KERAJAAN MALAYSIA

JABATAN PENGAIRAN DAN SALIRAN MALAYSIA

DESIGN OPTION OF THE FLOOD MITIGATION PLAN OF SG. MUDA, SUNGAI MUDA, KEDAH

DRAFT FINAL REPORT

UNIVERSITI SAINS MALAYSIA

Pusat Penyelidikan Kejuruteraan Sungai dan Saliran Bandar (REDAC)

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September, 2006

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di atas segala kerjasama yang diberikan semasa projek ini dijalankan.

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DESIGN OPTION OF THE FLOOD MITIGATION PLAN OF SG. MUDA, SUNGAI MUDA, KEDAH

CONTENTS

Executive Summary

USAINS HOLDING Sdn Bhd through River Engineering and Urban Drainage Research Centre (REDAC) has been appointed by Jabatan Pengairan dan Saliran Malaysia to carry out DESIGN OPTION OF THE FLOOD MITIGATION PLAN OF SG. MUDA, SUNGAI MUDA, KEDAH beginning 1 April 2006 for a period of six months.

The Draft Final Report presents seven chapters as follows:

CHAPTER 1	INTRODUCTION
CHAPTER 2	SITE VISITS AND RECENT FLOODS
CHAPTER 3	PAST STUDIES OF SG. MUDA
CHAPTER 4	HYDROLOGICAL MODELLING
CHAPTER 5	RIVER MODELLING
CHAPTER 6	PROPOSED DESIGN CRITERIA
CHAPTER 7	CONCLUSIONS

The Flood Control Remediation Plan (FCRP) of Sg Muda has been reviewed with the perspective to possibly enhance the proposed design. The objectives of this review are to: (1) ensure that design cross-sections and alignment of the main river channel are economic, effective and environmentally sound; (2) propose alternative designs for identified locations to meet the above requirements; and (3) examine the long term river behaviour through model studies to minimise expensive repair works in future resulting from the new alignment.

The current bund height proposed by JPZ is based on a 50 year ARI design discharge of 1,815 cumecs plus freeboard. This design is found to be highly conservative and will pass flows with period of return far in excess of 100 years. The main conclusion of this review is that the design of the bund height should be based on the 2003 flood discharge of 1,340 cumecs plus a one meter freeboard. The proposed channel widening in Alternative 2 of the JPZ report also appears not to be necessary. If retained, channel widening should correspond to significant lowering of the bund height.

A plan to address the sand and gravel mining issues on Sg Muda is also strongly recommended to ensure: (1) stability of the proposed river bank protection structures; (2) stability of the bridge piers at Ladang Victoria; and (3) operations of irrigation pumping stations. Channel realignment is proposed at two sites to increase flood conveyance and further lower the proposed bund height. In-stream mining should not be allowed between Ladang Victoria and the Muda barrage. Off-stream mining at a minimum distance of 50 m from the river bank should be permitted instead.

With a design discharge reduction of 25%, this study shows the potential for very significant cost savings of this FCRP for Sg. Muda. A more detailed analysis of the reduced bund elevation should include the effects of the reduced design flood discharge and the proposed realignment. Channel widening is not recommended, but if retained, the bund heights should be lowered accordingly. The details on the locations and sand mining volumes extractable from off-stream mining activities should be examined.

Chapter 1

Introduction

1.1 Background

Urbanization normally brings about an increase in the discharge of a river due to increase in impervious areas. As a result, the sediment transporting capacity of the river also increases causing changes to the river equilibrium. Recurrence of flooding has been linked to the high rate of sedimentation in the river channel. Failures of bank protection structures frequently occur during and after the construction of a flood mitigation project. Causes of the failures are numerous and river bed degradation or erosion resulting in the instability of the structures in a river is the pertinent one. Erosion and sedimentation in rivers involve a dynamic process resulting from the interaction between the flowing water and sediment bed. An understanding of this interaction which causes sediment movement and hence cross-sectional changes is important to control the erosion and sedimentation within allowable limits to ensure the stability of the river channel.

1.2 Objectives

Sg. Muda experiences floods almost every year, each differing only in their magnitude. The October 2003 flood saw 45,000 people affected with catastrophic damages. At the upstream end of Sg. Muda is the Muda dam which acts as an extra storage for the Pedu dam. The two dams are part of the MUDA irrigation scheme. With the northern states being a water deficit area, the first flood mitigation option was to increase the storage volume of Muda dam. This idea however, was not well received by Kedah state government. Therefore the next best option is the rapid conveyance of the flood water into the sea.

The valley or flood plain is part of the river system. Over the years, large numbers of inhabitants have encroached into the flood plain. To make matters worse many of the dwellings are built close to the river. Sg Muda is also a major source of sand for the northern region. A study by JICA in 1995 showed that total sand being excavated from the river from more than 100 mining locations far exceeded the total yield of sand by the river (in the region of 100 times). As such the river bed had severely degraded throughout its length with many stretches of river banks also badly eroded.

The government requires consultancy services to carry out a review study of the on-going Sg. Muda flood mitigation project to achieve the following objectives:

(i) Ensure that design cross-sections and alignment of the main river channel are economic, effective and environmentally sound;

(ii) Propose alternative designs for identified locations to meet the above requirements;

(iii) Examine the long term river behaviour through model studies, to minimise expensive repair works in future resulting from the new alignment.

1.3 Scope of Work

The Consultant shall conduct a review of the following:

(a) Rainfall data in space and time leading to chosen flood events.
(b) Runoff discharge and stage records of the chosen events;
(c) Computer simulation of the flood events;
(d) Computer simulation of long term river behavior to determine stretches prone to meandering, hence needing extra protection;
(e) Changes in alluvial river geometry in terms of aggradation and degradation as well as lateral channel migration as a result of the flood events;
(f) Design criteria used for the Flood Control Remediation Plan; and
(g) Specific design of the proposed structures including levee protection, riverbank protection works and protection of bridge crossings and other structures.

Chapter 2

Site Visit and Recent Floods

Two site visits were carried out on 26th April and 18th May, 2006 to the Project area to have a preliminary survey of the site. Important observations of the current conditions of Sungai Muda have been made through the visit. A brief discussion on recent floods in Sg. Muda is also given. Flood frequency analysis was also carried out in light of the 2003 flood.

2.1 Site Observations

Starting from the downstream of Muda River in the Project area, Figure 2.1 shows the current flood mitigation project at the Sg. Muda River Mouth and Figure 2.2 shows the current condition of Sg. Muda River Mouth.

Figure 2.1 Flood Mitigation Project at Sg. Muda River Mouth

Figure 2.2 Sg. Muda River Mouth

Figure 2.3 shows the Sg. Muda near Kota Kuala Muda. The new bridge has provided the link for villages along Penang and Kedah boundary. A few houses along the Sg. Muda have extended into river reserve as indicated in Figure 2.4.

Figure 2.3 New Bridge at Sg. Muda Near Kota Kuala Muda

Figure 2.4 Houses Extended into River Reserve

Figure 2.5 shows the on-going construction of the new Sg. Muda Barrage at Rantau Panjang whilst the view of the Sg. Muda from the new barrage is as illustrated in Figure 2.6.

Figure 2.5 Construction of New Sg. Muda Barrage (CH 9400)

Figure 2.6 New Sg. Muda Barrage

The rainfall station at Rantau Panjang is shown in Figure 2.7 while Figure 2.8 shows the floodplain (the padi field).

Figure 2.7 Rainfall Station @ Rantau Panjang

Figure 2.8 Flood Plain (Padi Field) along Muda River near Rantau Panjang

Figure 2.9 shows the Flood Mitigation component at Pekula Pumping Station. The recreational park near the pumping station has been abandoned since the start of Package 2 of the Flood Mitigation project (Figure 2.10). The irrigation canal has been filled up for the construction of the Sg. Muda bund (Figure 2.11) whilst Figure 2.12 shows the existing condition of the irrigation canal on 25th May 2005.

Figure 2.9 Phase II Flood Mitigation Project at Muda River (Pekula Pumping Station)

Figure 2.10 Abandoned Recreational Park at Pekula Pumping Station (26th April 2006)

Figure 2.11 Construction Works at Pekula Pumping Station

Figure 2.12 Irrigation Canals at Pekula Pumping Station (25th May 2005)

Figure 2.13 shows the sand mining activity and river alarm station (Figure 2.14) at Sg. Muda near Pinang Tunggal whilst Figure 2.15 shows the view of Sg. Muda at CH 12400 and Sg. Korok.

Figure 2.13 Sand Mining Activities

Figure 2.14 River Alarm Station @ Kampung Tepi Sungai Pinang Tunggal

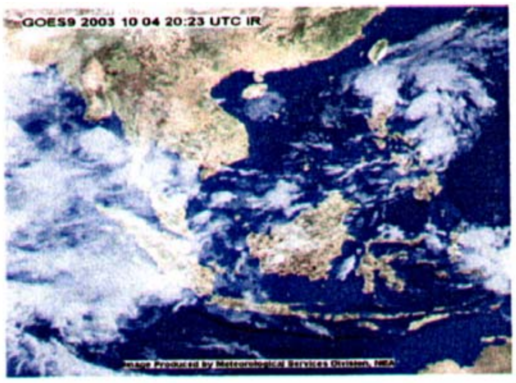
(a) Sg. Muda @ CH 12400

(b) Sg. Korok

Figure 2.15 Sg. Muda @ CH 12400 and Sg. Korok

2.2 Rainfall Distribution

Satellite images (Figure 2.16) show that the 2003 Flood originated primarily from the southern part of the Sg. Muda watershed. Table 2.1 gives a summary of rainfall distribution for several rainfall stations in the catchment of Sg. Muda. Stations such as Gunung Jerai, Sg. Petani, Sik and Kulim indicate that the 2003 Flood is a 100-year event. Figure 2.17 shows that most of the rain occurred in the southern part of the Sg. Muda catchment. The flood inundation area for the 2003 Flood is shown in Figure 2.18.



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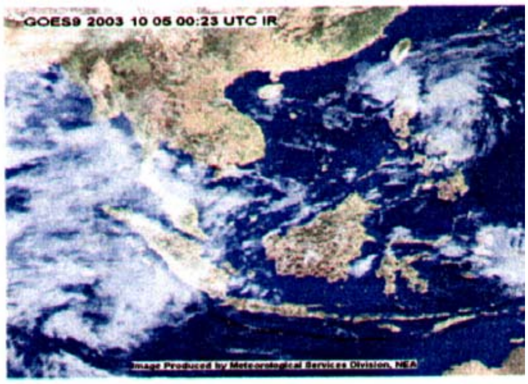

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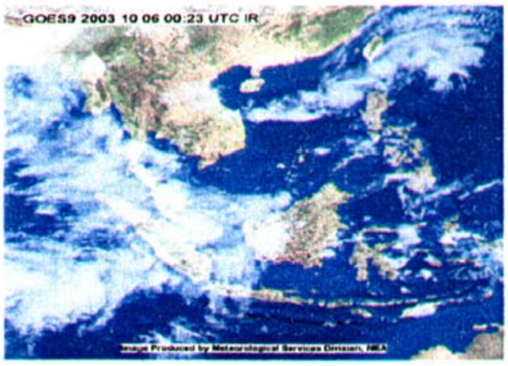

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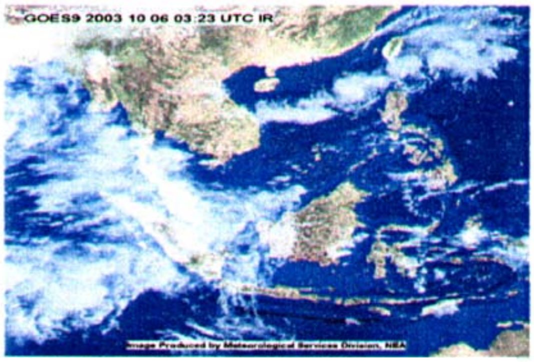

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Figure 2.16 Cloud Movements During 2003 Flood

Table 2.1 Summary of Rainfall Distribution for 2003 Flood

No.	Rainfall Station	District	2/10	3/10	4/10	5/10	Total (2-5 Oct)	Total Rainfall (3 Day Max)	ARI (3 day Max)
1	Pulai	Baling	20	27	80	46	173	153	Normal
2	Kuala Pegang	Baling	43	56	120	27	246	219	5
3	Jam. Syed Omar	Kuala Muda	32	79	148	57	316	284	30
4	Gunung Jerai	Kuala Muda	147	238	252	128	765	637	>100
5	Sg. Petani	Kuala Muda	47	124	177	68	416	369	>100
6	Pendang	Kota Setar	34	72	41	15	162	147	Normal
7	Alor Setar	Kota Setar	33	60	33	26	151	125	Normal
8	Sik	Sik	96	80	220	85	480	396	>100
9	Jeniang	Sik	71	90	115	96	372	301	50
10	Kulim	Kulim	12	74	242	77	403	392	>100

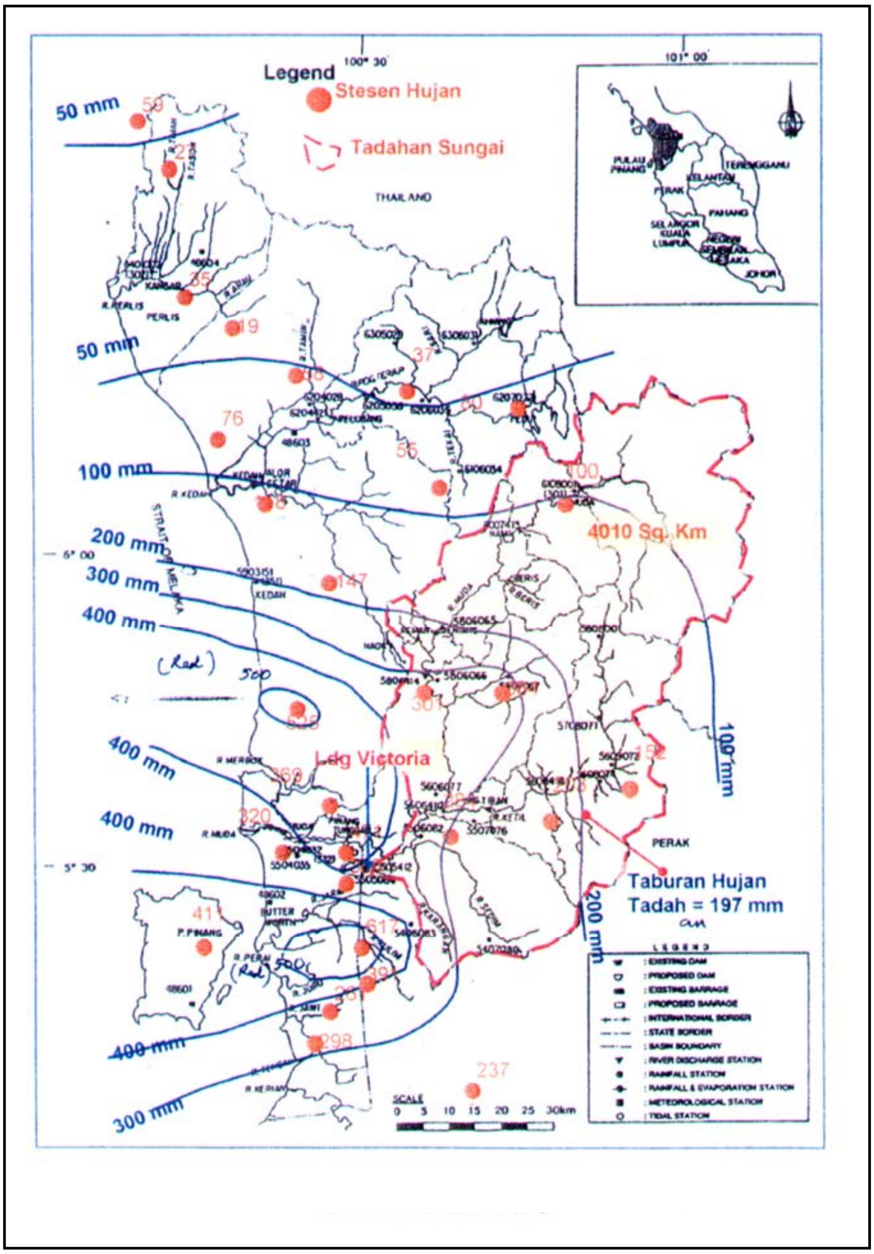


Figure 2.17 Rainfall Distribution

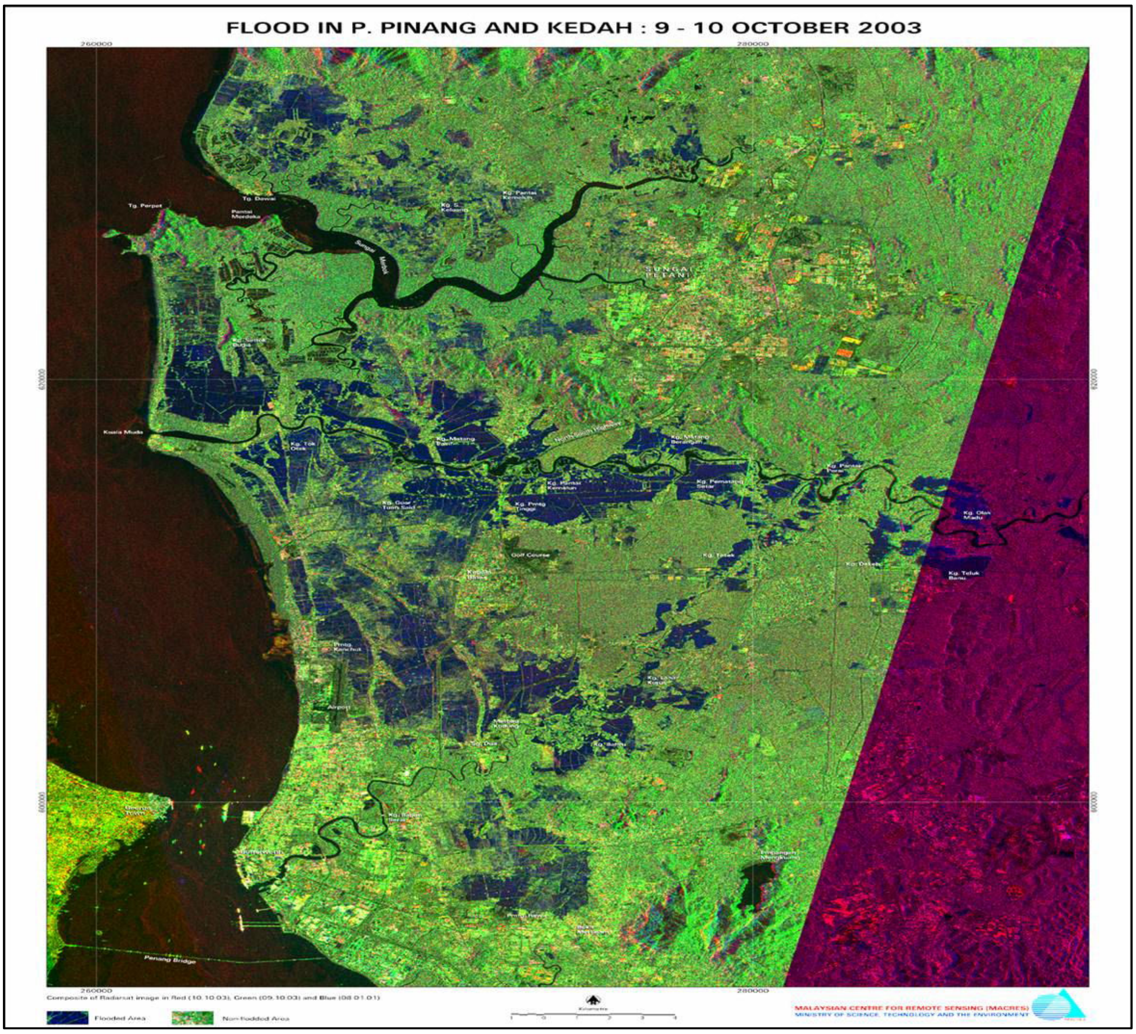


Figure 2.18 2003 Flood Inundation Areas

2.3 Flood Frequency Analysis

Three major floods occur in 1988, 1998 and 2003 within the 15-year span. The ranking of the flood over a 44 year period is given in Table 2.2. The review indicates that the 2003 flood at Ladang Victoria was the highest discharge measured in a 44 year period. It is this considered that the discharge of 1,340 cumecs measured in 2003 is the highest during that period of record. This value, which is based on measurable peak discharges, provides a reliable and long period of record Ladang Victoria. This measured value of 1,340 cumecs over a period of 44 years should be very close to the 50-year flood.

A flood frequency analysis was carried out using the 44 year period of data. It was found that the best result was obtained using Gumbel Extremal Type I (Figure 2.19). The flood frequency analysis provided by the Department of Irrigation and Drainage (DID), JICA (2005) and the present study is given in Table 2.3. The results show that the flood frequency analysis by DID, JICA and also independently done in the present study provides very consistent results with 50-year flood peaks between 1,254 and 1,275 cumecs at Ladang Victoria.

It is therefore concluded that 2003 flood discharge of 1,340 cumecs is slightly larger than the 50-year peak discharge. Consequently, it should seriously be considered as the design peak discharge for the lower Muda River. It is most important to consider that the bund elevation at different locations in the lower 43km of the Muda River should be determined from the flood stage calculations at a discharge of 1,340 cumecs plus freeboard.

Table 2.2 Flood Ranking for Sg Muda @ Ladang Vitoria

Rank	Year	Q (m^3/s)		Rank	Year	Q (m^3/s)
1	2003	1340		23	1977	542
2	1988	1225		24	2001	539
3	1999	1200		25	1963	516
4	1996	1100		26	1984	500
5	1998	980		27	1980	480
6	1967	912		28	1979	450
7	1965	861		29	1985	449
8	1971	789		30	1981	436
9	1973	781		31	1990	433
10	1972	706		32	1982	399
11	1966	661		33	1983	393
12	1964	640		34	1991	382
13	1997	626		35	1987	377
14	2000	626		36	1978	375
15	2002	612		37	1961	374
16	1970	602		38	2004	340
17	1960	572		39	1989	332
18	1968	572		40	1993	326
19	1975	565		41	1992	319
20	2005	565		42	1986	315
21	1976	549		43	1962	268
22	1969	546		44	1974	264

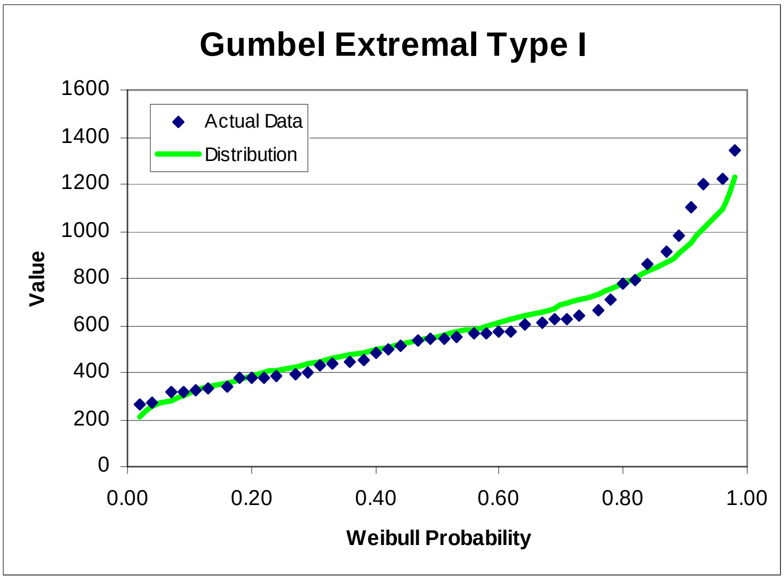


Figure 2.19 Flood Frequency Analysis Using Gumbel Extremal Type I

Table 2.3 Flood Frequency Analyses for Sg. Muda @ Ladang Victoria

Return Period	Discharge (m^3/s)		
	DID	JICA (1995)	PRESENT STUDY Gumbel Extremal Type I (Discharge Data from 1960 – 2005)
2	517		552
5	760	810	776
10	916	950	926
25	1125		1114
50	1275	1260	1254
100	1423	1340	1393
200	1572		1531

Chapter 3

Past Studies of Sg. Muda

3.1 JICA (1995)

Japanese International Cooperation Agency or JICA (1995) conducted a comprehensive river basin study for Sg. Muda in 1994. Details of the study and information on Sg. Muda from the study are included herein.

3.1.1 Objectives of the Study

The Study is to formulate a comprehensive management plan for the Muda river basin by integrating the following four components and setting the year 2010 as the target year: (a) flood mitigation plan; (b) water resources management plan; (c) river environmental management plan; and (d) watershed management and monitoring plan. All of these plans are to be formulated on the master plan level.

The objectives of each component of the comprehensive plan are as discussed below.

(a) Flood Mitigation Plan

Both the structural and non-structural plans for flood mitigation shall be studied with particular attention to the natural retarding effect of the river basin. The effect of the present sand mining activities to the stability of the river channel shall also be studied to ensure the success of the proposed river channel improvement.

