \times 10^6 m^3$, sedimentation vol. = $3.1 \times 10^6 m^3$ from PKP
*4 Main dam + secondary dam
*5 Main dam + secondary dam + saddle dam

TABLE II.5.3.1 COST COMPARISON OF NPV OF RIVER MOUTH IMPROVEMENT WORK ALTERNATIVES

Case-1 : Capital and Maintenance Dredging
Case-2 : Capital and Maintenance Dredging and Submerged Jetty

1. Work Quantity and Cost

Item	Quantity (m^3)	Unit Cost *1 (RM)	Cost (RM)
Capital Dredging			681,000
Outer Channel	87,000	7	609,000
Inner Channel	12,000	6	72,000
Maintenance Dredging (Without Sub. Jetty)	59,000	7	413,000
Maintenance Dredging (With Sub. Jetty)	27,000	7	189,000
Submerged Jetty (Ruble Mound with Sand-filled Tube Type)	15,200	190	2,888,000
Maintenance of Sub. Jetty (Replacement of Sand-filled Tube) *2			1,732,800

2. Net Present Value of Construction Cost

Interest 8 % Unit : 1,000 Ringgit

Year	Case-1			Case-2			
	Cap. Dredging	Main. Dredging	Total	Cap. Dredging	Main. Dredging	Sub. Jetty	Total
1	681		681	681		2,888	3,569
2		413	413		189		189
3		413	413		189		189
4		413	413		189		189
5		413	413		189		189
6		413	413		189		189
7		413	413		189		189
8		413	413		189		189
9		413	413		189		189
10		413	413		189		189
11		413	413		189		189
12		413	413		189		189
13		413	413		189		189
14		413	413		189		189
15		413	413		189		189
16		413	413		189	1,733	1,922
17		413	413		189		189
18		413	413		189		189
19		413	413		189		189
20		413	413		189		189
21		413	413		189		189
22		413	413		189		189
23		413	413		189		189
24		413	413		189		189
25		413	413		189		189
26		413	413		189		189
27		413	413		189		189
28		413	413		189		189
29		413	413		189		189
30		413	413		189		189
NPV of Direct Cost			5,289				6,224
NPV of Project Cost *3			7,363				8,664

Note : *1 ; Unit costs are from "National River Mouths Study, JICA"
*2 ; Flexible sand-filled tubes are replaced every 15 years.
*3 ; (NPV Of Direct Cost) x 1.392