(b) Water Resources Management Plan

The structural measures to develop water resources shall be studied according to the results of a review made on previous plans. The appropriate water allocation plan in an extra drought year shall also he formulated in due consideration of the interstate requirements of Kedah, Pulau Pinang and Perlis.

(c) River Environmental Management Plan

The plan for the management of quantity and quality of river flow shall be formulated. The management plan for land use along the river corridor and dam reservoir shall also be studied with particular attention to the improvement of river environment.

(d) Watershed Management and Monitoring Plan

The zoning plan for the entire watershed shall be formulated to control the excessive basin development activities that could cause adverse effects on the aforesaid river management plan. The monitoring plan for river activities and basin development activities shall also be formulated to maintain a well-balanced river management. The monitoring plan shall include an institutional set-up to ensure the proposed monitoring and river management works.

3.1.2 Study Area

The study area for all components of the comprehensive plan except the water resources management plan shall be within the limits of the Muda river basin (Figure 3.1). Since the water supply area of the water resources of Sg. Muda extends beyond the Muda river basin and covers the whole states of Kedah and Pulau Pinang as well as a part of the State of Perlis, the water demand projection as well as the water supply and demand simulation shall be made for the whole water supply area of Sg. Muda.

The states of Kedah, Pulau Pinang and Perlis are located in the northwestern part of Peninsular Malaysia, occupying a total of 11,252 km , i.e., 9,426 km for the State of Kedah, 1,031 km" for the State of Pulau Pinang, and 795 km" for the State of Perlis. The upper and middle reaches of Sg. Muda belong to the State of Kedah, while the river downstream with a length of about 30 km forms the boundary between the states of Kedah and Pulau Pinang. The Muda river basin has a catchment area of 4,210 km, most of which is located within the State of Kedah.

Each of the above three states is administratively divided into several districts, and each district is further divided into parishes called *Mukim* in Malaysian term. The three states cover 17 districts and 239 mukims, out of which the Muda river basin covers 6 districts and 28 mukims.

3.1.3 Climate

The study area has two typical monsoons; namely, the northeast monsoon and southwest monsoon. The northeast monsoon usually occurs from November to February.

During this season, the northeast monsoon unloads its moisture contents over the east coast of Peninsular Malaysia. However, the study area located in the west coast receives a little rain during this monsoon due to the sheltering effect of the central mountain range running from north to south in Peninsular Malaysia.

The southwest monsoon usually reaches the west coast of Peninsular Malaysia from the Indian Ocean and prevails over Peninsular Malaysia from May to August. The monsoon contains heavy moisture and causes the fairly heavy rainfall in the study area from April to May.

In the transition period between the above two monsoons, from September to November, the western wind prevails and causes the heaviest rainfall in the study area in a year. Thus, the study area tends to have two rainy seasons in a year; one is from April to May and another, from September to November (Figure 3.2).

The annual rainfall depth in the Study Area is about 2,000 to 3,000 mm. The heavy annual rainfall is observed around the central mountain of Gunong Jerai and the southern mountainous areas declining northward and to the river mouth (Figure 3.3).

The temperature in the study area is around 27"C on average, and its annual variation is less than 2°C. The humidity in the study area varies from the lowest of about 75% in January to the highest of about 88% in October. The annual average sunshine hours is around 7 hours varying from the minimum of less than 6 hours in September to the maximum of more than 8 hours in February. The monthly pan evaporation at Alor Setar is about 135 mm on average containing the lowest of 110 mm in November and the highest of 175 mm in January.

3.1.4 River Morphology

3.1.4.1 River System

Sg. Muda with a catchment area of 4,210 km^2 originates in the north mountainous area of Kedah State and flows down toward the south. It changes its course towards the west coast after passing the confluence of the main stream and its tributary, Ketil River. The total length of the main stream is about 180 km.

There are three major tributaries of the Sg. Muda river system; namely, Sg. Ketil with a catchment area of 868 km^2, Sg. Sedim with 626 km^2 and Sg. Chepir with 335 km^2. Sg. Ketil is the largest tributary including its secondary tributary, Sg. Kupang that has a catchment area of 147 km^2.

3.1.4.2 River Channel Profile

The main channel of Sg. Muda has a length of about 180 km with a slope of 1/2,300 from the river mouth to Muda Dam. The channel lengths and slopes of the tributaries are 70 km and 1/750 for Sg. Ketil, 30 km and 1/550 for Sg. Sedim, and 25 km and 1/800 for Sg. Chepir.

The channel width is 300 m near the river mouth and tends to be narrower upstream. The channel tends to erode due to the sand mining operations, aggravating bank erosion and riverbed degradation. The average riverbed had subsided by 2 to 5 m for the period 1983 to 1994, as proven by the longitudinal profile survey in those years (Figure 3.4) and, in parallel with the subsidence of the riverbed, the water level has also been lowering by 1 to 2 m for the past 20 to 30 years (Figure 3.5).

The riverbed subsidence seriously affects river structures such as bridges and water intake facilities. Foundation piles of the bridge at Ldg. Victoria are exposed by 2 to 3 m above the eroded riverbed (Figure 3.6). Moreover, the lowering of water level also causes difficulty in abstracting water from the river at the existing intake points.

On the other hand, the river mouth tends to be affected by the accumulation of sediment causing aggravation of the riverbed and development of sand bar. DID dredged 1.2 km of the outer channel in 1986, deepening the channel bed to 4 m below LSD, but it silted up by 2 to 3 m in 76 months after dredging (Figure 3.7). The shallowest point surveyed in 1994 is 2 m below LSD at 0.5 km off the river mouth, causing difficulty to navigation during low tide. Judging from the sand mining operations on the river as well as the bed materials mentioned in later subsections, the major cause of sediment accumulation around the river mouth could be cither ocean sand drift or the suspended/wash load supplied from Sg. Muda.

3.1.4.3 Channel Flow Capacity

The bankfull flow capacity was estimated by non-uniform calculation using the updated channel survey results in 1994 (Figure 3.8). The lower stretches of Sg. Muda tend to have a smaller flow capacity than the upper stretches. At many points downstream of the confluence with Sg. Sedim, the flow capacity is to accommodate the flood discharge of less than a 2-ycar return period. Moreover, low-lying areas are scattered along the Sg. Ketil and Sg. Chepir where flood inundation of even a 2-ycar return period occur. In the upper stretches of Sg. Muda from the confluence with Sg. Chepir, however, the river forms a valley, and the elevation of riverbanks is high enough to accommodate the flood discharge of 10-year return period.

3.1.4.4 River Water Quality

DOE had carried out water quality sampling at 1C) sites in the Muda river system for the period 1978-1994 (Figure 3.9). The water quality records by DOE indicate low concentrations of BOD, SS and NH4-N of Sg. Muda. In this connection, DOE had evaluated that Sg. Muda is clean and suitable for domestic water supply (refer to Table 3.1).

Table 3.1 Water Quality Index of Sg. Muda by DOE Classification

YEAR	OVERALL INDEX WQI	INDEX BY-BOD	INDEX BY SS	INDEX BY NH4-N
1985	83	93	78	86
1986	86	95	73	88
1987	81	93	73	82
1988	82	91	74	79
1989	79	91	69	74
1990	81	92	72	80
1991	80	94	72	72
1992	79	95	71	87
1993	81	89	71	72
1994				
mean	81.33	92.56	72.56	80.00

	OVERALL:	BOD:	SS:	NH4-N
Dirty	<60	<80	<70	<71
Slightly dirty	61 – 80	80 ~ 90	70 ~ 75	71 ~ 91
Clean	81 <	90 <	75 <	91 <

Note: The index figures are obtained from DOE.

Table 3.2 Results of Water Quality Test by JICA Study Team (First Survey)
(Based on DOE Classification)

Loca.	pH	DO	Elct. Cond	Tub	SS	BOD	T. Coli	NH3-N	As	Cd	Cr(VI)	Pb	Fe	T-Hg	P	Cn	F
		Mg/l	Umhos/cm	NTU	Mg/l	Mg/l	No./100ml	Mg/l	Mg/l	Mg/l	Mg/l	Mg/l	Mg/l	Mg/l	Mg/l	Mg/l	Mg/l
First Sampling																	
M1	II	II	I	II	I	II	III	IV	II	II	II	II	V?	II?	V?	II?	II
M2	II	II	I	II	I	II	II	IV	II	II	II	II	V?	II?	V?	II?	II
M3	II	II	I	II	III	II	III	IV	II	II	II	II	V?	II?	V?	II?	II
M4	II	II	I	II	II	II	II	IV	II	II	III <	II	V?	II?	V?	II?	II
M5	II	II	I	I	II	I	II	IV	II	II	III <	II	V?	II?	V?	II?	II
C1	II	II	I	II	I	II	III	III	II	II	II	II	V?	II?	V?	II?	II
K1	III	II	I	II	III	III	III	III	II	II	II	II	V?	II?	V?	II?	II
S1	II	II	I	II	II	II	III	IV	II	II	II	II	V?	II?	V?	II?	II
F1	III	II	I	I	II	II	II	III	II	II	II	II	V?	II?	V?	II?	II
F2	II	II	I	II	II	II	III	IV	II	II	III <	II	V?	II?	V?	II?	II
Second Sampling																	
M3	II	II	I	II	I	I	II	III	II	II	III <	II'III	V?	II?	V?	II?	II
K1	III	II	I	II	I	I	III	III	II	II	III <	II'II	V?	II?	V?	II?	II

Table 3.3 Results of Water Quality Test by JICA Study Team (Second Survey)
(Based on DOE Classification)

Loca.	pH	DO	Elct. Cond	Tub	SS	BOD	T. Coli	NH3-N	As	Cd	Cr(VI)	Pb	Fe	T-Hg	P	Cn	F	TDS	COD	F.Coli.	T-N	Se
		Mg/l	Umhos/cm	NTU	Mg/l	Mg/l	No./100ml	Mg/l	Mg/l	Mg/l	Mg/l	Mg/l	Mg/l	Mg/l	Mg/l	Mg/l	Mg/l	Mg/l	Mg/l	No./100 ml	Mg/l	Mg/l
First Sampling																						
M1	II	III	I	II	I	II	III	IV	II	II	II	II	III	II	II	II	II	I	II	III	-	-
M2	II	III	I	II	II	II	III	IV	II	II	II	II	III <	II	II	II	II	I	III	III	-	-
M3	II	III	I	II <	II	II	III	II	II	II	II	II	III <	II	II	II	II	I	II	III	-	-
M4	II	III	I	II <	II	II	III	IV	II	II	II	II	III <	II	II	II	II	I	II	III	-	-
M5	II	III	I	II <	III	II	III	III	II	II	II	II	III <	II	II	II	II	-	-	III	-	-
C1	II	III	I	II	I	I	III	III	II	II	II	II	III <	II	II	II	II	I	I	III <	-	-
K1	II	III	I	II	I	II	III	III	II	II	II	II	III <	II	II	II	II	I	II	III <	-	-
S1	II	III	I	II <	II	III	III	IV	II	II	II	II	III <	II	II	II	II	I	II	III <	-	-
F1	II	III	I	II	I	III	III	IV	II	II	II	II	III <	II	II	II	II	I	I	III	-	-
F2	II	IV	I	II <	III	V	III	IV	II	II	II	II	III <	II	II	II	II	II	V	III <	-	-
Second Sampling																						
M1	II	III	II	II<	III	II	III	III	II	II	II	II	III <	II	II	II	II	I	III	III <	-	III <
M2	II	III	II	II<	III	II	III	III	II	II	II	II	III <	II	II	II	II	I	II	III	-	II
M3	II	III	II	II<	III	I	III	IV	II	II	II	II	III <	II	II	II	II	I	II	III <	-	II
M4	II	III	II	II<	II	III	III	IV	II	II	II	II	III <	-	II	II	II	I	II	III	-	II
M5	II	III	-	II	III	III	III	IV	II	-	II	III	II	II	II	II	II	-	-	III	-	III <
C1	II	II	II	II<	II	II	III	III	II	II	II	II	III <	II	II	II	II	I	II	III <	-	III <
K1	II	III	II	II<	IV	II	III	V	II	II	II	II	III <	II	II	II	II	I	III	III <	-	II
S1	II	II	II	II<	IV	I	III	III	II	II	II	II	III <	II	II	II	II	I	III	III	-	III <
F1	II	III	II	II	II	II	III	III	II	II	II	II	III <	II	II	II	II	I	I	II	-	II
F2	V	IV	II	II<	III	IV	V	IV	II	II	II	II	III <	II	II	II	II	I	III	III <	-	III <

Note: II< or III< mean that the further classification by DOE standards is impossible.
- means that no classification is available or nit appropriate to make classification.

To clarify the data of DOE, the JICA Study Team also carried out a water quality survey at 10 sites in November 1994 and in May to June 1995 (Figure 3.10). Evaluation of the survey results was made based on the classifications (I, IIA, IIB, III, IV and V) prepared by DOE (refer to Tables 3.2 and 3.3). Among the classifications, indices of more than Class IV are not acceptable for domestic water supply.

As shown in Tables 3.2 and 3.3, classified as Class IV or V are the following water quality items: DO, Turbidity, BOD, T. Coliform, NH3-N, Fe, COD, F, Coliform and Se. The water quality changes by various conditions such as discharge, rainfall, sampling location, time, etc. It is, however, necessary to pay a special attention to the water quality indices classified as Class IV and V.

Moreover, among the sampling points, point F-2 contains a low quality of BOD. The point F-2 is located along Jerung River and river discharge directly flows into the downstream of Sg. Muda, which could aggravate the major water intake facilities placed therein.

This low water quality is attributed to the effluent from a rubber factory, as proven by the fact that water quality at sampling point F-l which is located upstream of the factory shows non-problematic result. The factory has a treatment system with some ponds, however, a part of the effluent is occasionally released directly to the river. Under these conditions, it is indispensable to continue intensive monitoring works on the effluent from the rubber factory, and to execute certain control works.

3.1.4.5 River Flow Regime

Both the Sg. Muda and Sg. Kedah tend to have a high flow regime twice a year; one from September to November and another from April to May. The maximum discharge is usually recorded during the primary rainy season from September to November. On the other hand, the lowest flow regime usually occurs either in February or Mareh.

The daily average river flow discharge both for Sg. Muda and Sg. Kedah was estimated through the Tank Model Simulation. The simulation period is 33 years from 1951 to 1991, and the average flow regime for these years was estimated at five reference points, as below.

Table 3.4 River Flow Regime of Sg. Muda and Sg. Kedah

Station Name	River System	Catch-ment Area (km^2)	River Flow Regime (m'^s)					
			Mean	Max.	95-day Discharge	185-day Discharge	275-day Discharge	355-day Discharge
Sg. Muda:								
Nami	Main	1,220	25	145	34	T>	11	4
Jeniang	Main	1,740	45	294	62	39	20	8
Victoria	Main	4,010	105	367	145	87	47	20
Kupang	Ketil	704	24	260	30	18	10	5
Sg. Kedah:								
Lengkus	Main	1,270	24	245	23	9	5	4

3.1.4.6 Riverbed Material

A riverbed material survey was made to know the particle size distribution and specific gravity of riverbed materials at thirty (30) sampling sites. The locations of sampling sites are as shown in Figure 3.11, and the results of laboratory tests on the samples are as shown in Figure 3.12 and 3.13.

Ft was clarified from the results of the laboratory tests that sand (0.074 to 4.76 mm) and gravel (4.76 to 76.2 mm) are dominant on the main stream and tributaries, and the riverbed materials sampled upstream tend to be coarser.

The riverbed materials sampled at the north side of the river mouth are very fine and muddy, while those at the south side are coarse and sandy. Moreover, a sand bar has formed from north to south of the river mouth, as shown in Figure 3.14. These noteworthy facts show that there is a dominant southward ocean current around the mouth of Sg. Muda carrying sandy materials from the north to the south.

3.1.4.7 River Bed Load

Sediment in the river channel is divided into bed load, suspended load and wash load. Among them, bed load is the most influential in the change of sandy riverbed like the Sg. Muda. In this connection, the bed load sampling test was carried out at 5 locations (refer to Figure 3.11).

Rating curves between the observed bed load and flow discharge were developed for each sampling point from the results of the sampling test, as shown in Figure 3.15. Furthermore, based on the daily discharge records and the bed load rating curves, it was estimated that the annual bed load of Sg. Muda is about 10,000 m (refer to Table 3.4).

3.1.4.8 Fauna and Flora

Sg. Muda had been well known as a habitat of freshwater turtles. However, the number of turtles has remarkably decreased since the sand mining was intensively made. It would now be a kind of endangered species. The artificial breeding of freshwater turtles has been carried out on Penang Island since 1980 and the young turtles have been released to Sg. Muda as well as the rivers in Penang Island. In addition to the freshwater turtles, the following species of fish live in Sg. Muda:

> River Crab, Climhing Perch, Freshwater Catfish, Swamp Eel, Fcathcrback, Gourami, Snakehead and Goby.

Forest areas cover a large part of the Muda river basin and most of them are delineated as forest reserve by FDHPM. In the forest reserve area, the dominant species identified through the survey for Boris Dam Project are Kedondong, Kelat, Kerwing, Periang and Nyatoh.

Natural vegetation along Sg. Muda is, however, quite limited except the upstream area of Muda Dam. The dominant vegetation along the river is the planted agricultural trees such as rubber tree, oil palm tree, fruit/garden trees, and nippa palm.

Table 3.4 Estimation of Annual Bed Load at River Discharge Station

% of time	Pinang Tunggal ($4,172\ km^2$)		Ldg Victoria ($4,010km^2$)	Jam. Syed Omar ($3, 33, km^2$)		Jeniang Bridge ($1, 740\ km^2$)		Nami ($1, 220\ km^2$)		Kg. Tiban ($825\ km^2$)	
	Discharge (m^3/s)	Bed Load (M3)	Discharge (m^3/s)	Discharge (m^3/s)	Bed Load (M3)	Discharge (m^3/s)	Bed Load (M3)	Discharge (m^3/s)	Bed Load (M3)	Discharge (m^3/s)	Bed Load (M3)
5	375	2, 195	356	276	1, 524	78	760	24	732	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 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.

3.1.5 Flood Prone Areas and Types of Flood

Due to the poor flow capacity of river channels, floods occur almost every year and affect the low-lying residential and agricultural areas. DID have identified the flood-prone areas where three types of flood occur; namely, (a) flash flood; (b) flood associated with extensive inundation; and (c) tidal flood. The flood-prone areas are in the lower and middle reaches, as shown in Figure 3.16.

In the middle reaches, flood-prone areas have been identified in and around the potential urban centers such as Sic and Baling. The typical type of flood at these areas is the flash flood. Flash floods occur due to short but very intensive local rainfall. When such flash floods occur, floodwater levels tend to suddenly rise but subside within a short period after the rainfall stops.

In the middle reaches, the flood-prone area has also been identified in and around Kuala Ketil where the development of an urban center associated with an extensive industrial area is planned. This area tends to be affected by flood associated with extensive inundation due to widespread and prolonged heavy rainfall. This type of flood often lasts for more than two or three days.

In the lower reaches, the flood-prone area is located along the downstream from Muda Barrage. This flood-prone area 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 rises by the backwater effect of the high tide and may spill over the banks.

3.1.5.1 Maximum Flood Recorded

The maximum flood recorded occurred in November 1988, the worst since the flood in 1967. In this flood, rainfall continued from November 20 to 23, 1988, and the heavy rainfall was biased to the northern mountainous areas (refer to Figure 3.17). The daily rainfall at Pedu Dam exceeded 200 mm on November 20. Such biased heavy rainfall in the northern area caused spilling over the Muda dam crest. At Ldg. Victoria which is located in the lower reaches, the flood discharge exceeded 1,000 m'/s for three days from November 24 to 26. Moreover, (Figure 3.18) at the Jeniang Gauging Station which is located in the middle reaches, the water level continued to exceed the danger level for six days from November 21 to 26.

Due to such high water level, inundation occurred along almost all the entire stretch in the middle and lower reaches. In the "Annual Flood Report, 1988," the flood damage to riverbanks in the Muda river system was estimated at RM 1,224,000, but no casualties were reported.

The inundation areas were identified on 1 is to 10,000 top sheets newly prepared in 1994 through a series of field investigation and interview surveys (refer to Figure 3.19, 3.20 and 3.21). The total inundation areas and number of houses and buildings affected are as tabulated below.

Table 3.5 Flood Inundation Area and Number of Houses Affected by 1988 Flood

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

The recurrence probability of the 1988 flood at Ldg. Victoria, Jeniang Cable and Kuala Pegang was estimated through normal log distribution. As the results, the return period of 1988 flood 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, as summarized below.

Table 3.6 Recurrence Probability of 1W8 Flood

River	Discharge Station	Return Period of 1988 Flood Discharge	Return Period of 1988 Flood Rainfall
Sg. Muda	Ldg. Victoria	45.0 years	30 years*
	Jeniang Cable	140.0 years	40 years*
Sg. Ketil	Kuala Pegang	5.5 years	10 years**

* 3-day rainfall
'* 1-day rainfall

In mid-September 1995, flood caused by Tropical Storm Ryun occurred in the Muda river basin. Newspapers had reported that the 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. This flood seems to be a little smaller than the 1998 flood judging from the water level records obtained.

3.1.5.2 Probable Rainfall and Probable Flood Runoff Discharge

Probable Rainfall

The dominant storm rainfall duration was clarified for each reference point in the Muda river basin on the basis of the hourly rainfall records in eleven storms. Then, the probable rainfall for each storm rainfall duration was estimated by the logarithmic normal distribution of annual basin average maximum rainfall for a 34-year period from 1959 to 1992. The results of the estimation are as tabulated below.

Table 3.7 Probable Rainfall at Each Reference Points in Muda River Basin

Reference Point	Catchment Area (km")	Rainfall Duration	Probable Rainfall for Lach Return Period (min)					
			2-year	5-year	10-year	20-year	50-year	100-year
Jeniang	1,740	3-day	120	144	159	172	188	199
J. S. Omar	3,330	3-day	104	123	134	144	156	165
Ldg. Victoria	4,010	3-day	100	119	130	140	153	161
K. Pegang	704	1-day	59	72	81	88	97	104
Sik	153	1-day	69	82	90	97	105	111

Probable Flood Runoff Discharge

Based on the probable basin rainfall with 1- or 3-day rainfall duration, the actual hourly rainfall recorded in the 11 major floods was enlarged in the following manner:

$$T^N = R^N / Ra$$

Where,

T^N : Adjustment rate for N-year return period

R^N : Probable basin rainfall of N-year return period for fixed rainfall duration

Ra : Recorded rainfall in actual flood

N : Return period (5, 10, 20, 50 and 100-year)

The recorded hourly rainfall enlarged as described above was assumed as the model hyetograph of N-year return period for each of the 11 actual major floods. Then, the flood discharge hydrographs corresponding to each return period were estimated by applying the model hyetographs and the Storage Function Model used for flood runoff simulation.

The peaks of the estimated flood discharge hydrographs were provisionally assumed as the probable discharge enlarged from the 11 actual major floods. The typical probable flood discharge was then assumed as the value to cover 70% of the above peak discharges enlarged from the 11 actual major floods. On the premise of the coverage rate of 70%, the fourth largest enlarged peak discharge was selected as the typical probable discharge.

In the above estimation of the probable flood runoff discharge, however, the natural flood regulation effect by the existing Muda Dam was not taken into consideration. Muda Dam is solely a water supply purpose dam and docs not have any specific flood control capacity. However, the dam inflow discharge is naturally regulated by the surcharge volume above the spillway crest.

The dam water level will increase as the dam inflow discharge increases, and the water impounded by the dam starts to overflow when the water level exceeds the crest level of the spillway. The overflow discharge could be calculated by the dam inflow discharge together with its reservoir storage capacity curve and its spillway discharge rating curve. Thus, the following probable flood runoff discharges were estimated on the premise of the natural regulation by Muda Dam, and adopted as the final estimated values for the Muda river basin (refer to Figure 3.22).

Table 3.8 Probable Discharge at Reference Points in Muda River Basin

Reference Point	Catchment Area (km^2)	Probable Discharge for Each Return Period (m^3/s)				
		5-year	ID-year	20-year	50-year	100-year
Muda Dam Site	984	230	270	310	370	420
Jeniang	1,740	390	470	560	680	770
J. S. Omar	3,330	700	<S10	920	1,060	1,160
Ldg. Victoria	4,010	810	950	1,080	1,260	1,340

Probable Flood Inundation Area

The probable extent of flood inundation caused by the runoff discharge of 100-year return period was estimated through the non-uniform calculation using the topographic and channel survey results taken in 1994 (refer to Figure 3.23 and 3.24). Belt-shaped areas along the Muda and Ketil rivers are possibly submerged under flood water. The width was as wide as 1 to 5 km in the lower stretches of Sg. Muda downstream of the confluence with Ketil River, while it was narrower and 1 km at the maximum in the upstream valley. Such definite tendency was not found for Ketil River, and it varied from 0.5 m to 2 km due to local topographic conditions. The total inundation areas and the number of houses and buildings located there are as summarized below.

Table 3.9 Probable Food Inundation Area

River	Stretch	Length (km)	Inundation Area (km^2)	No. of Houses and Buildings
Sg. Muda	River Mouth to Ldg. Victoria (Lower Sg. Muda)	40.3	45.0	5,640
	Kuala Ketil Town Strecth *1	5.4	1.4	610
	Ldg. Victoria to Prorp. Jeniang Barrage *2	72.9	33. 1	560
Sg. Ketil	Sg. Muda to Kg. Tg. Merbau *2	39.2	16.9	1,200
	Baling Town Stretch	0.8	0.3	200
Sg. Chepir	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 Sg. Muda to Cross Section No. 1 of Sg. Ketil.
* 2: Excluding Kuala Ketil Town Stretch.

3.1.5.3 Existing Flood Mitigation Facilities

The Muda river system has hardly been provided with flood mitigation works other than the construction of a Sg. Muda bund and the flood forecasting and warning system. The Sg. Muda bund was constructed downstream along the left bank of the Muda main stream by a private enterprise about a century ago (refer to Figure 3.25). It has been maintained and rehabilitated by DID. The purpose of the bund is to confine flood discharge of the Sg. Muda in its own course and 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.

In addition to the above bund construction, DID had established a Flood Forecasting and Warning System which is composed of water level monitoring stations, warning stations and flood operation rooms. The State DID Kedah had established water level monitoring stations at ten (10) sites and the State DID Pulau Pinang, at two (2) sites (refer to Figure 3.26). For each of the monitoring stations, three (3) critical water levels are designated; namely, alert, warning and danger levels.

The water level readings are 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 sent to DID Pulau Pinang.

Among the monitoring stations, six (6) stations are scheduled to be equipped with a telemeter data transmission system. These stations are Jeniang, Jam. Syed Omar, Pinang Tunggal and Bumbung Lima along Sg. Muda, and Kg. Baru and Rumah Pam Pulai along Sg. Ketil.

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

The flood operation rooms are set up annually at DID state and district offices from the 1st of August to the 15th of January to forecast the flood conditions and issue the necessary instructions. The rooms are provided with communication equipment such as VHF set, telephones and facsimile machines to receive or send information such as rainfall, water level, warnings, flood damage and evacuation.

3.1.6 River Sand Mining

As of September 1993, there were 95 permit holders for mining operations on the Sg. Muda 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 Figure 3.27.

The annual sand mining volumes recorded for the recent three years were about 500,000 m^3 in 1991, 900,000 m^3 in 1992 and 1.200.000 m^3 in 1993. According to the officials concerned, however, the mining volume in 1990 reached the peak and was much more than those in recent three years due to use as construction material for the North-South Expressway.

These mining volumes are much greater than the annual bed load of about 10,000 m and, therefore, have caused serious subsidence of the riverbed. The present mining activities have also affected the surrounding river environment due to the following unfavorable conditions:

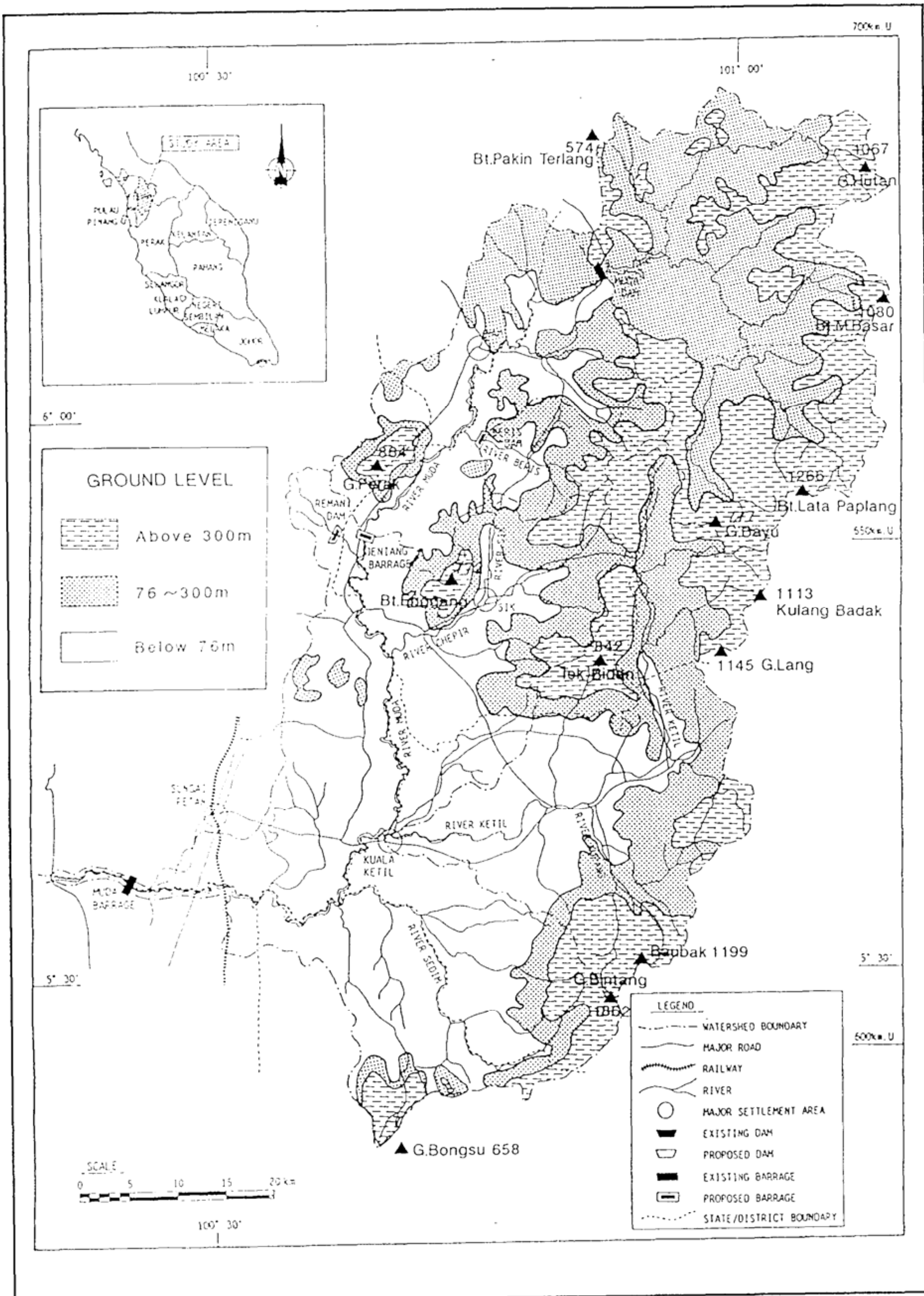
a) Abandonment of mining equipment in river channels and riverbanks;

b) Pipes and ropes crossing the river course, which hamper navigation;

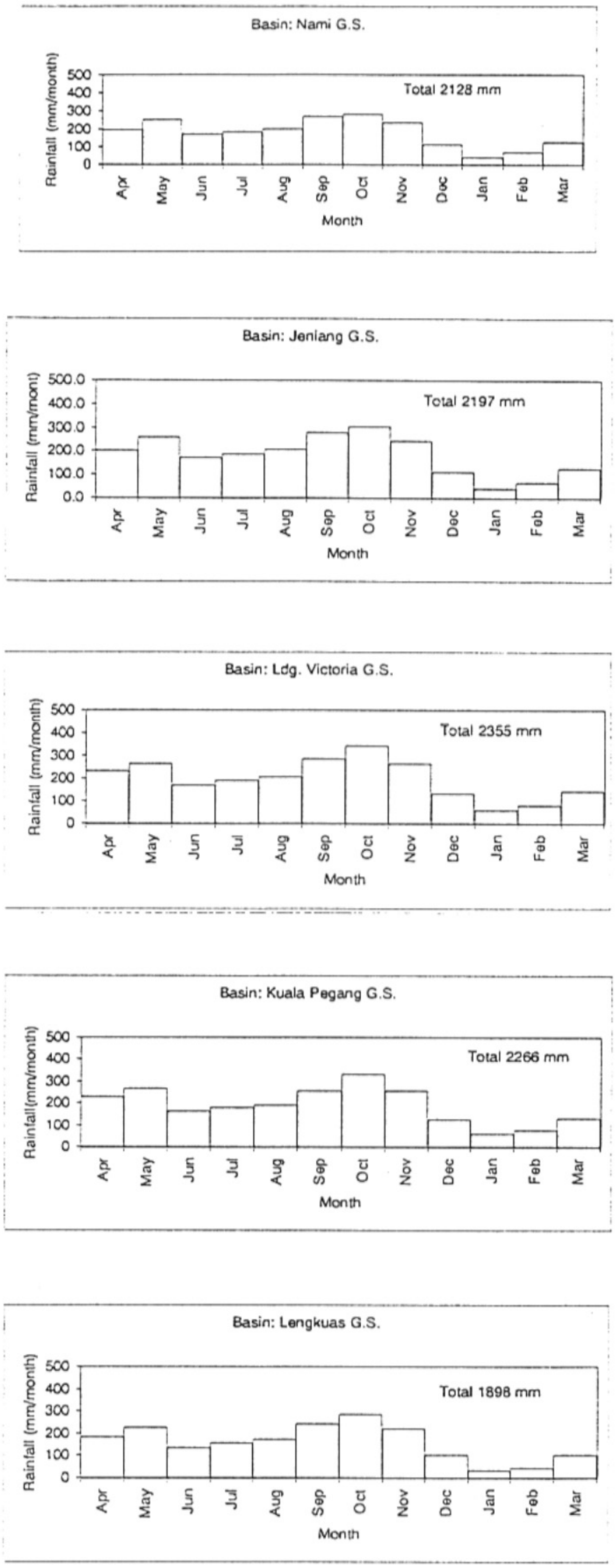
c) Illegal construction of access road to the river channel which reduce the river channel width; and

d) Absence of proper drainage from sand stockpiles.

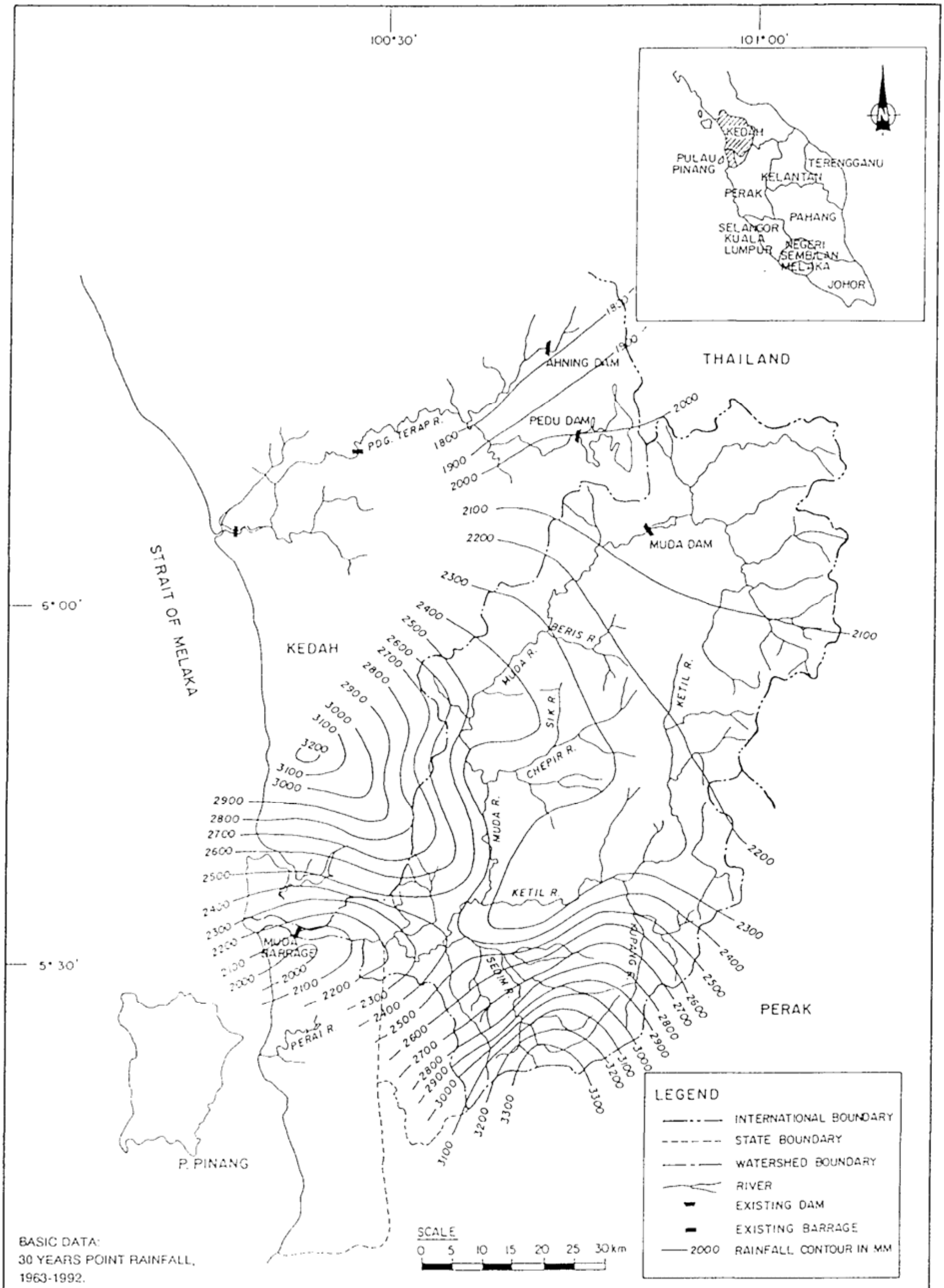
DID has provided a guideline for and mining operation in Malaysia as shown in Figure 3.28.



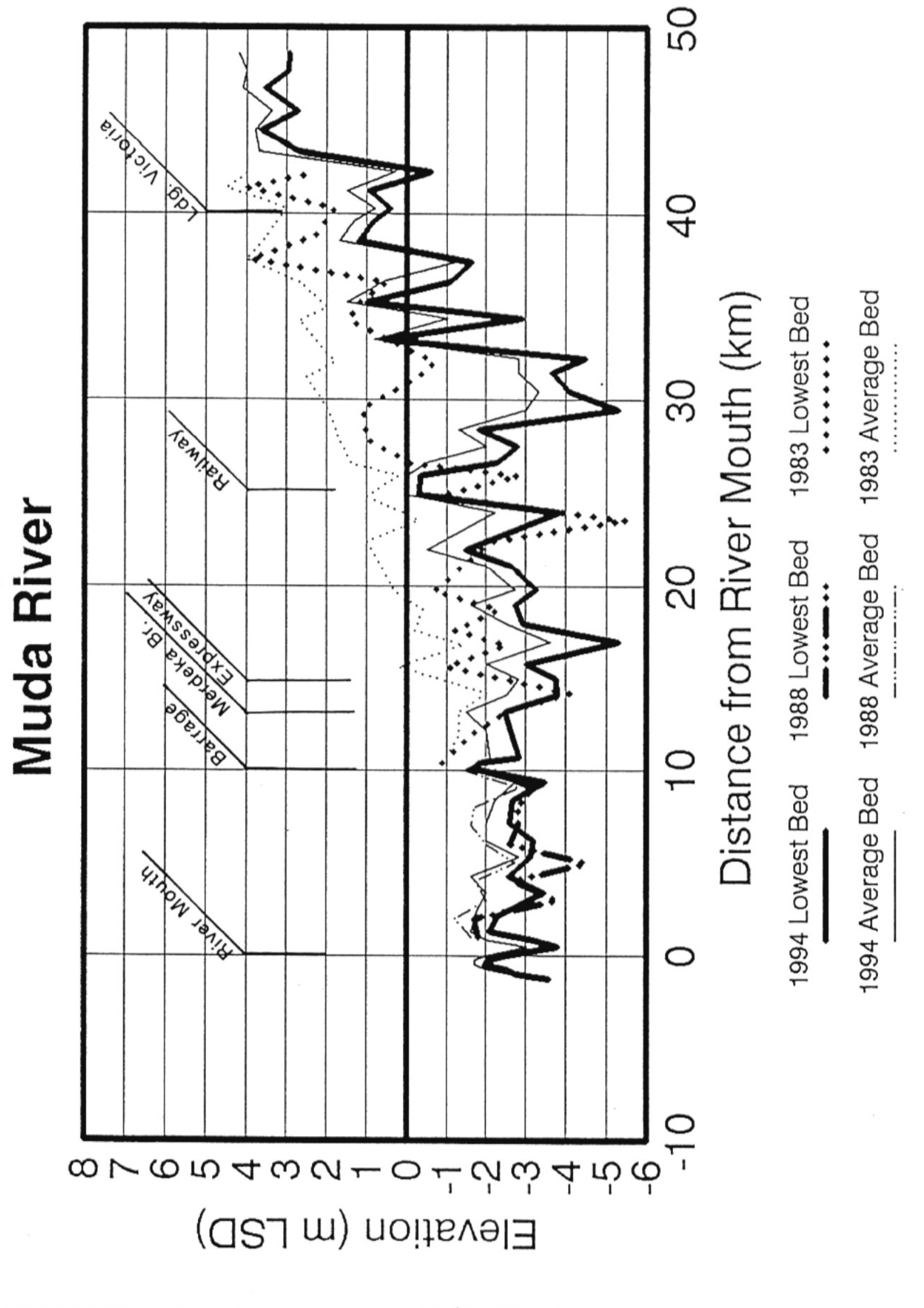
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. 2.1.1
JAPAN INTERNATIONAL COOPERATION AGENCY	TOPOGRAPHY OF MUDA RIVER BASIN



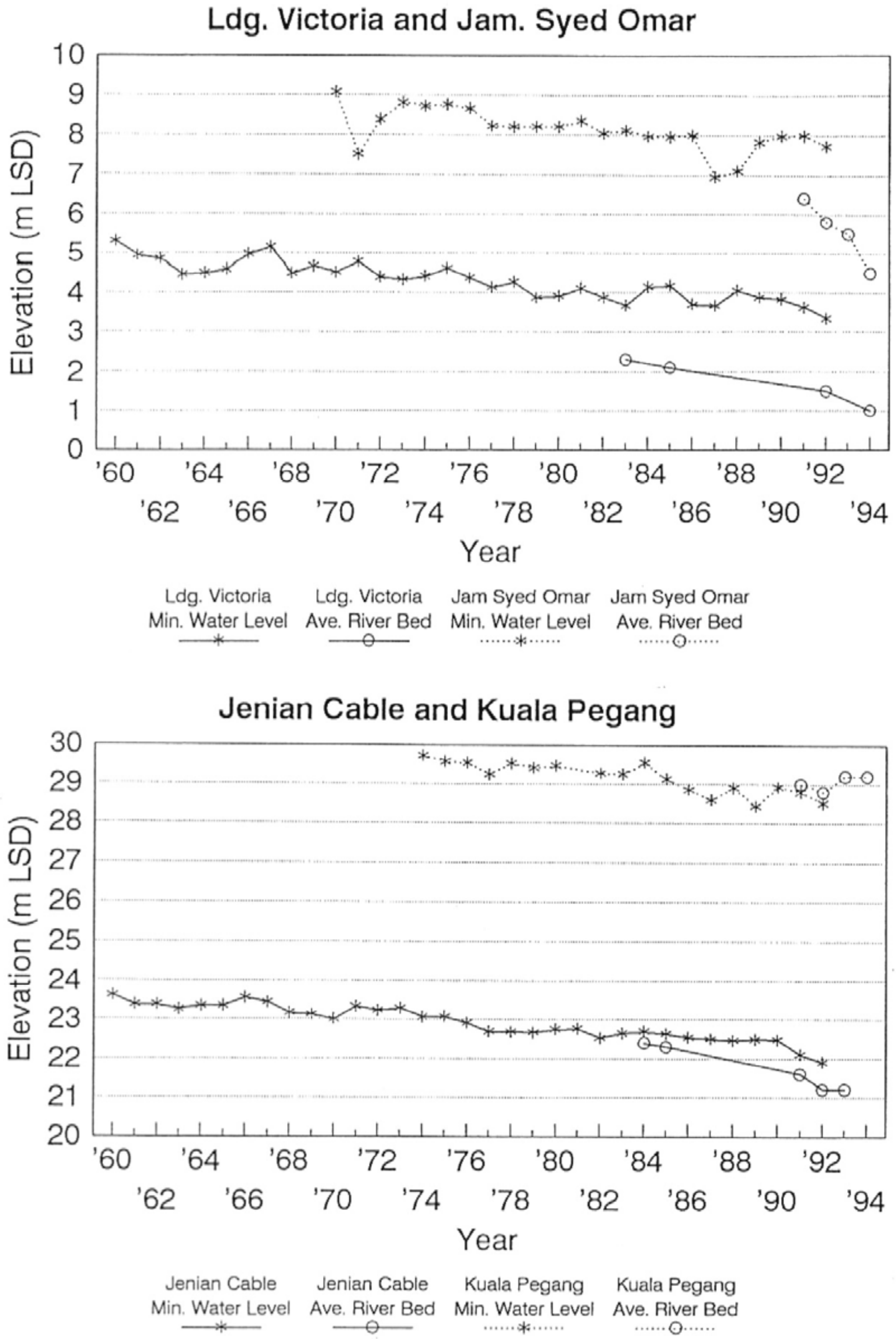
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. 2.2.1 HYETOGRAPH OF MONTHLY BASIN AVERAGE RAINFALL
JAPAN INTERNATIONAL COOPERATION AGENCY	



COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. 2.2.2
JAPAN INTERNATIONAL COOPERATION AGENCY	MEAN ANNUAL RAINFALL ISOHYETS OF MUDA RIVER BASIN



COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. 2.3.1
JAPAN INTERNATIONAL COOPERATION AGENCY	CHANGE OF LONGITUDINAL PROFILE OF MUDA RIVER

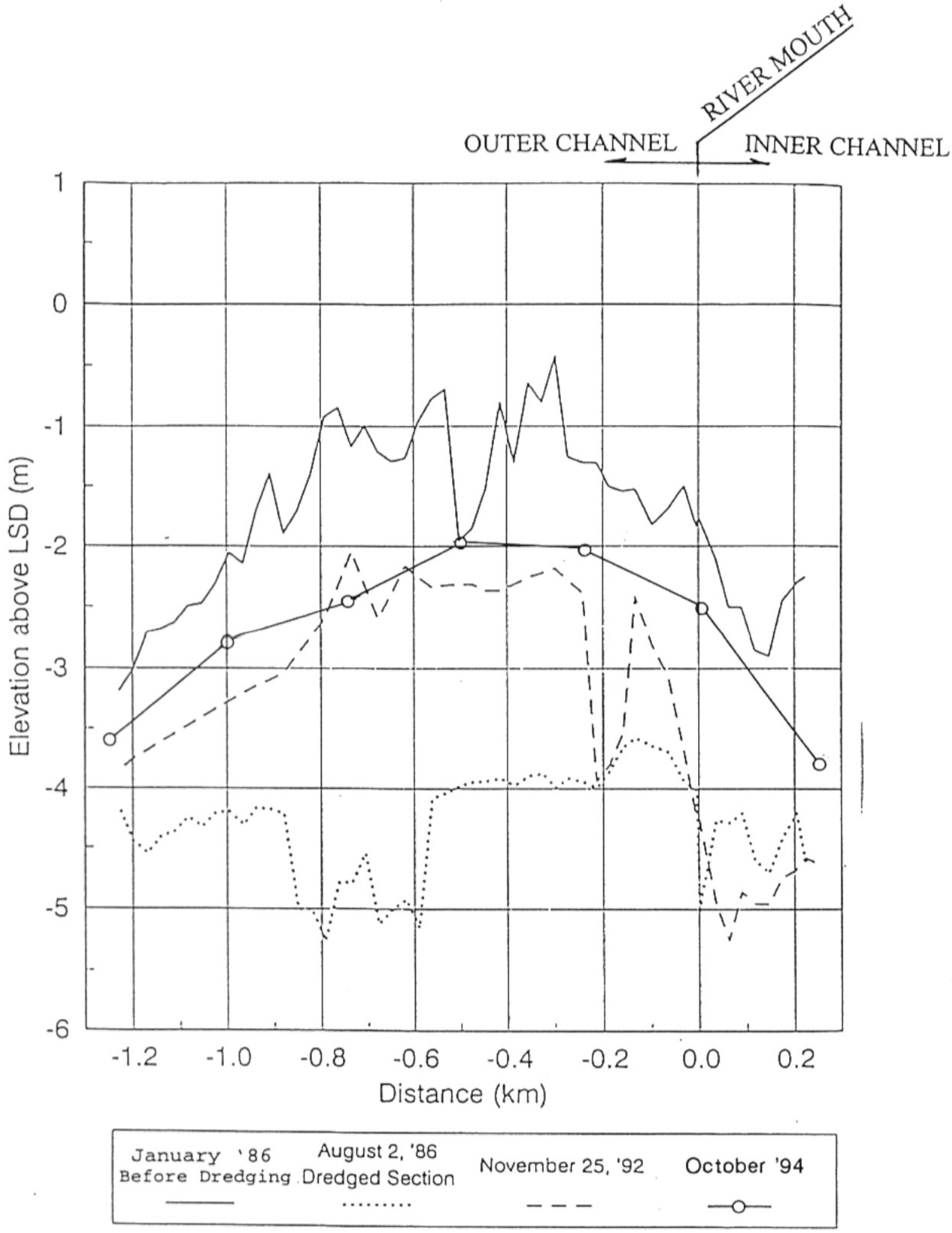


COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. 2.3.2
JAPAN INTERNATIONAL COOPERATION AGENCY	CHANGE OF ANNUAL MINIMUM WATER LEVEL AT RIVER DISCHARGE STATION

(1) Bridge Crossing Sg. Ketil (1km Upstream of Sg. Muda)

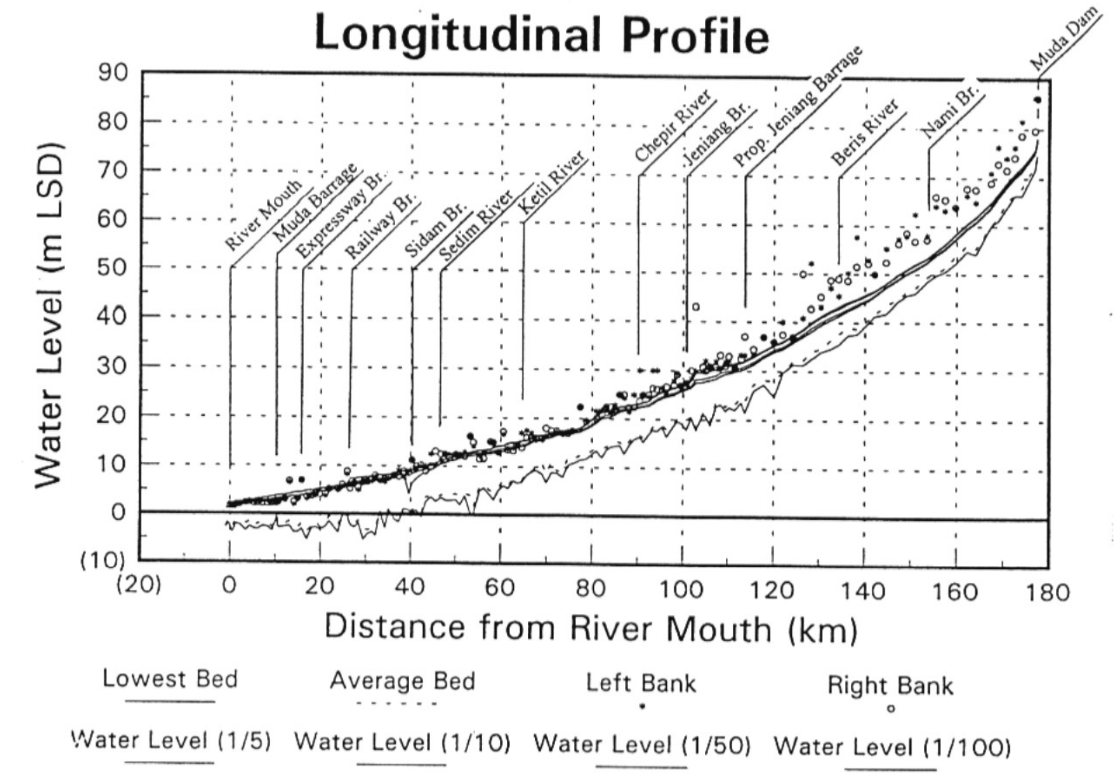
(2) Bridge Crossing Sg. Muda (Ldg. Victoria)

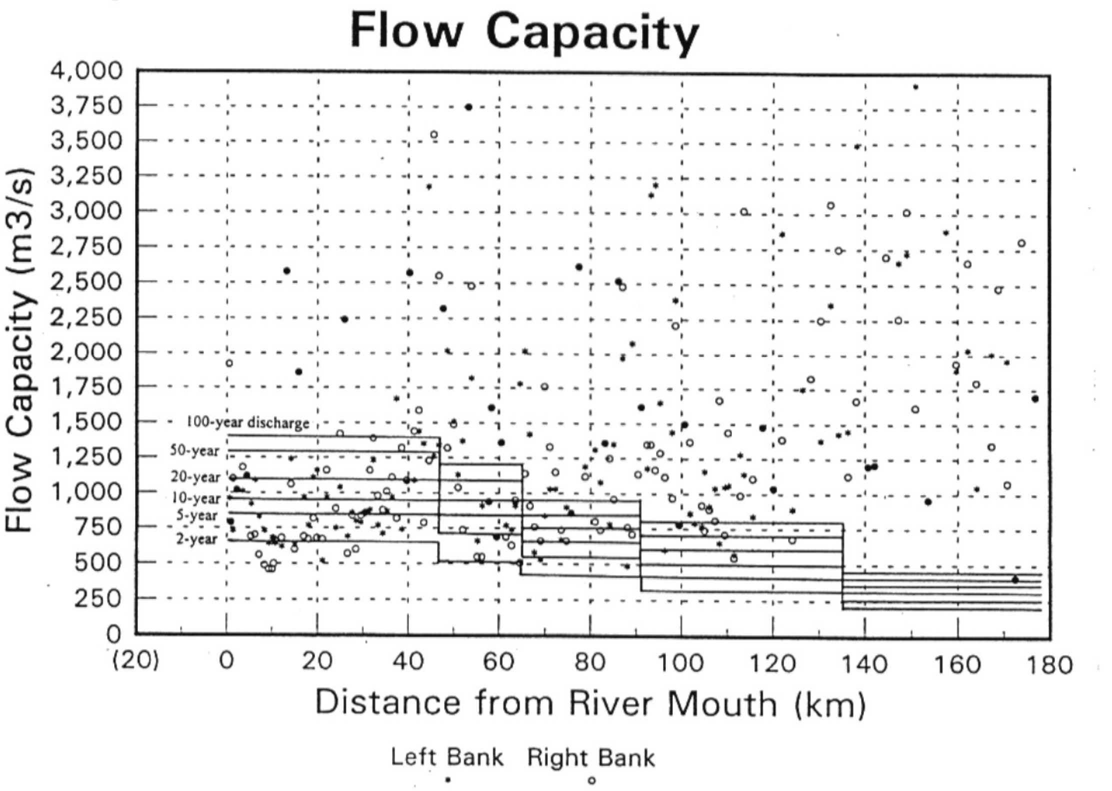
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY	Figure 3.6 PHOTOGRAPH OF BRIDGE AFFECTED BY RIVER BED SUBSIDENCE



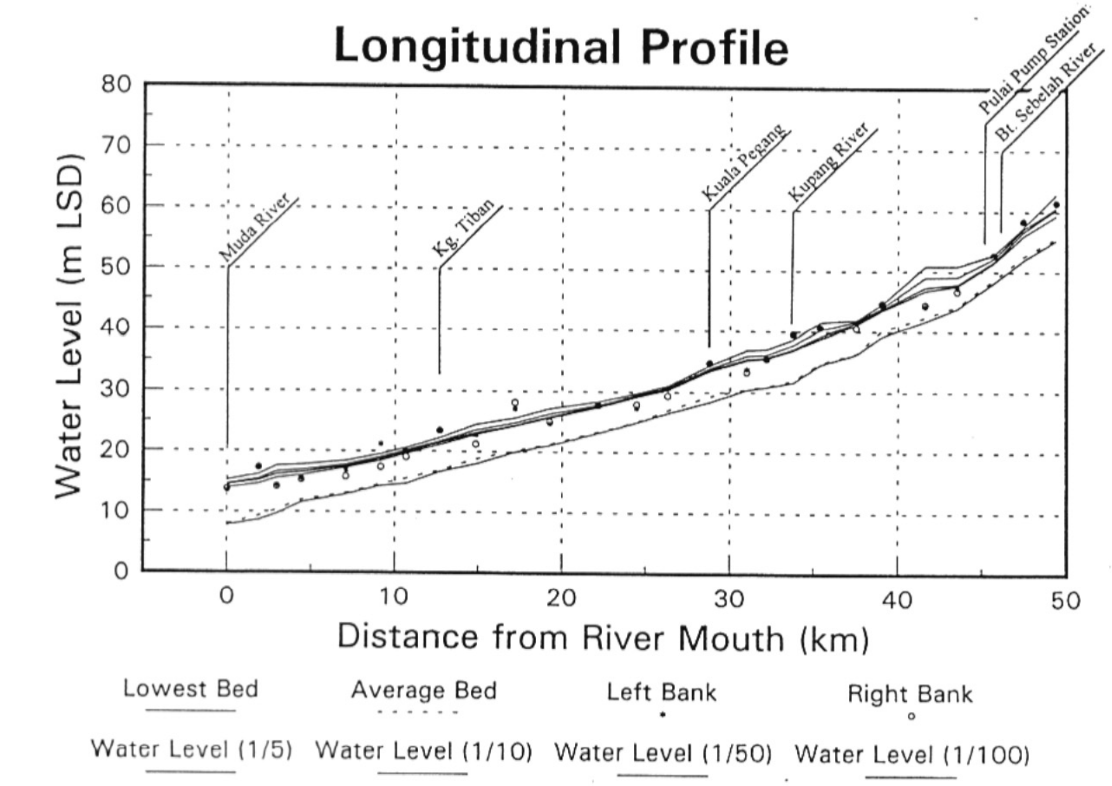
DATA SOURCE : " THE NATIONAL RIVER MOUTH STUDY " DRAFT FINAL REPORT
VOL. 3 SUPPORTING REPORT, JICA, MARCH 1994

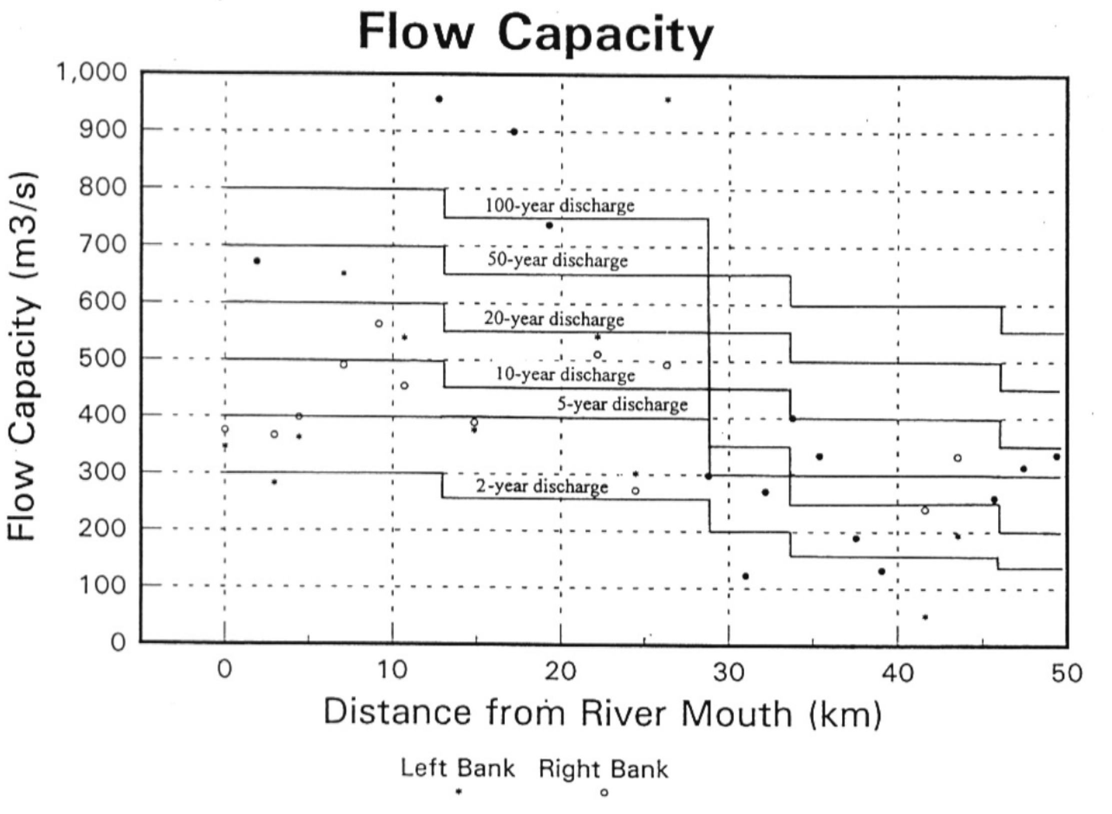
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. 2.3.4
JAPAN INTERNATIONAL COOPERATION AGENCY	LONGITUDINAL PROFILE AT MUDA RIVER MOUTH



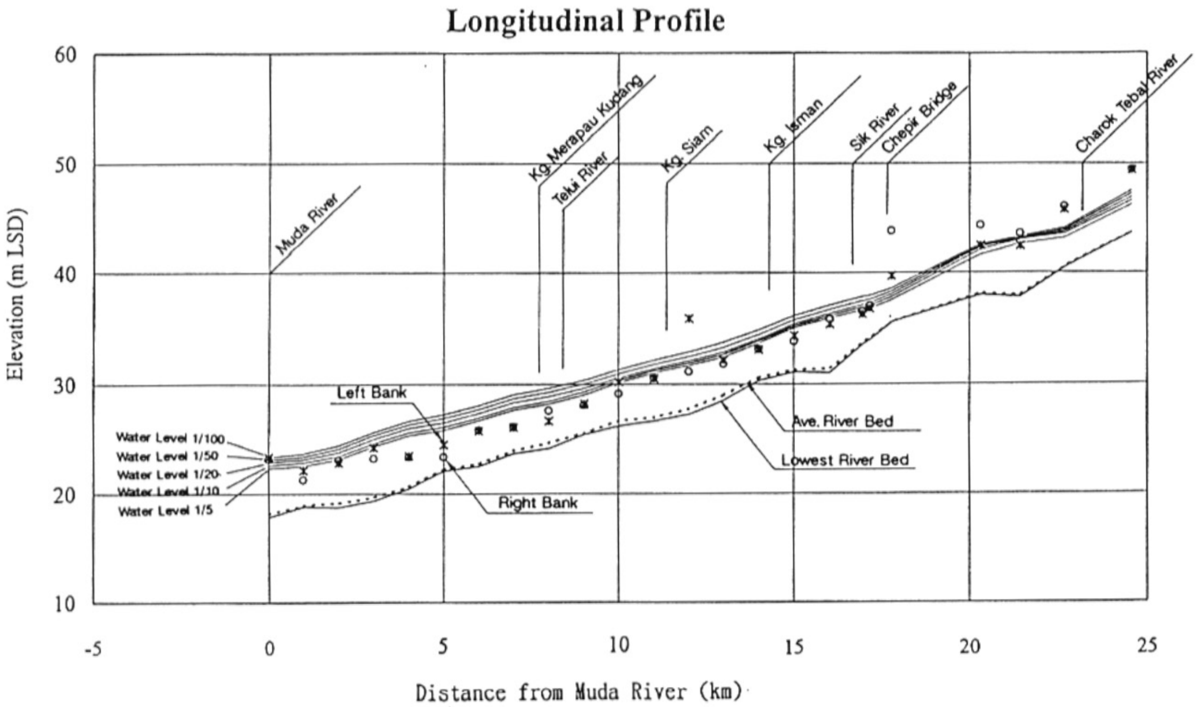


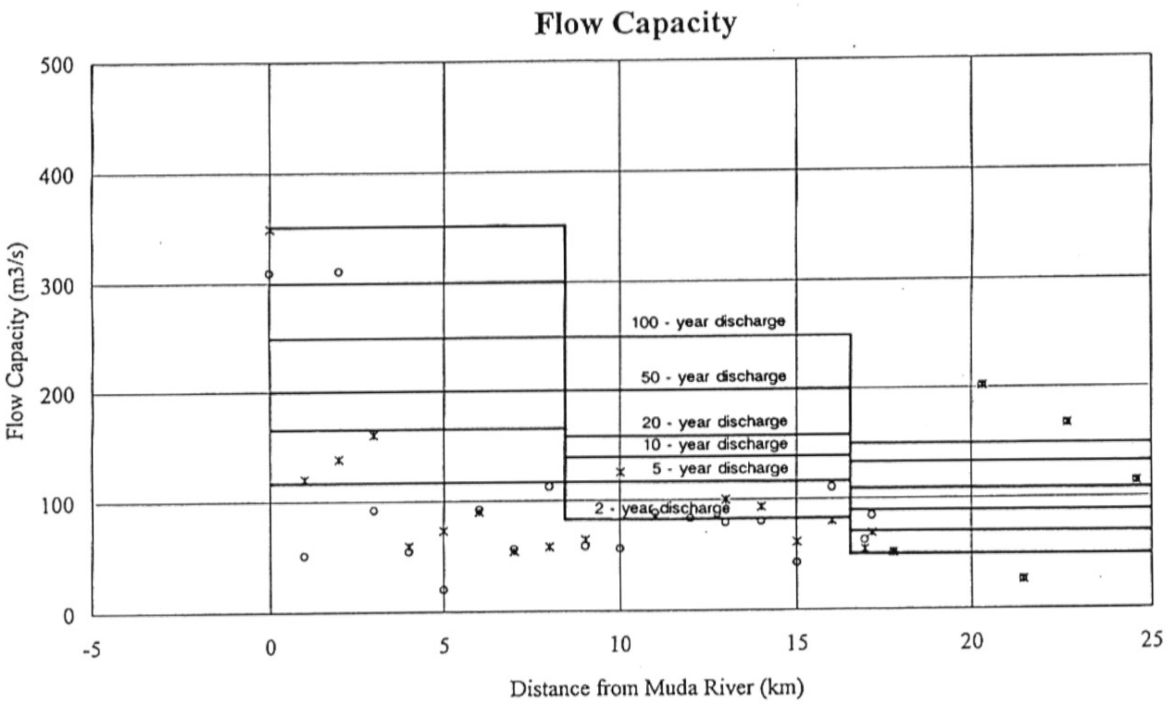
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. 2.3.5 (1/3) FLOOD WATER PROFILE AND FLOW CAPACITY (MUDA RIVER)
JAPAN INTERNATIONAL COOPERATION AGENCY	



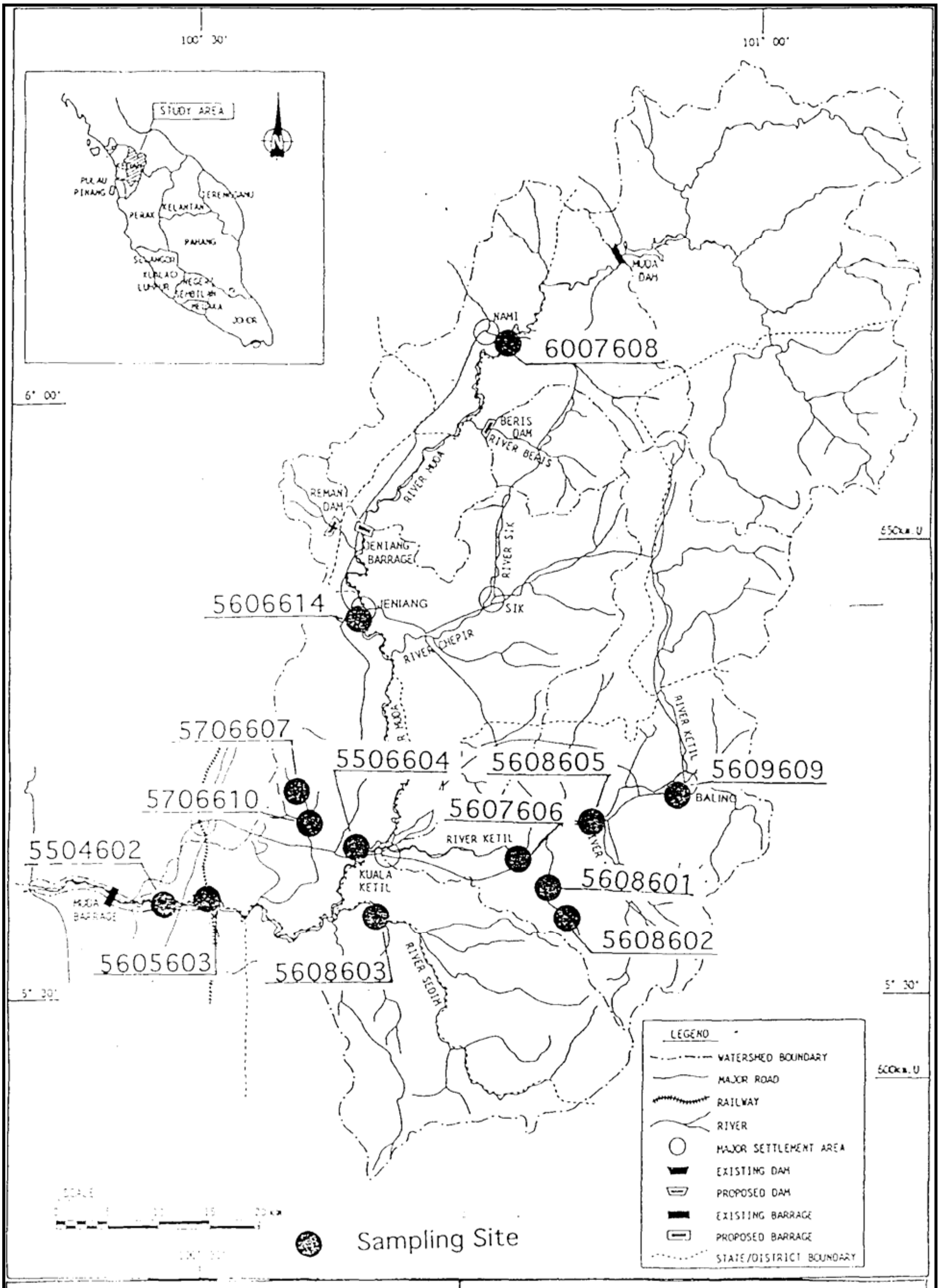


COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. 2.3.5 (2/3)
JAPAN INTERNATIONAL COOPERATION AGENCY	FLOOD WATER PROFILE AND FLOW CAPACITY (KETIL RIVER)

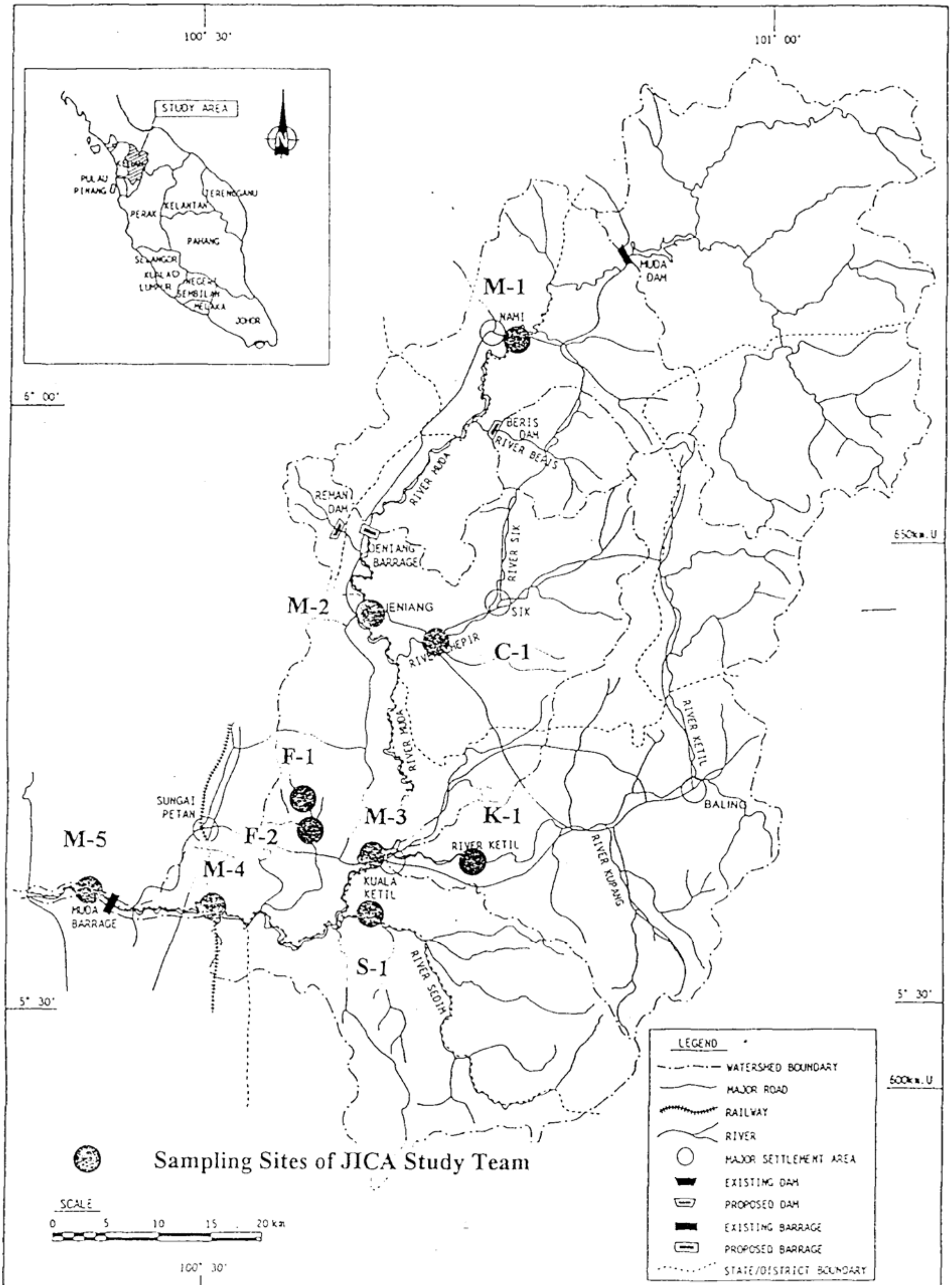




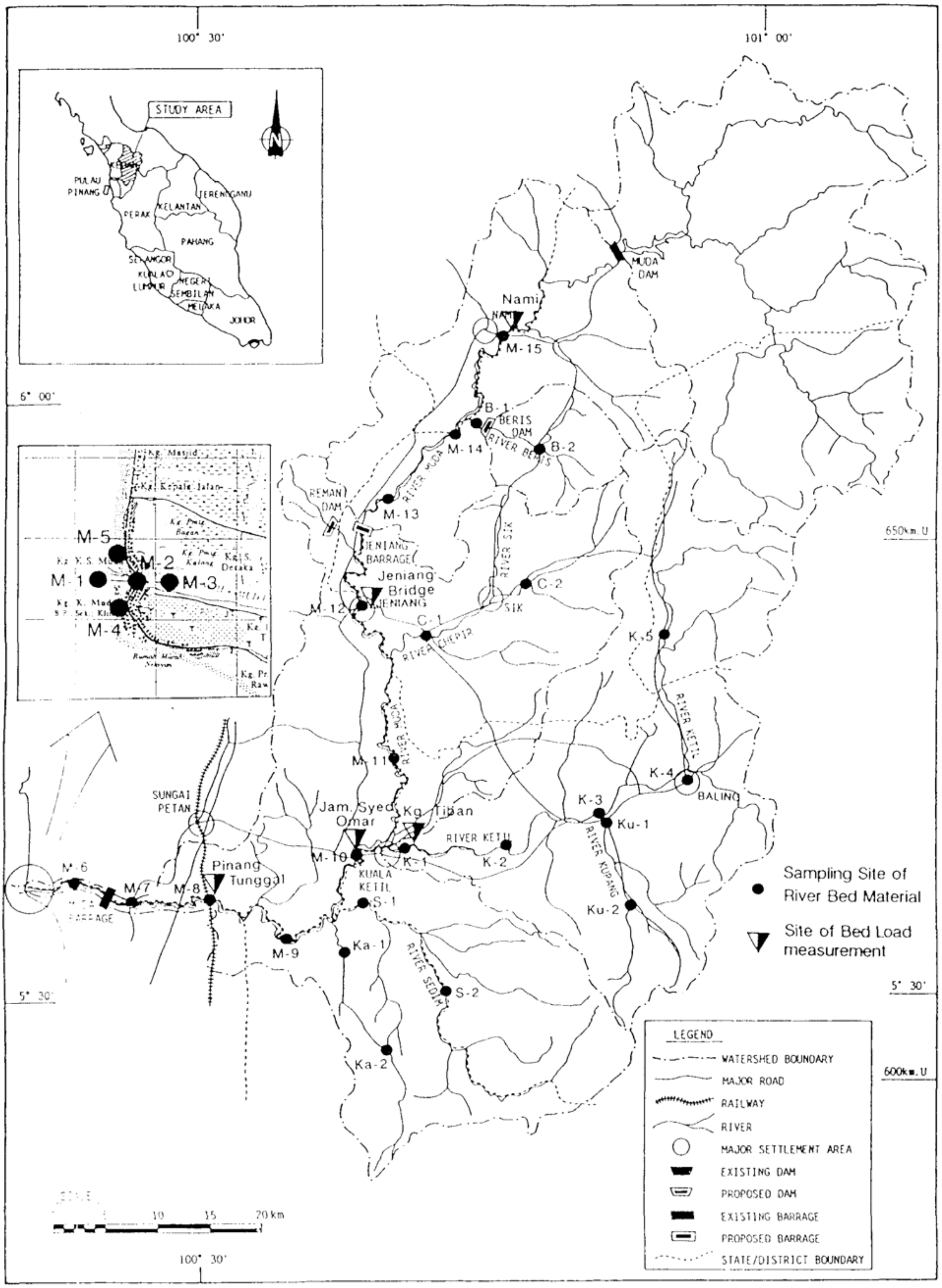
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. 2.3.5 (3/3)
JAPAN INTERNATIONAL COOPERATION AGENCY	FLOOD WATER PROFILE AND FLOW CAPACITY (CHEPIR RIVER)



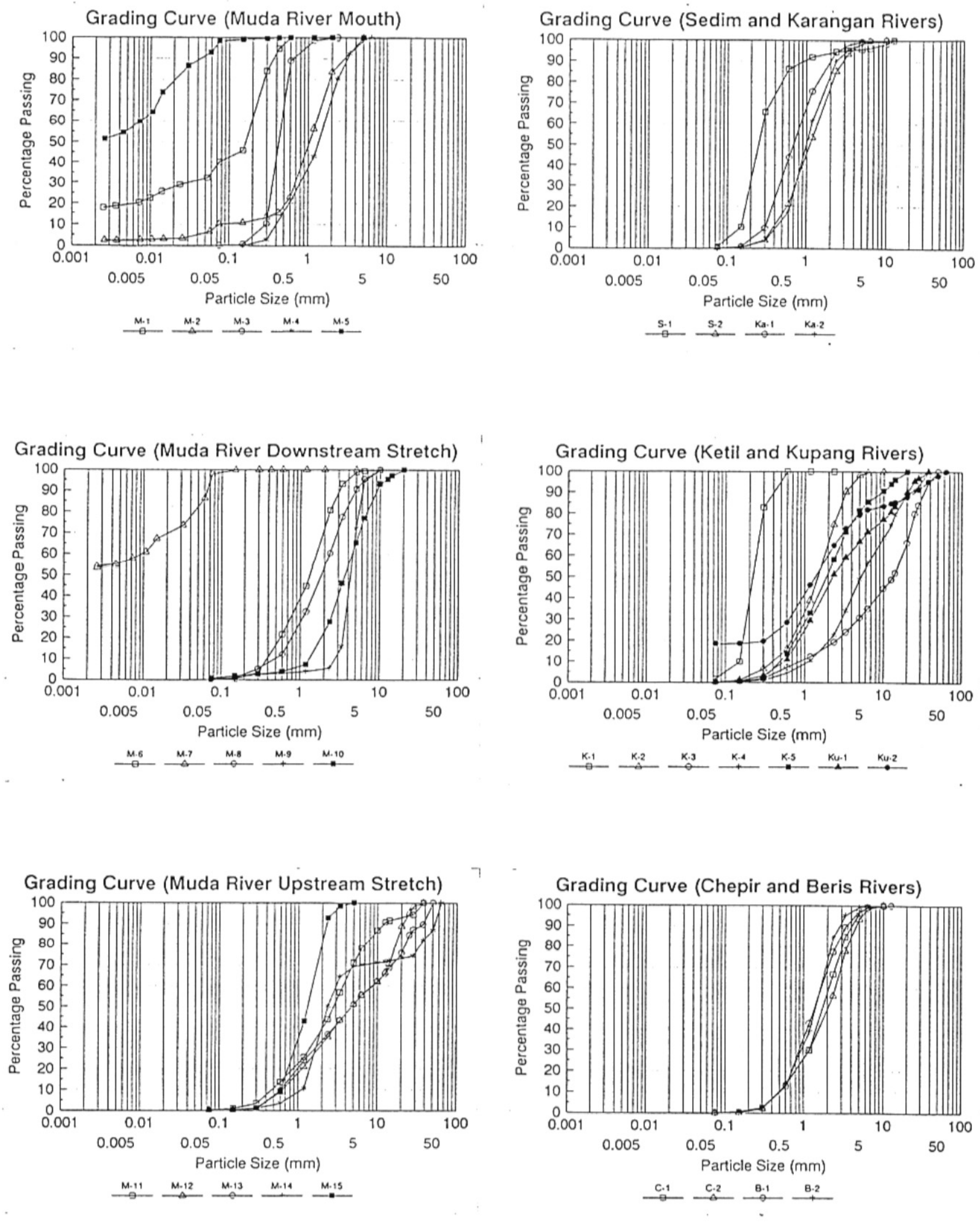
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY	FIG. 2.3.6 WATER SAMPLING LOCATIONS OF DOE



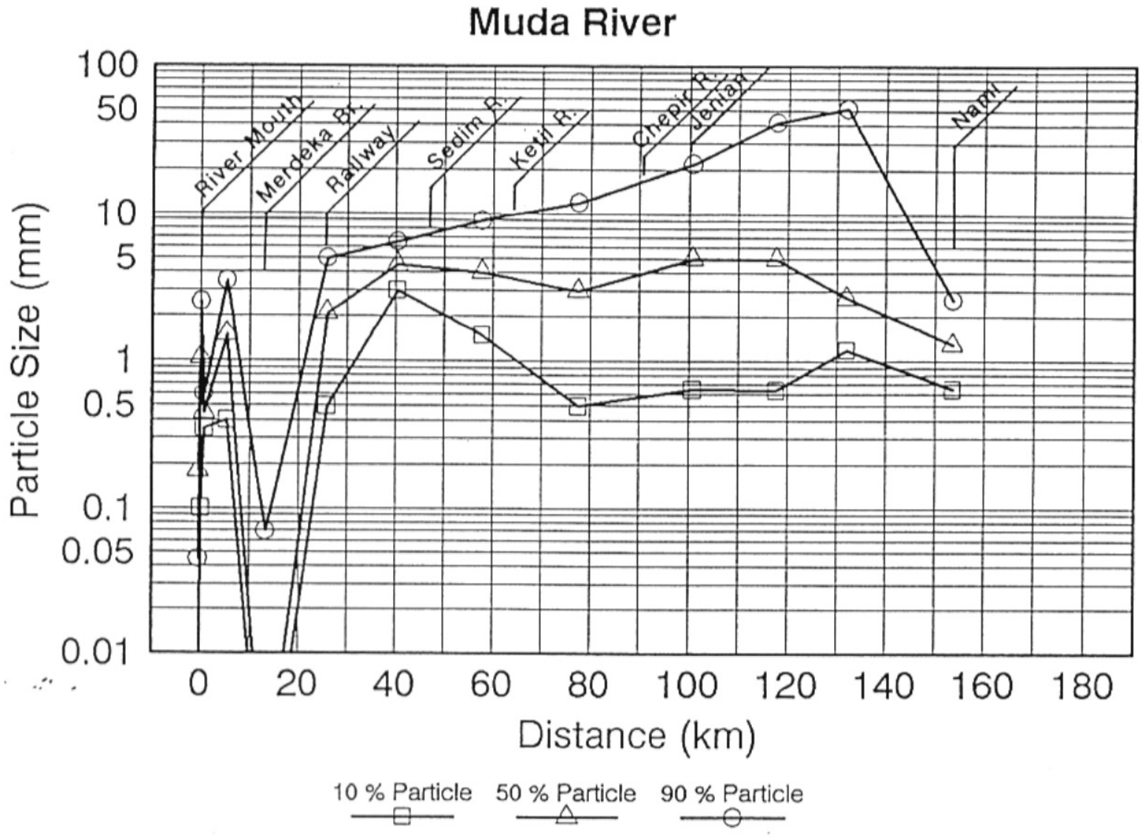
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. 2.3.7
JAPAN INTERNATIONAL COOPERATION AGENCY	WATER SAMPLING LOCATIONS JICA STUDY TEAM

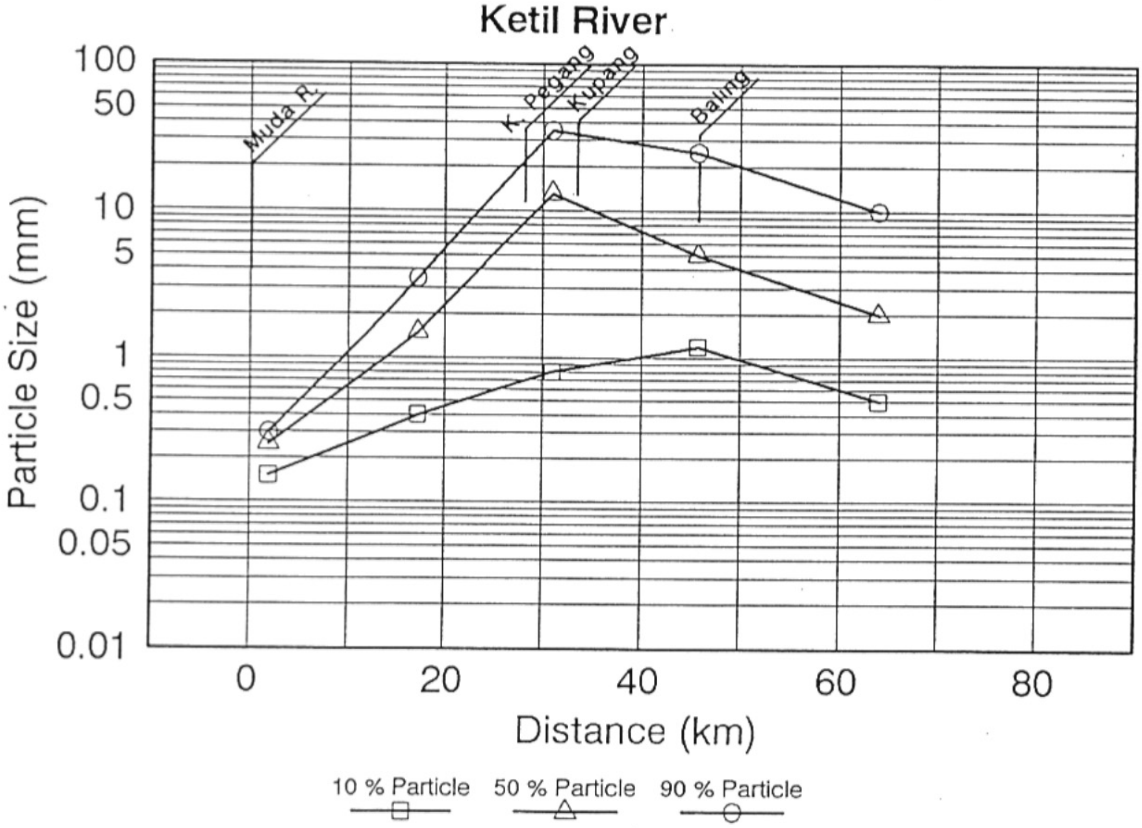


COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. 2.3.8
JAPAN INTERNATIONAL COOPERATION AGENCY	LOCATION OF RIVER SEDIMENT SURVEY

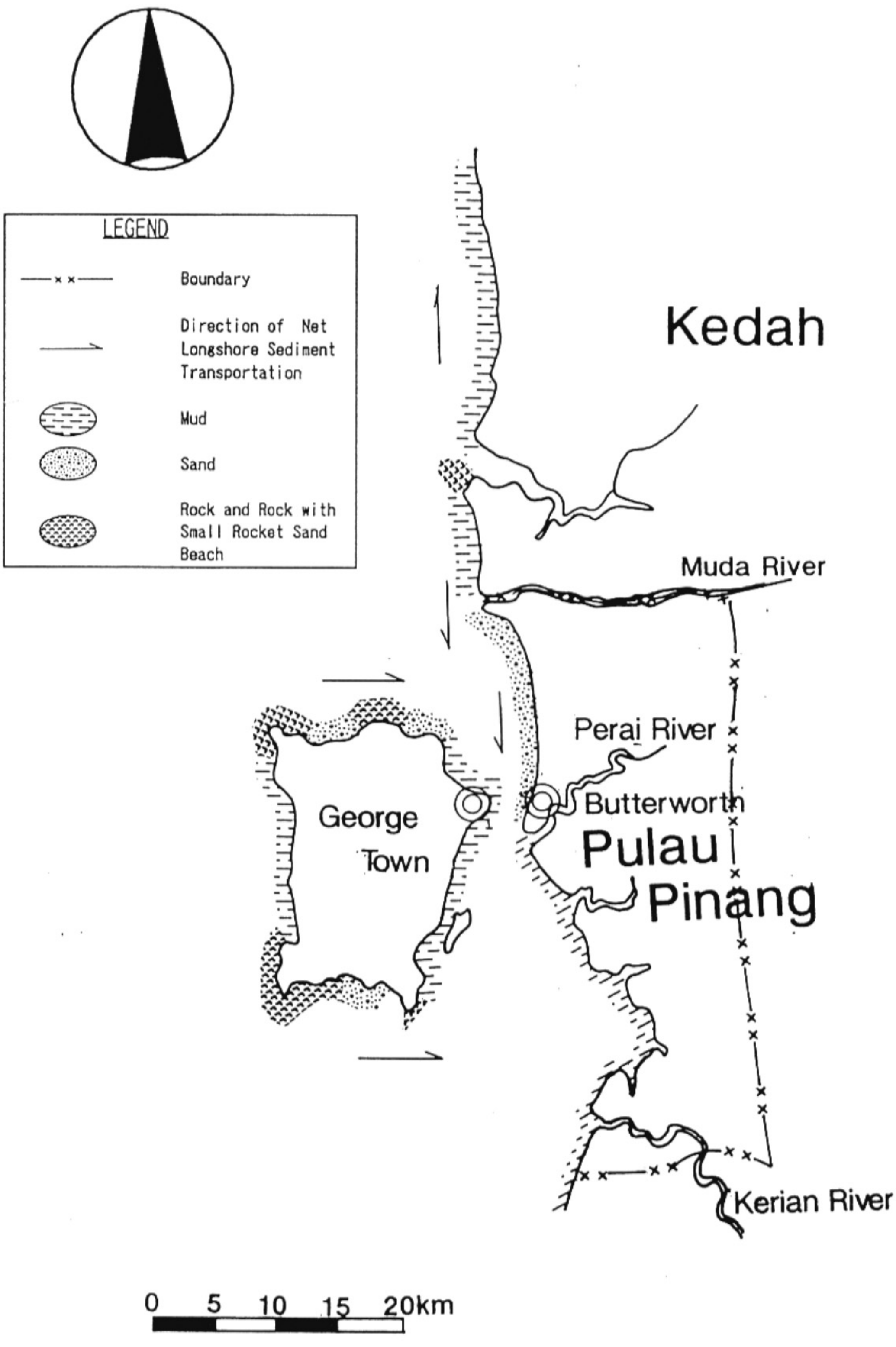


COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. 2.3.9
JAPAN INTERNATIONAL COOPERATION AGENCY	GRADING CURVES OF RIVER BED MATERIAL IN MUDA RIVER SYSTEM



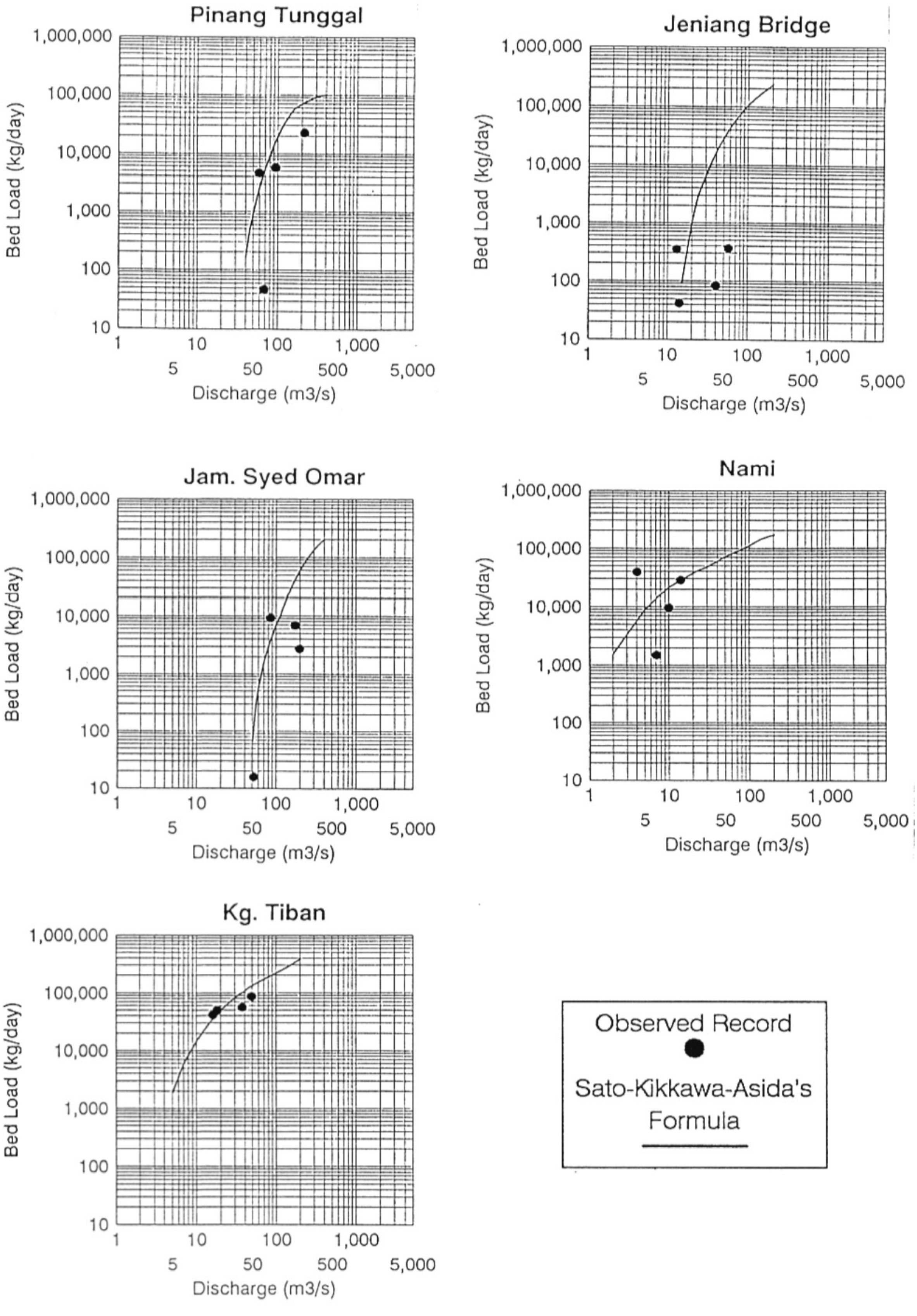


COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. 2.3.10
JAPAN INTERNATIONAL COOPERATION AGENCY	LONGITUDINAL DISTRIBUTION OF PARTICLE SIZE ALONG MUDA AND KETIL RIVERS

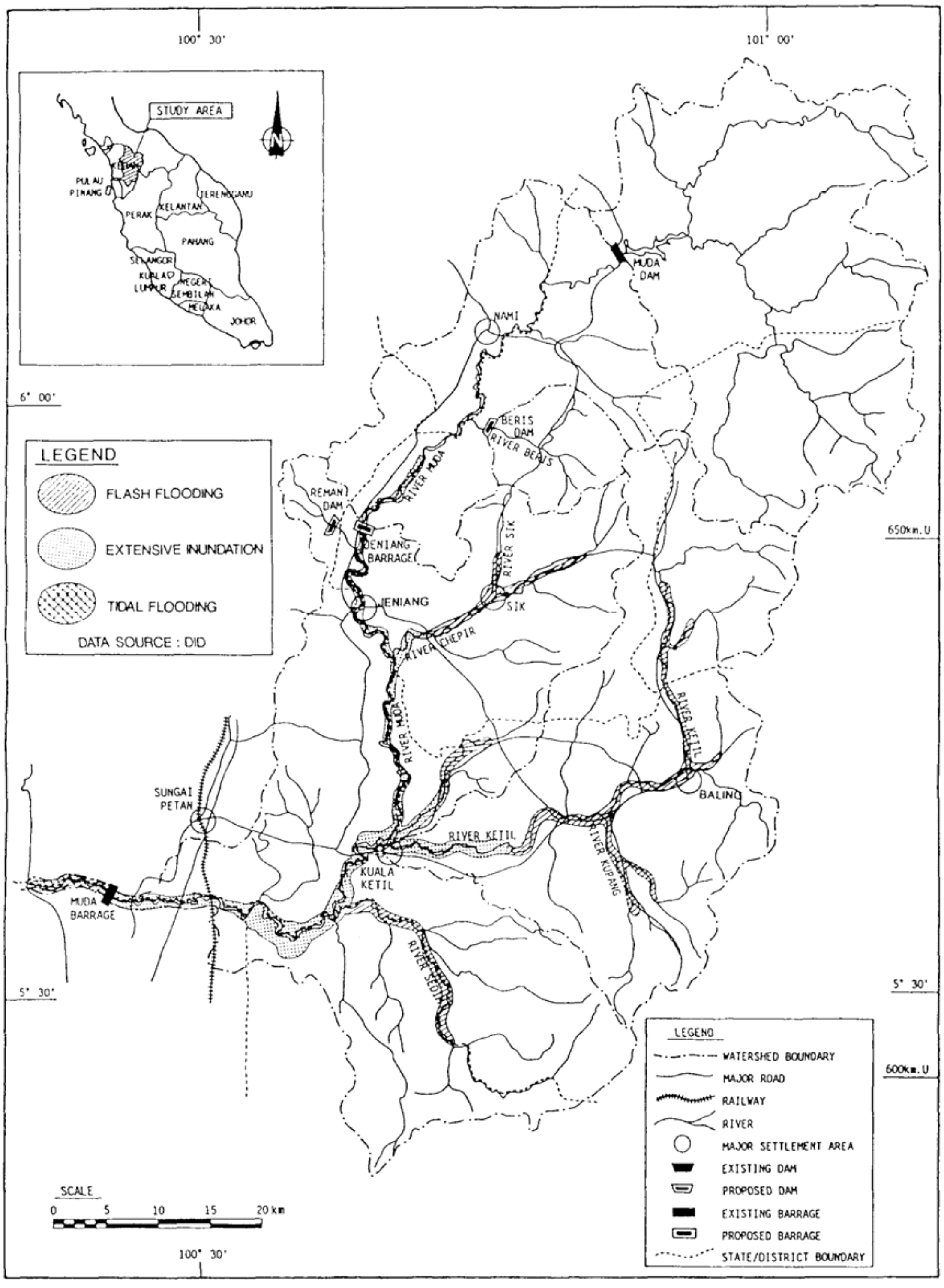


Data Source: National River Months Study, 1994. JICA

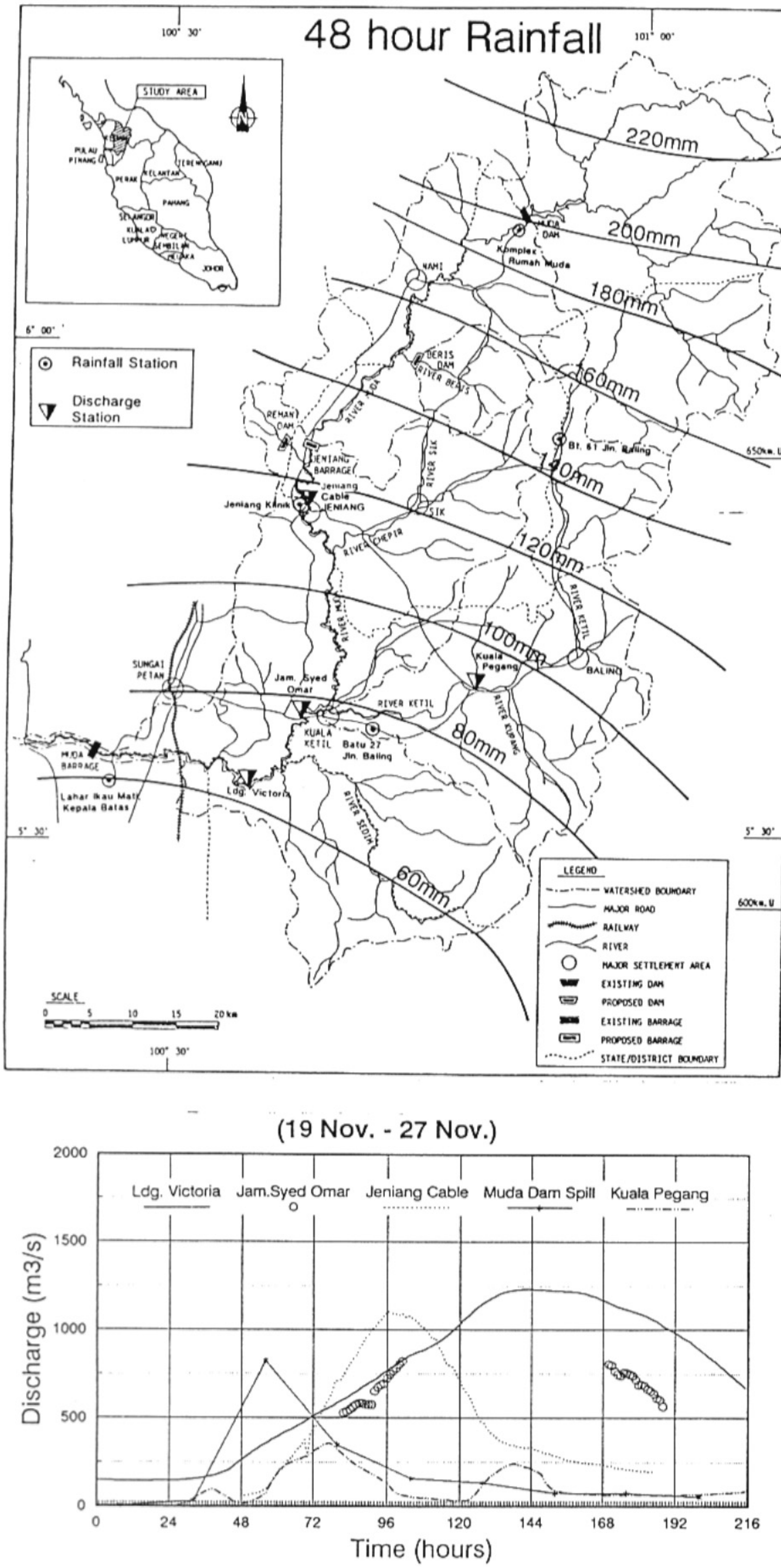
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. 2.3.11
JAPAN INTERNATIONAL COOPERATION AGENCY	BEACH MATERIAL DISTRIBUTION AND DIRECTION OF LONGSHORE SEDIMENT TRANSPORTATION



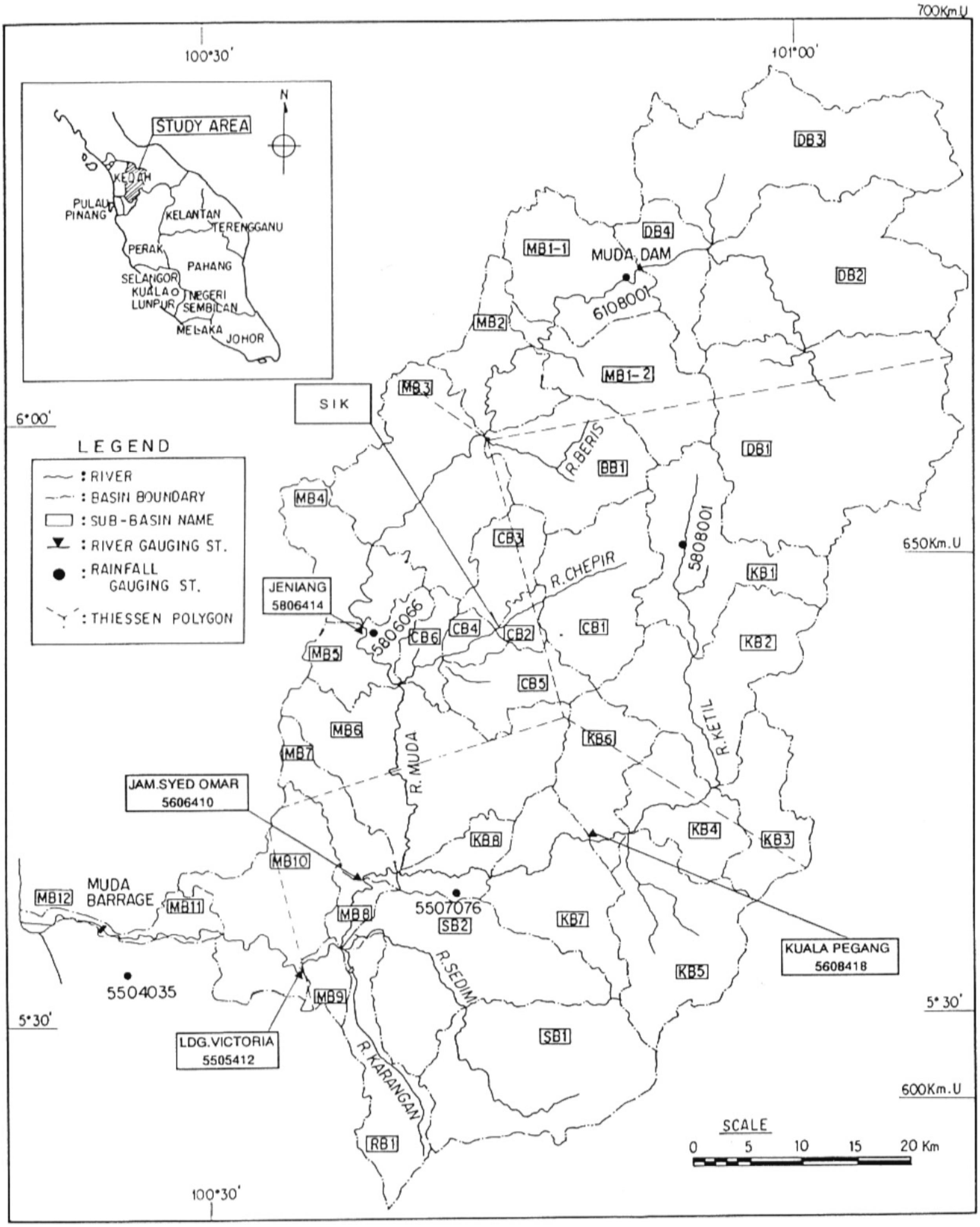
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. 2.3.12
JAPAN INTERNATIONAL COOPERATION AGENCY	RESULT OF BED LOAD SURVEY AND ESTIMATED RATING CURVE



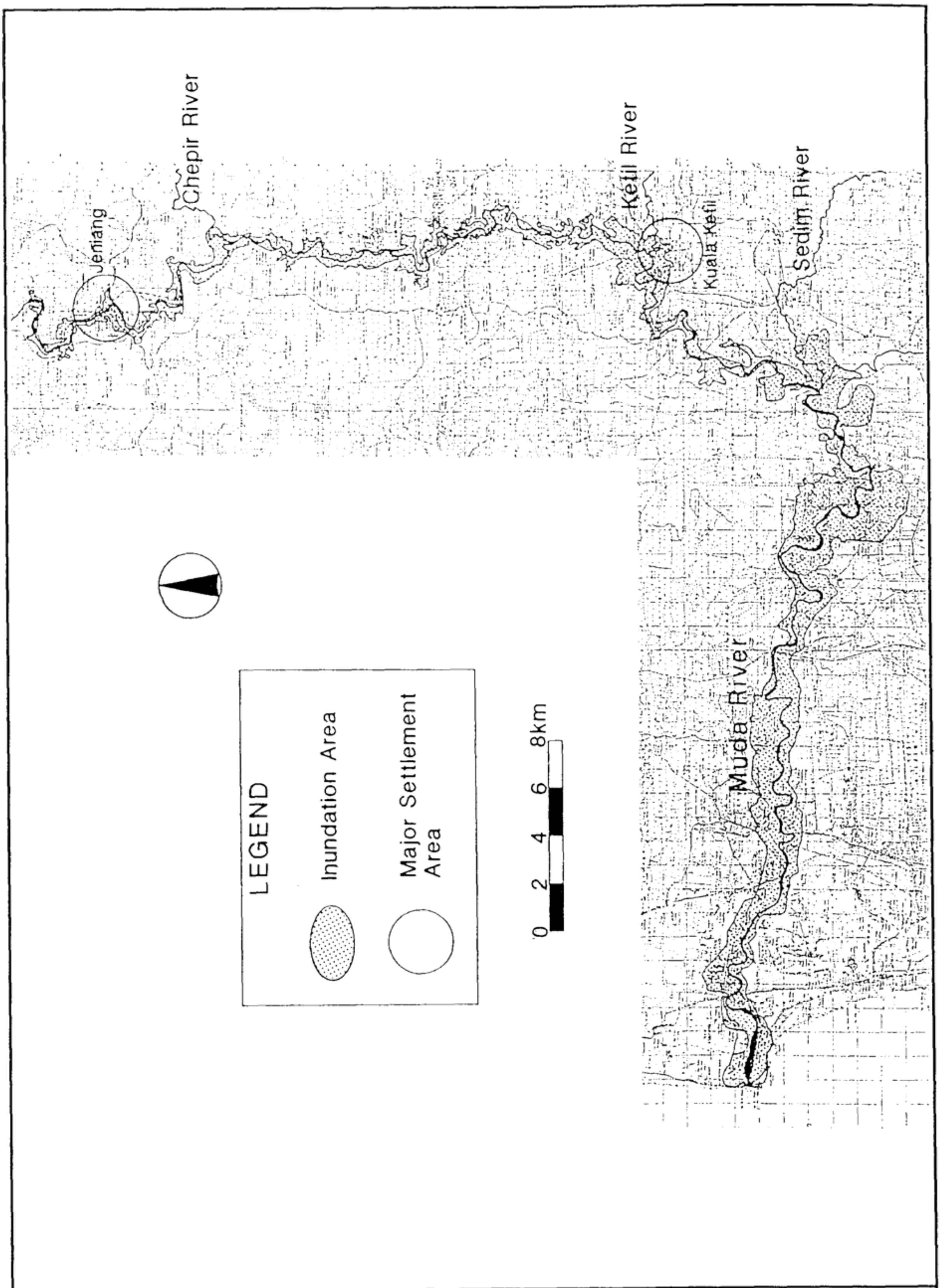
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY	FIG. 3.1.1 FLOOD PRONE AREA IN MUDA RIVER BASIN



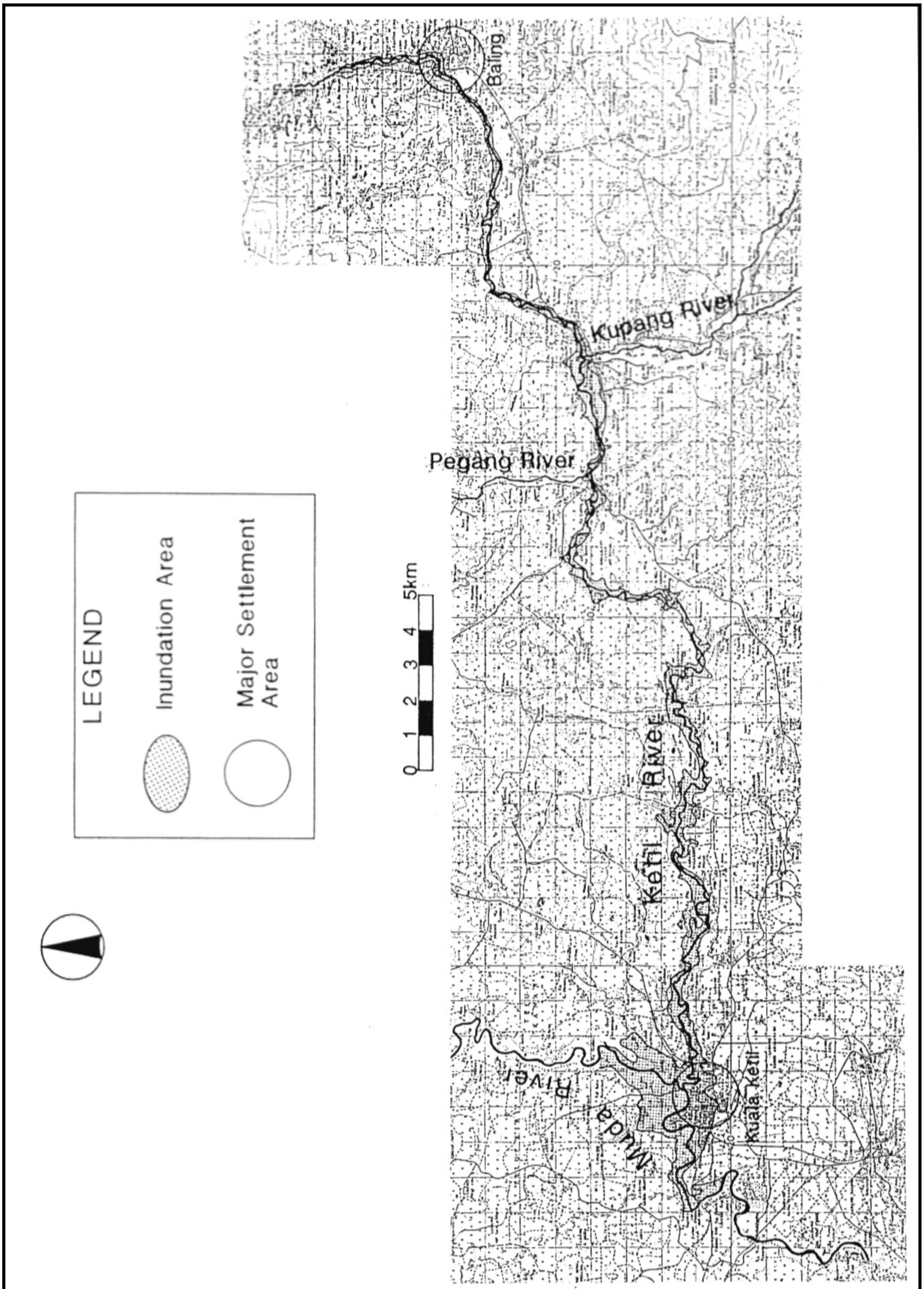
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. 3.2.1
JAPAN INTERNATIONAL COOPERATION AGENCY	ISOHYETAL MAP OF 48-HOUR RAINFALL AND FLOOD HYDROGRAPH DURING 1988 FLOOD



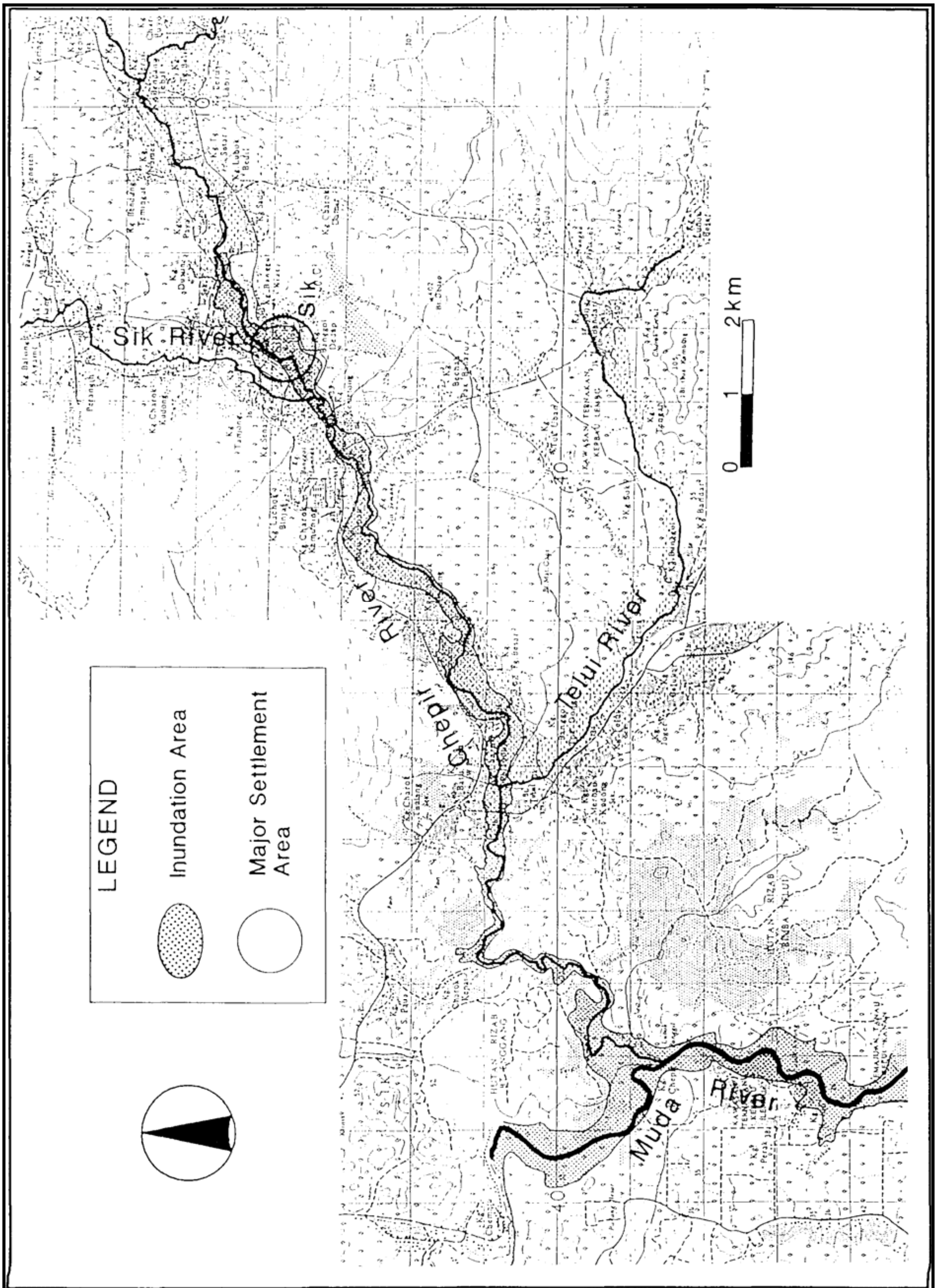
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. I. 6.1.1 LOCATION MAP OF REFERENCE POINTS AND DIVISION OF MUDA RIVER BASIN FOR FLOOD RUNOFF ANALYSIS
JAPAN INTERNATIONAL COOPERATION AGENCY	



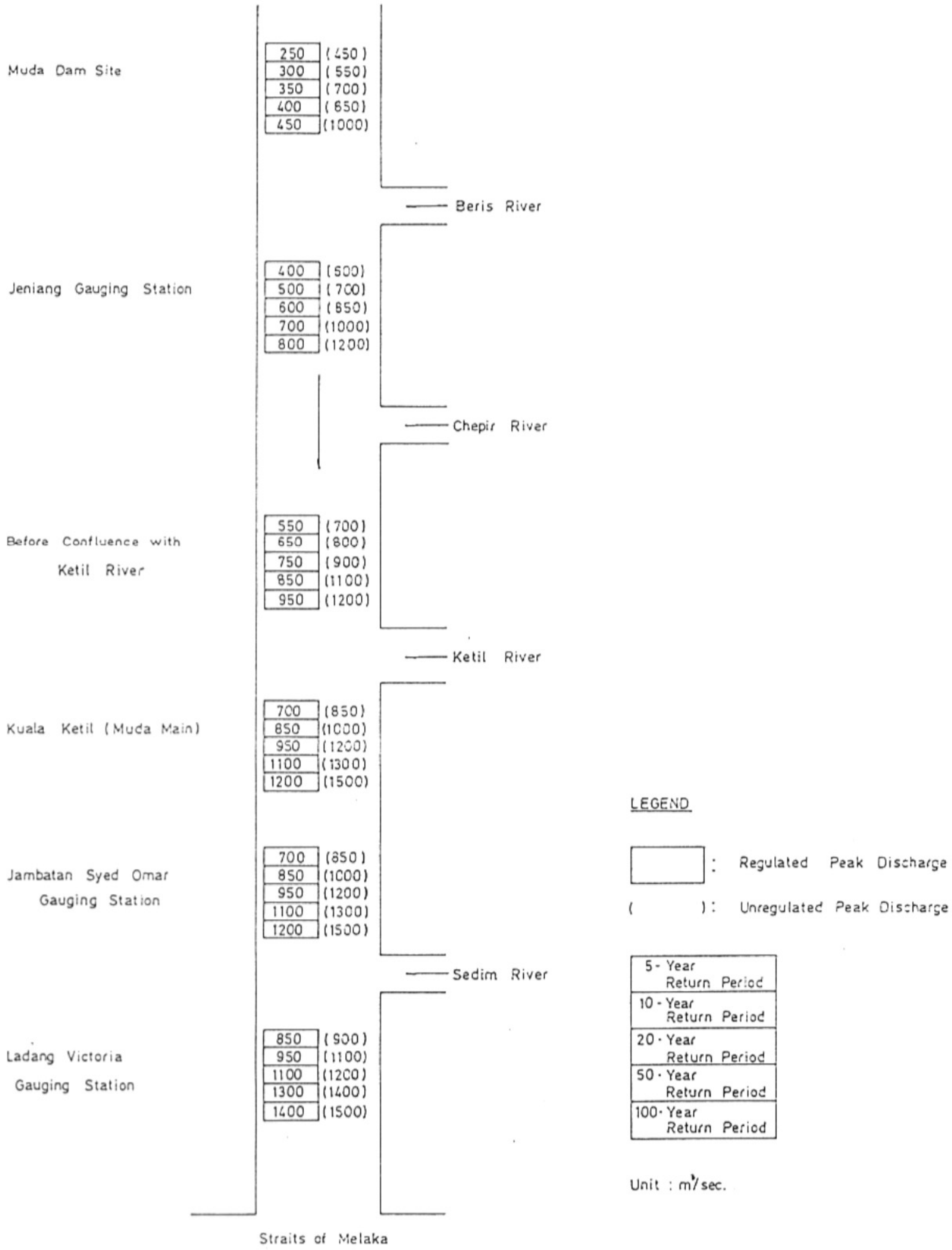
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. 3.2.2
JAPAN INTERNATIONAL COOPERATION AGENCY	FLOOD INUNDATION AREA ALONG MUDA RIVER DURING 1988 FLOOD



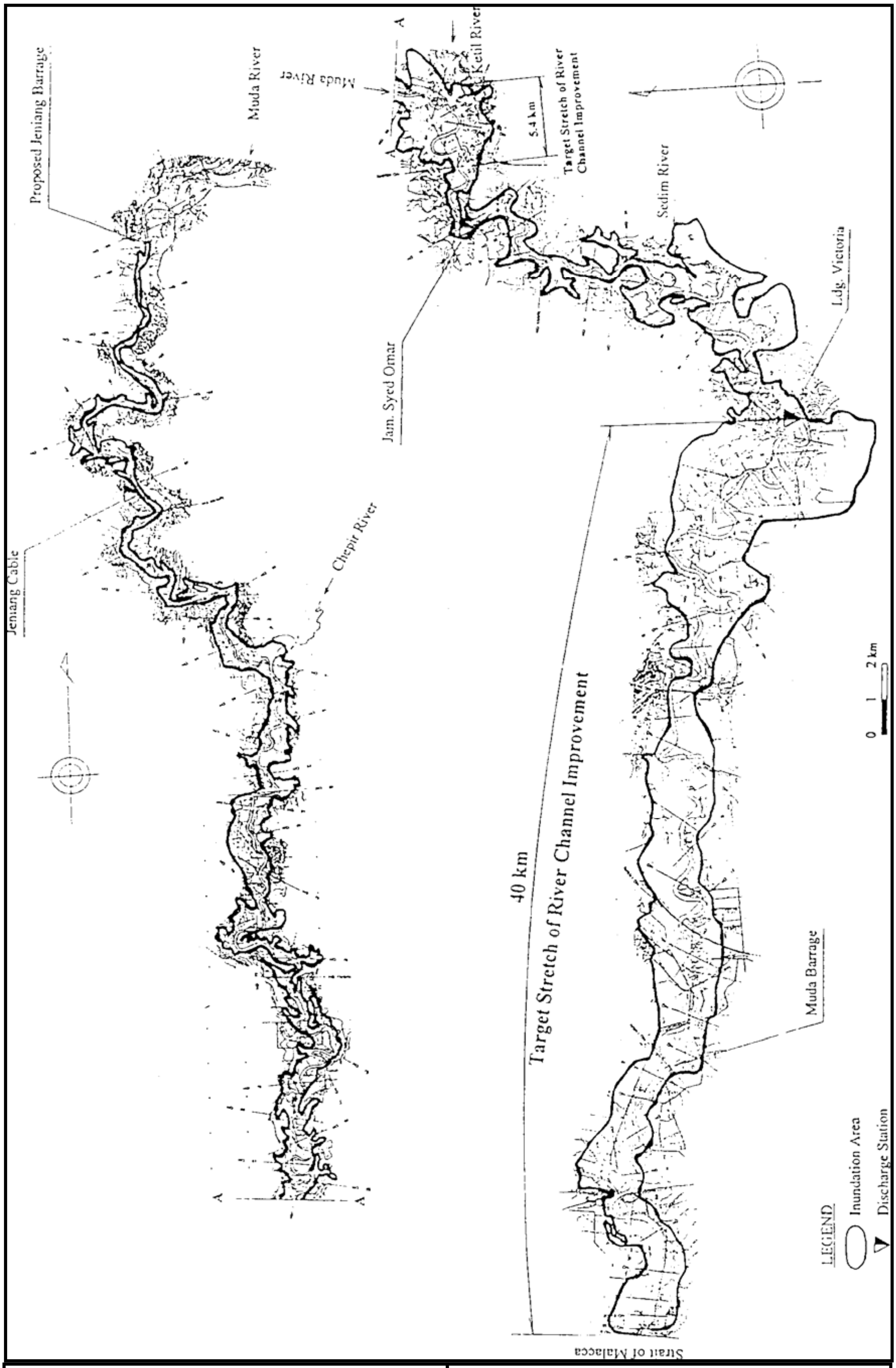
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. 3.2.3 FLOOD INUNDATION AREA ALONG KETIL RIVER DURING 1988 FLOOD
JAPAN INTERNATIONAL COOPERATION AGENCY	



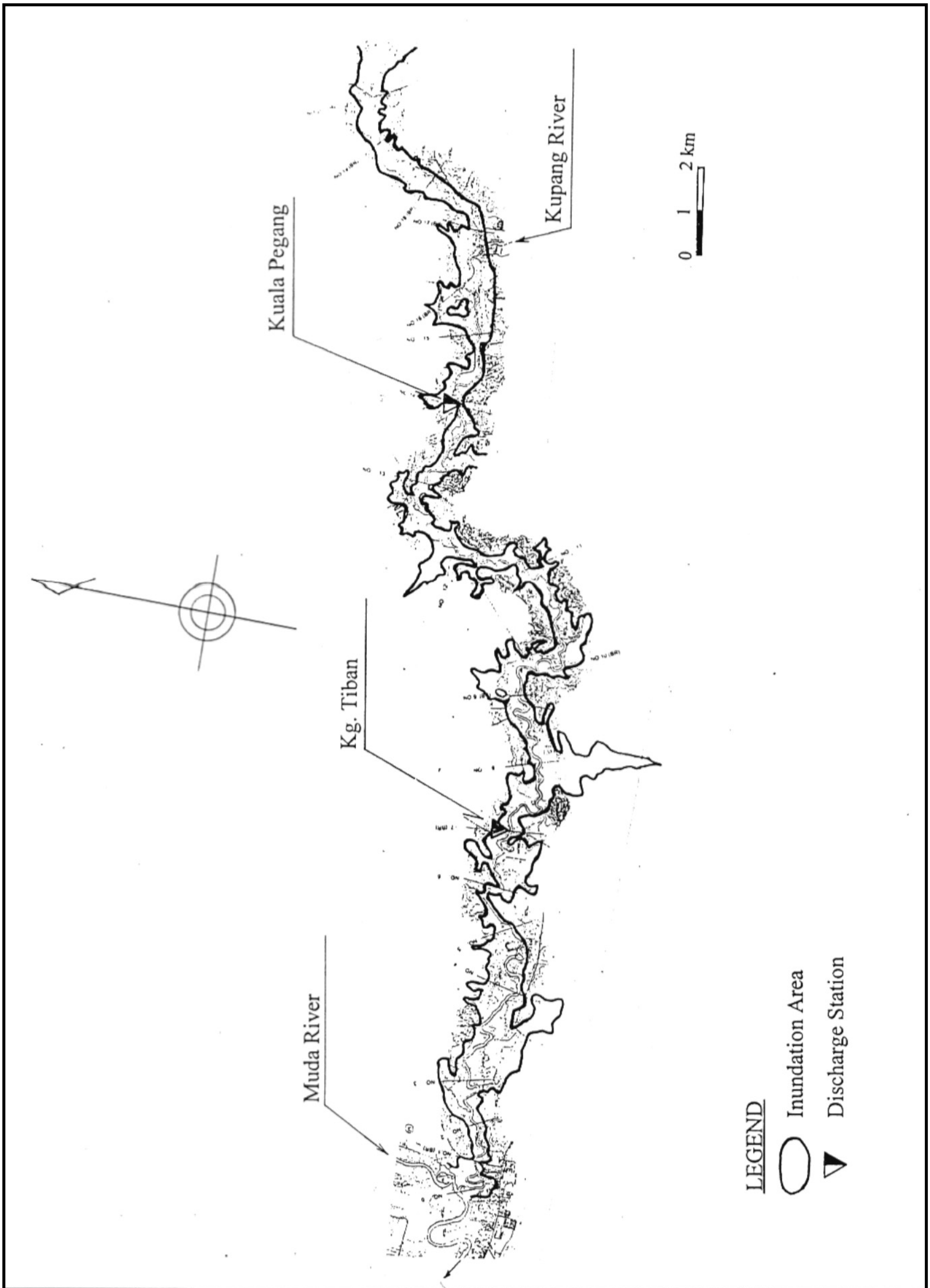
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. 3.2.4
JAPAN INTERNATIONAL COOPERATION AGENCY	FLOOD INUNDATION AREA ALONG CHEPIR RIVER DURING 1988 FLOOD



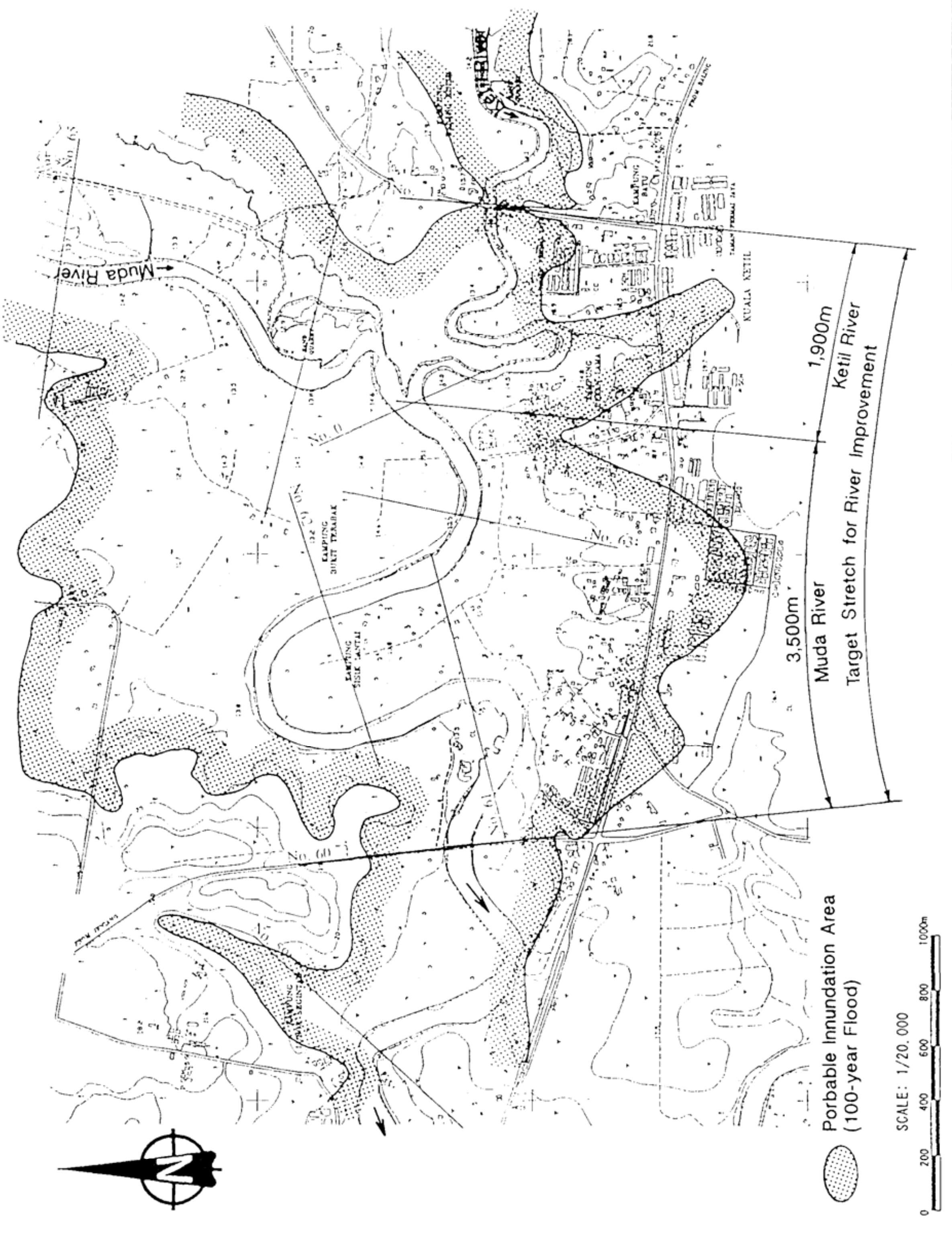
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. 3.3.1
JAPAN INTERNATIONAL COOPERATION AGENCY	REGULATED PROBABLE FLOOD DISCHARGE DISTRIBUTION



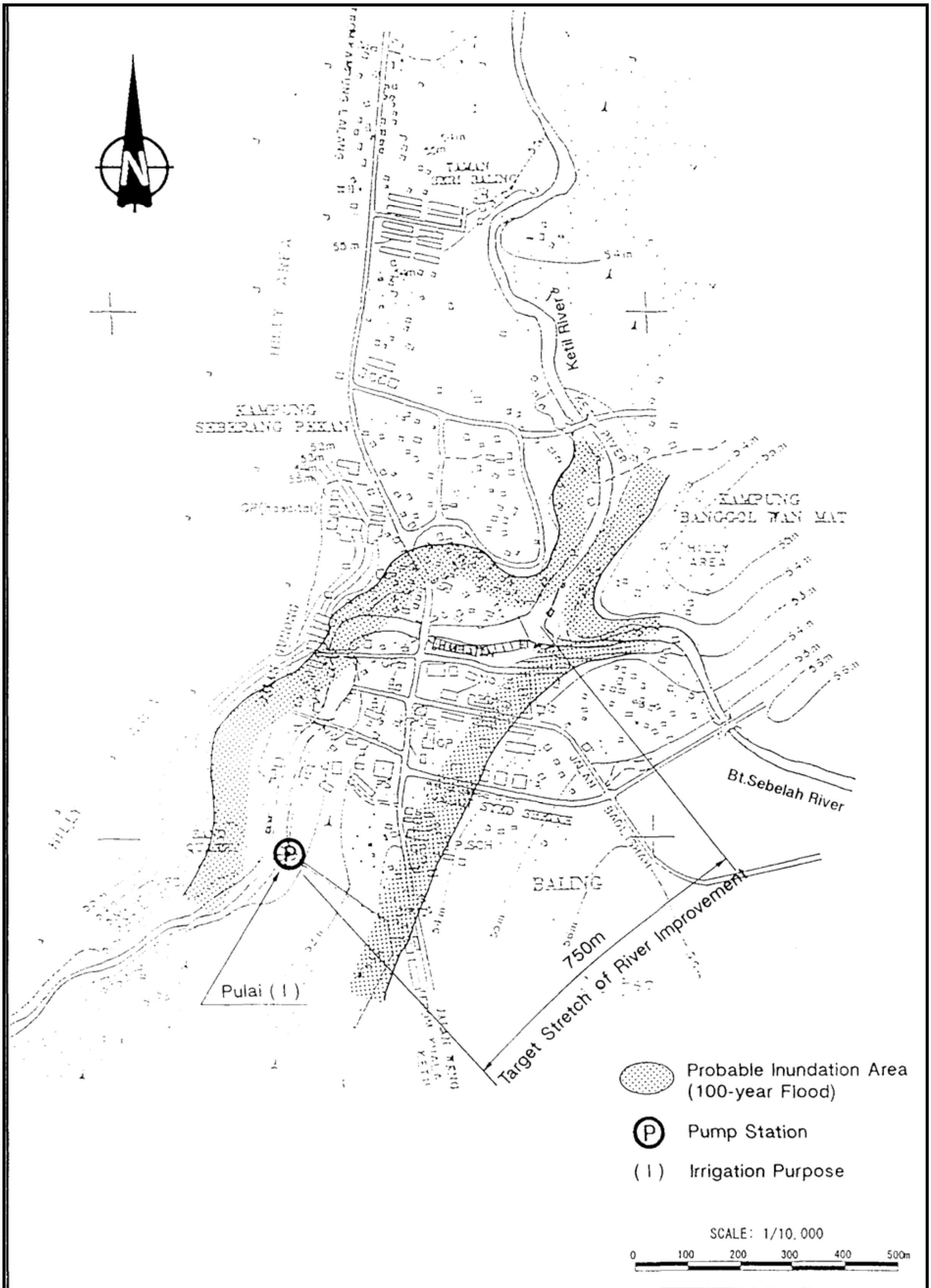
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVERS BASIN JAPAN INTERNATIONAL COOPERATION AGENCY	FIG. 3.4.1 (1/2) PROBABLE INUNDATION AREA BY 100 YEAR FLOOD (MUDA RIVER)



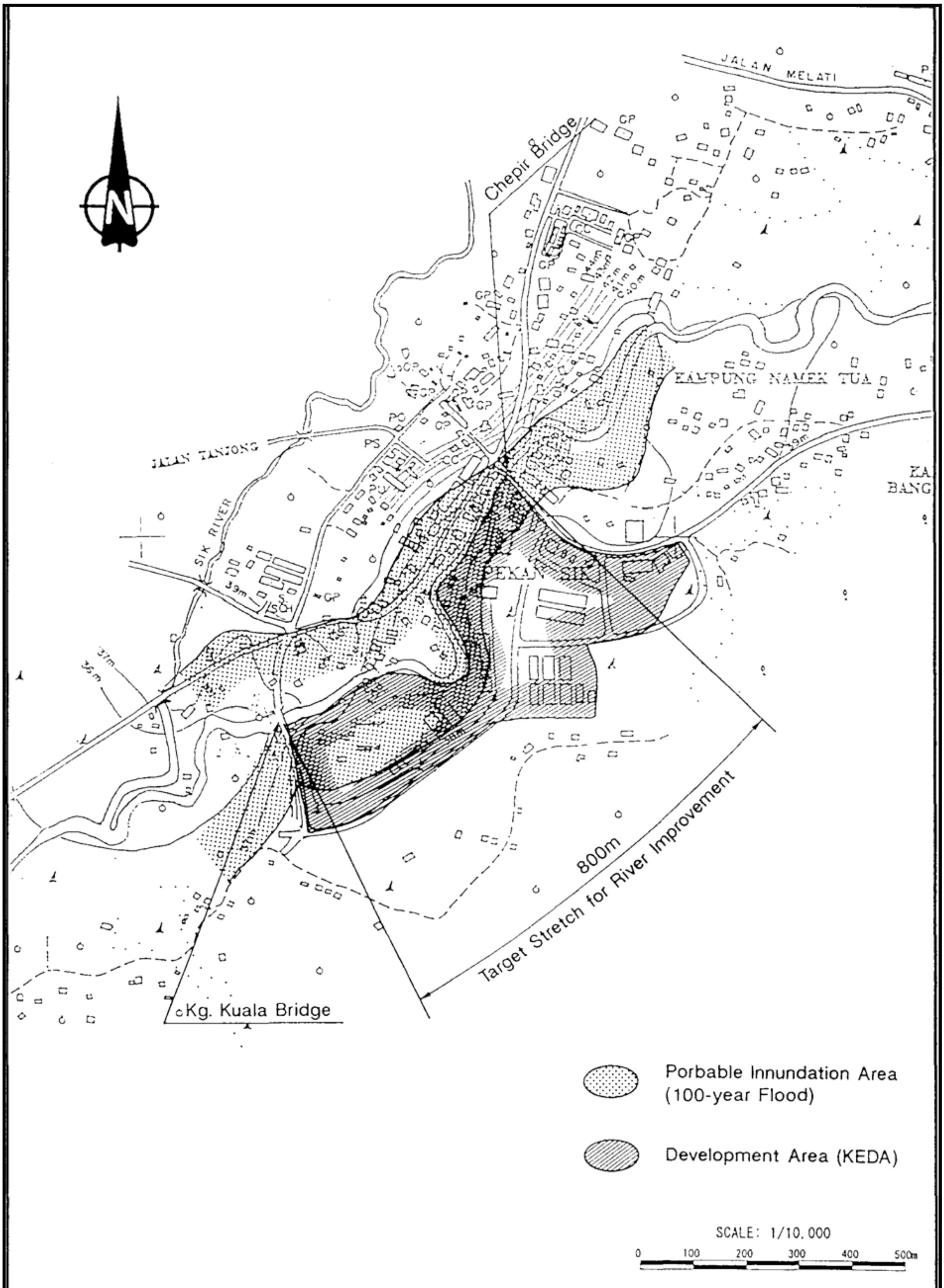
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. 3.4.1 (2/2)
JAPAN INTERNATIONAL COOPERATION AGENCY	PROBABLE INUNDATION AREA BY 100-YEAR FLOOD (KETIL RIVER)



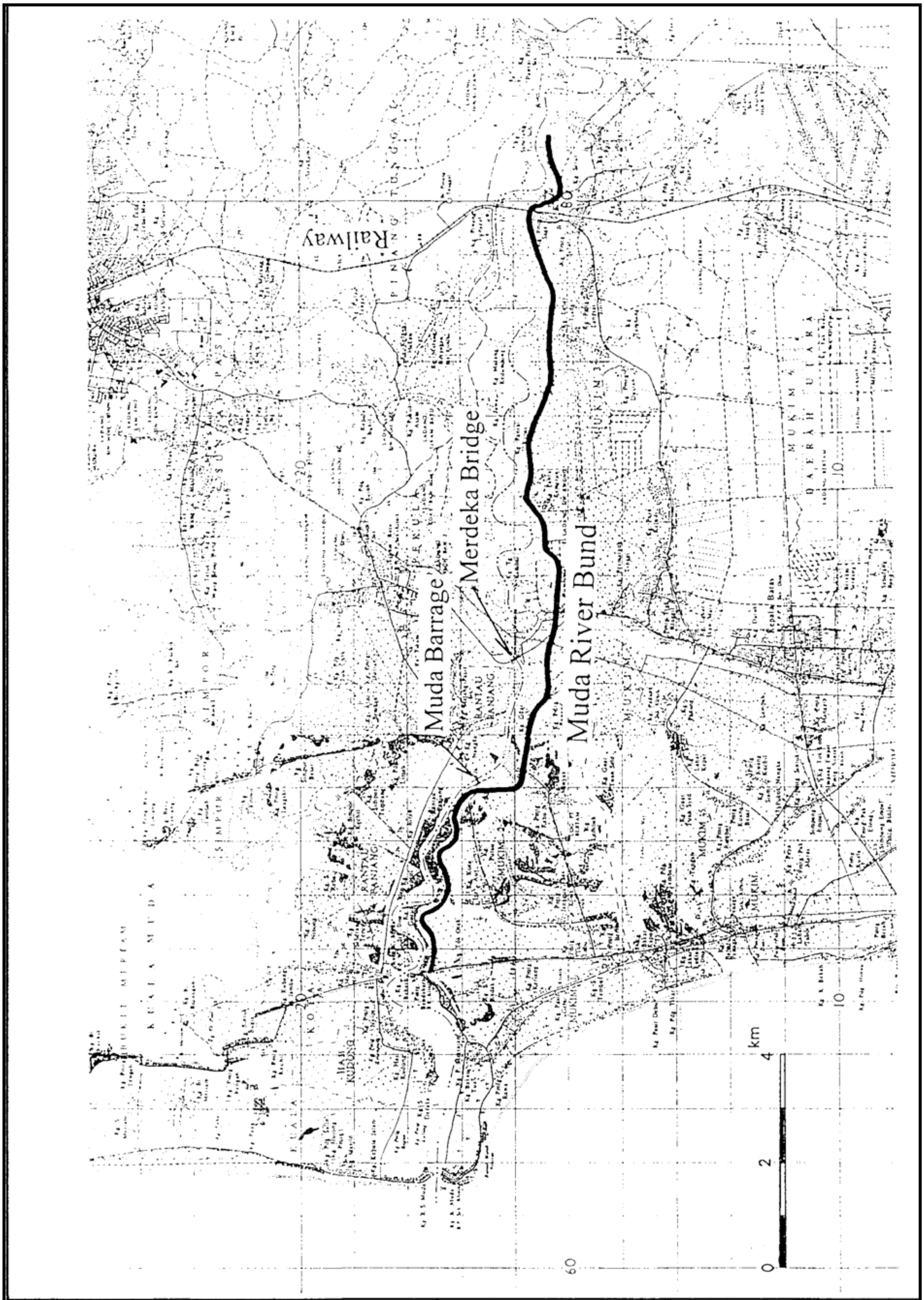
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY	FIG. 3.4.2 (1/3) PROBABLE INUNDATION AREA BY 100-YEAR FLOOD ALONG SHORT TARGET STRETCH (KUALA KETIL TOWN)



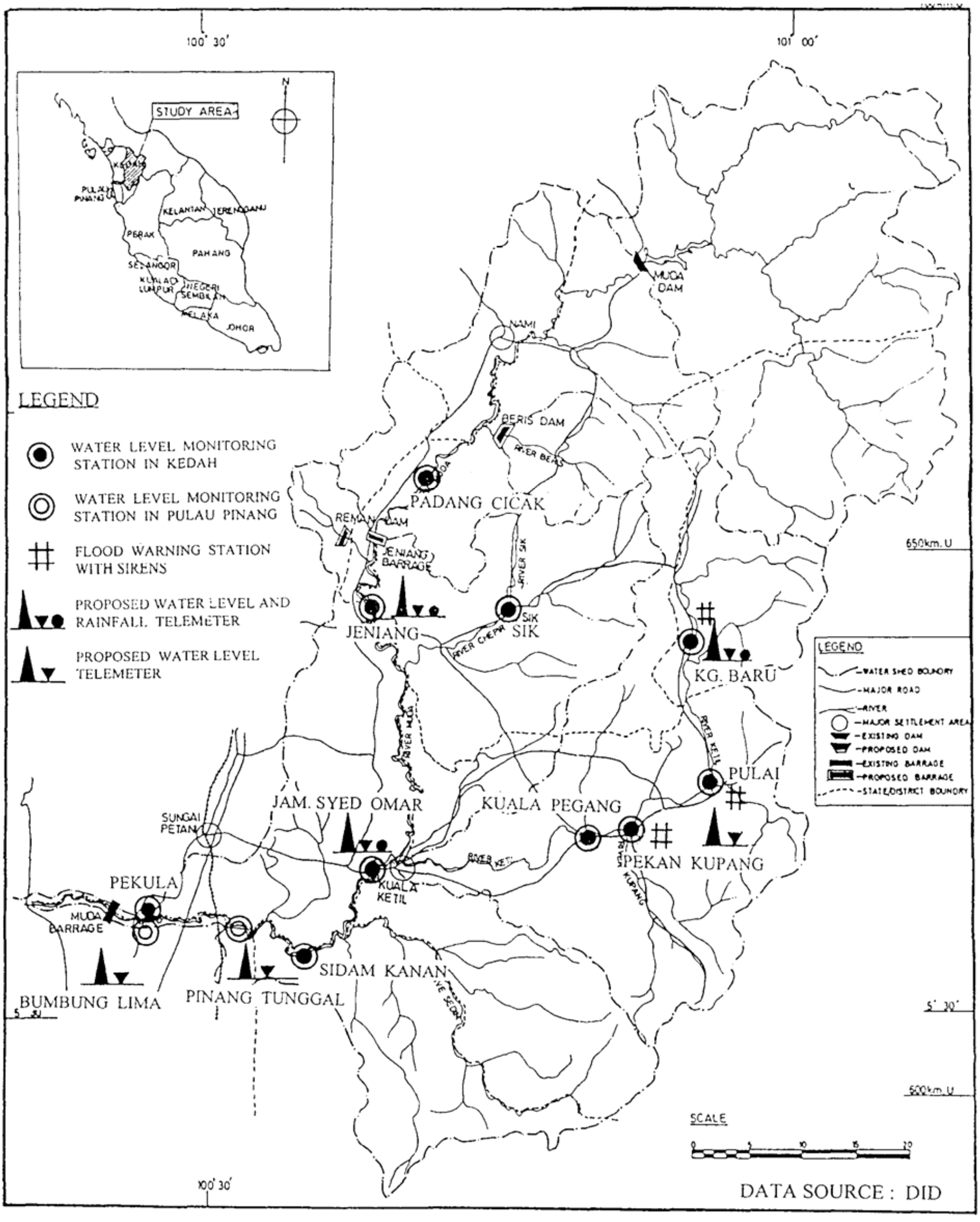
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. 3.4.2 (2/3)
JAPAN INTERNATIONAL COOPERATION AGENCY	PROBABLE INUNDATION AREA BY 100-YEAR FLOOD ALONG SHORT TARGET STRETCH (BALING TOWN)



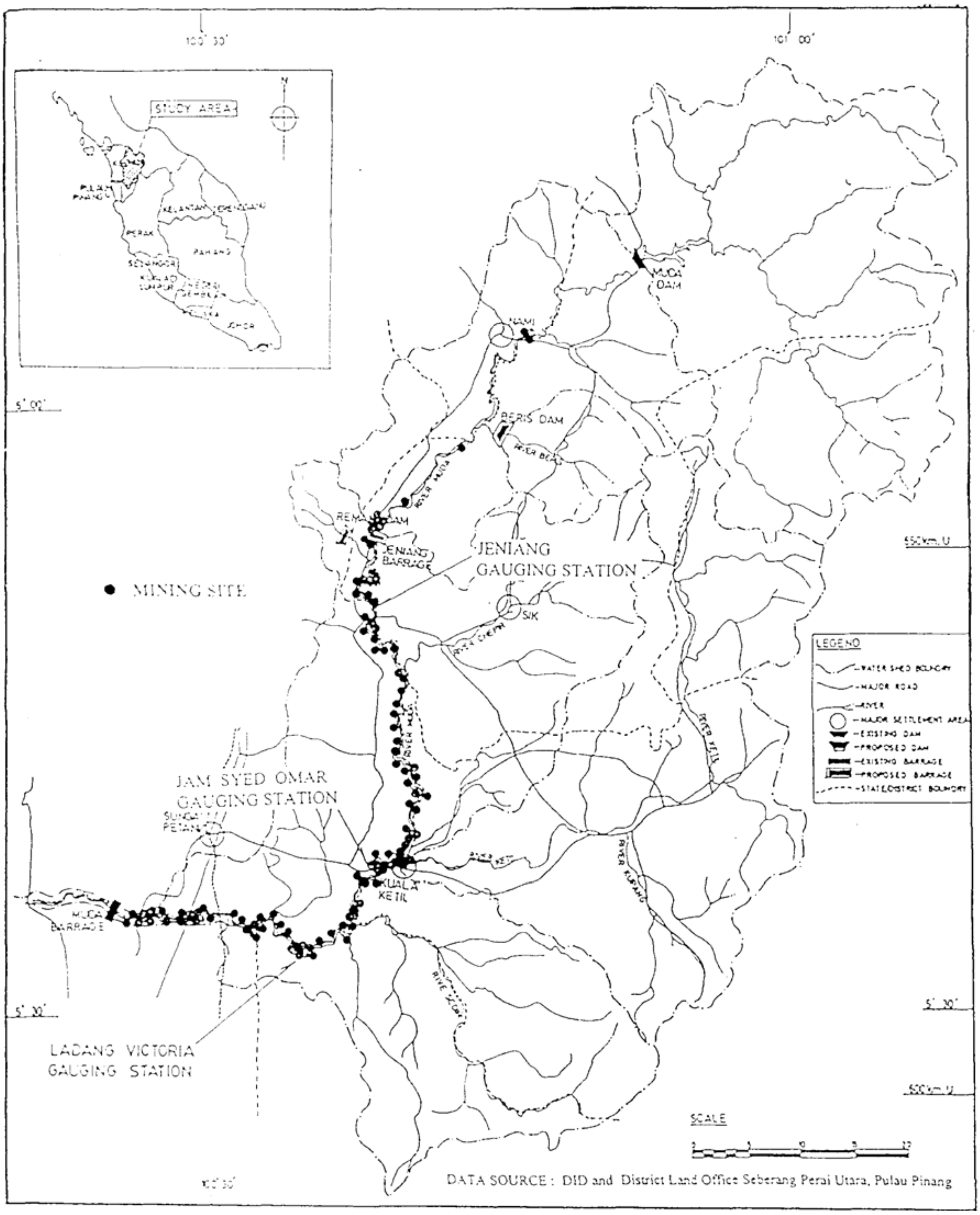
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. 3.4.2 (3/3)
JAPAN INTERNATIONAL COOPERATION AGENCY	PROBABLE INUNDATION AREA BY 100-YEAR FLOOD ALONG SHORT TARGET STRETCH (SIK TOWN)



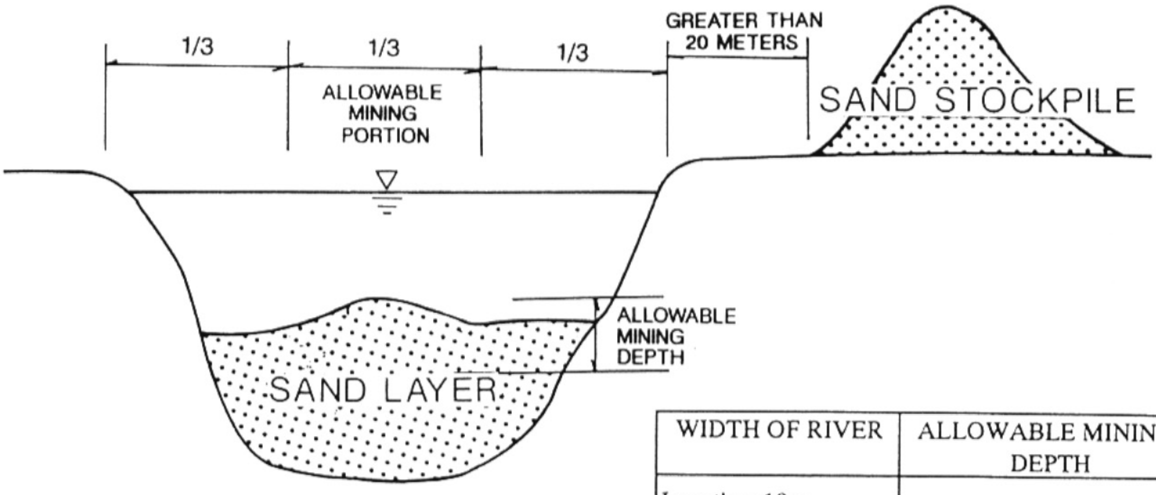
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. 3.5.1
JAPAN INTERNATIONAL COOPERATION AGENCY	LOCATION OF MUDA RIVER BUND



COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVERS BASIN JAPAN INTERNATIONAL COOPERATION AGENCY	FIG. 3.5.2 LOCATION OF WATER LEVEL MONITORING STATIONS IN MUDA RIVER BASIN



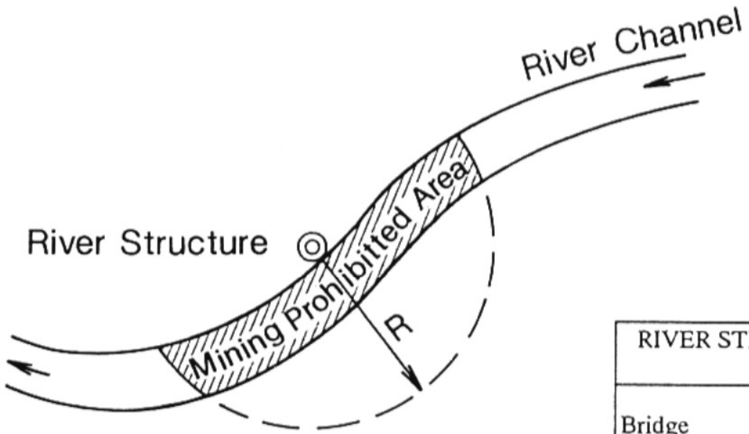
COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. 4.2.1
JAPAN INTERNATIONAL COOPERATION AGENCY	LOCATION OF SAND MINING SITES



WIDTH OF RIVER	ALLOWABLE MINING DEPTH
Less than 10m	-
Between 10 to 20m	0.5m
Between 20 to 30m	1.0m
More than 50m	1.5m

DATA SOURCE : DID

(1) CROSS SECTION



RIVER STRUCTURE	MINIMUM RADIUS R
Bridge Building Others	200m
Pump House Intake Structure Others	500m

(2) PLAN

COMPREHENSIVE MANAGEMENT PLAN OF MUDA RIVER BASIN	FIG. II.1.4.6
JAPAN INTERNATIONAL COOPERATION AGENCY	SAND MINING LOCATION REGULATED BY DID

3.2 Abdullah (2002)

Abdullah (2002) conducted survey works at several cross sections similar to those of JICA (1995). Comparisons of the cross sections for both studies show that several cross sections were affected by the on-going activities of sand mining operations along Sg. Muda.

3.1.2 Study Reach

The study was carried out along a 5 km stretch of Sg. Muda in the vicinity of Syed Omar Bridge (Figure 3.29). The data collections were made from February 2001 until March 2002.

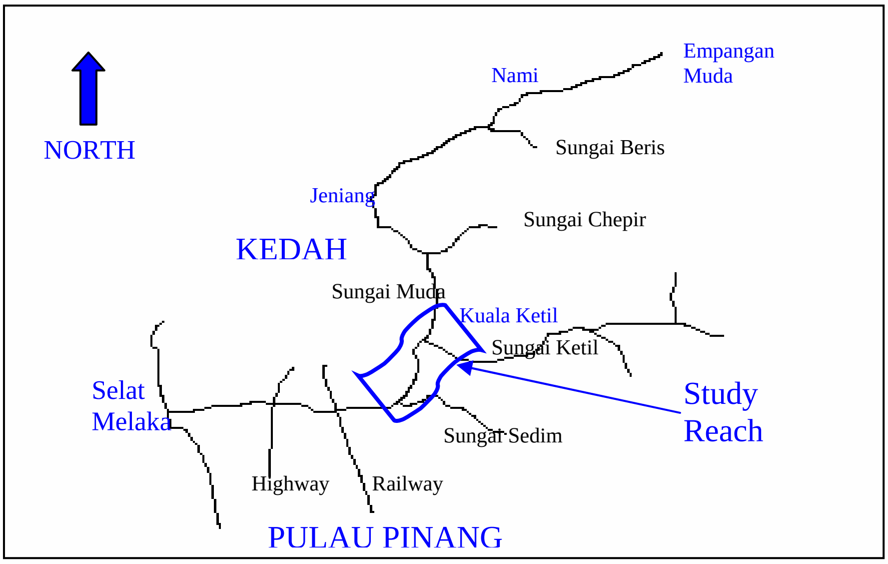


Figure 3.29 Study Reach @ Sg. Muda

3.2.2 Hydrological Data

Recent flood hydrographs were utilized in the river modeling using FLUVIAL-12. Figure 3.30 shows the 1997 flow rating curve of Syed Omar Bridge while Figure 3.31 gives the 1993, 1994, 1997 and 1998 hydrographs. Figure 3.32 show the flow rating curves at Syed Omar Bridge from 1993 until 2001.

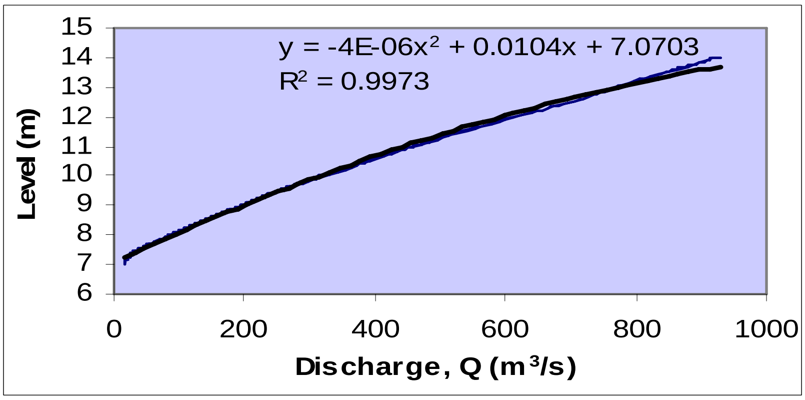


Figure 3.30 Flow Rating Curve at Syed Omar Bridge for 1997

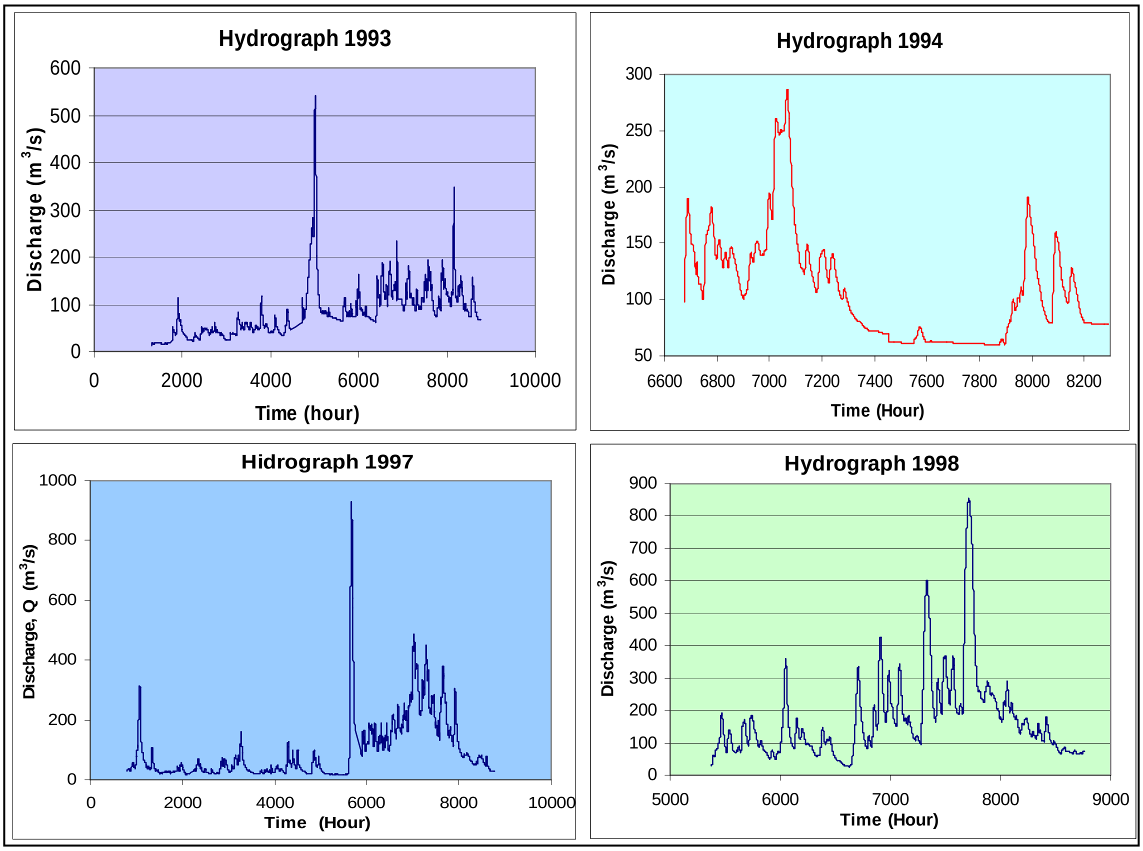


Figure 3.31 1993, 1994, 1997 & 1998 Hydrographs at Syed Omar Bridge

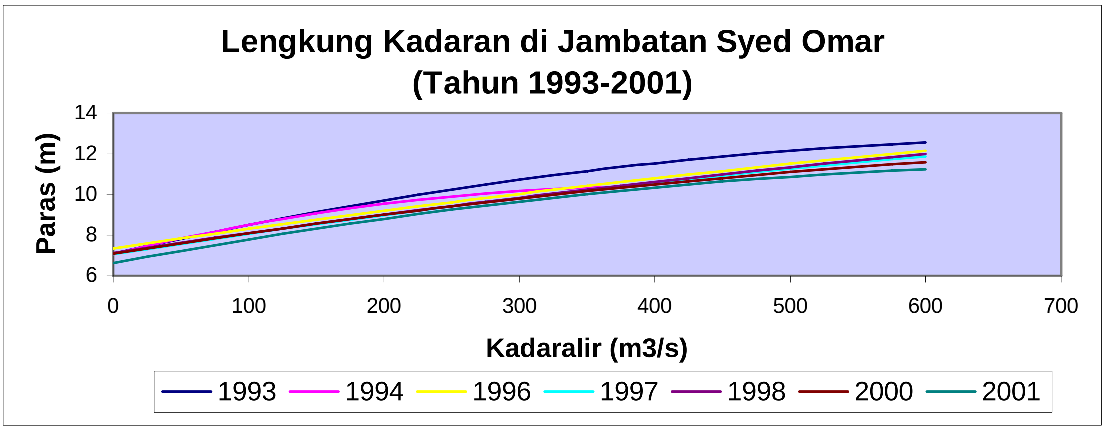


Figure 3.32 Flow Rating Curves at Syed Omar Bridge (1993-2001)

3.2.3 Field Data Collections

Table 3.10 gives a summary of field data that were collected during the study including bed material, cross-section surveys and water levels.

Table 3.10 Field Data Summary

Item	Type of Data	Locations	Period
1	Bed Material	A - Kg Kubang Berdengong B & C - Kg Lubuk Segintah D - Kg Tanjung Puteri E - Kg Sisek Lantai	February 2001 until December 2001
2	Cross Sections	See Figure 3.33 (KR 55 – KR 61)	June 2001 and March 2002
3	Water Levels at Cross Sections	See Figure 3.33	October 2001 until December 2001

Cross Sections

Two survey works were conducted at the chosen cross sections in June 2001 and February 2002. Figure 3.34 shows the conditions of the chosen cross sections in June 2001.

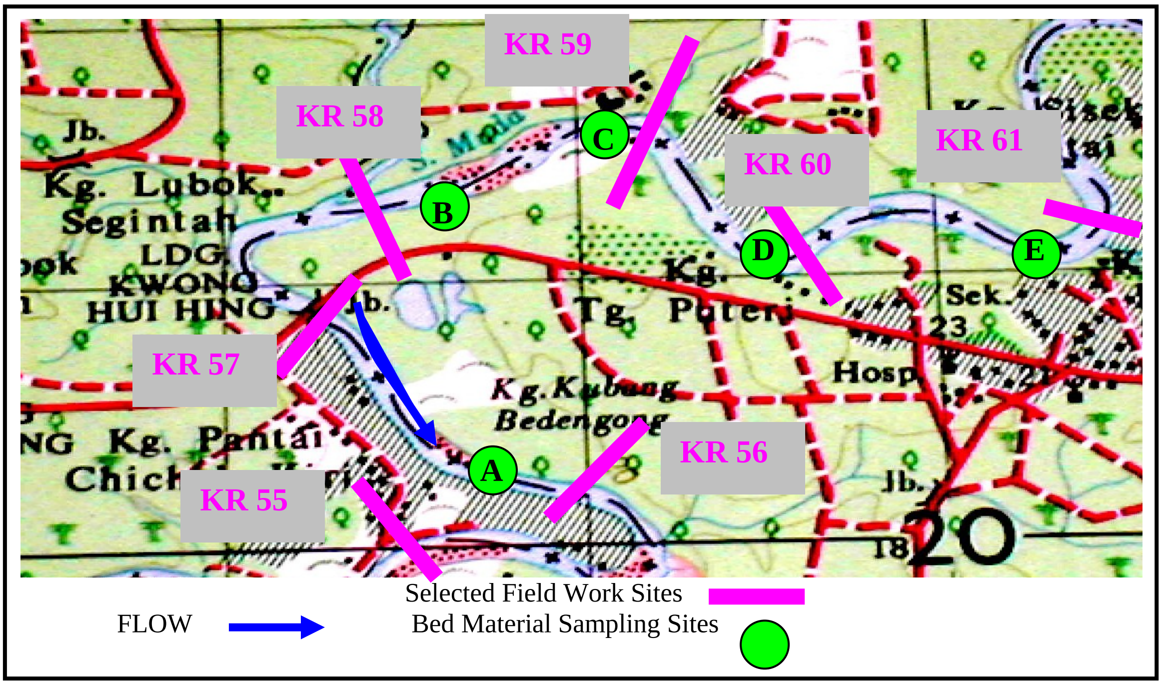


Figure 3.33 Field Data Sampling Sites

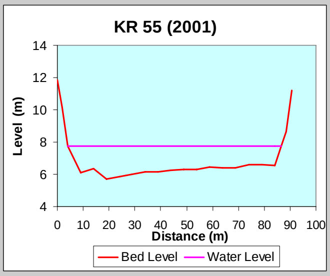
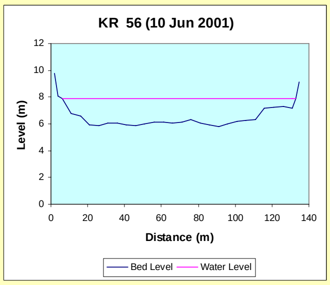
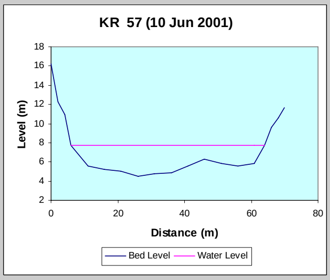
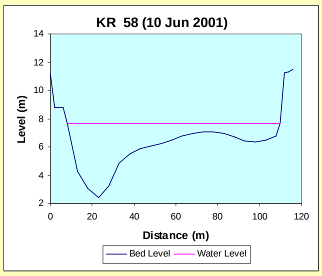
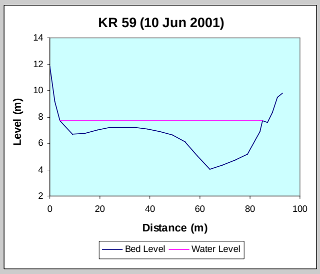
Location	Present Condition	Cross Section	Width (m)	Chainage (m)
KR 55			91	0
KR 56			135	467
KR 57			70	1934
KR 58			116	2441
KR 59			93	3440

Figure 3.34 Cross Section Condition in 2001 (KR 55, KR 56 & KR 57)

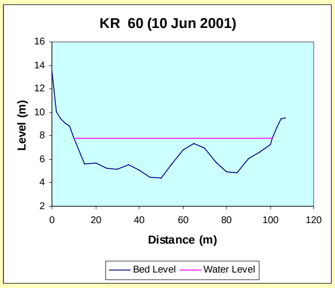
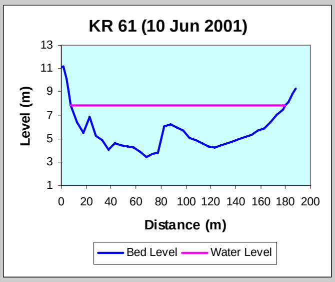
Location	Present Condition	Cross Section	Width (m)	Chainage (m)
KR 60			107	4439
KR 61			188	5146

Figure 3.34 Cross Section Condition in 2001 (KR 58, KR 59, KR 60 & KR 61)

Figure 3.35 and Table 3.11 show the river bed profiles and corresponding thalwegs along the study reach measured in 1994 (JICA, 1995) and present study. Significant degradation occurs between KR 57 and KR 59 where the bed has lowered around 3 m due to sand mining operations along the study reach.

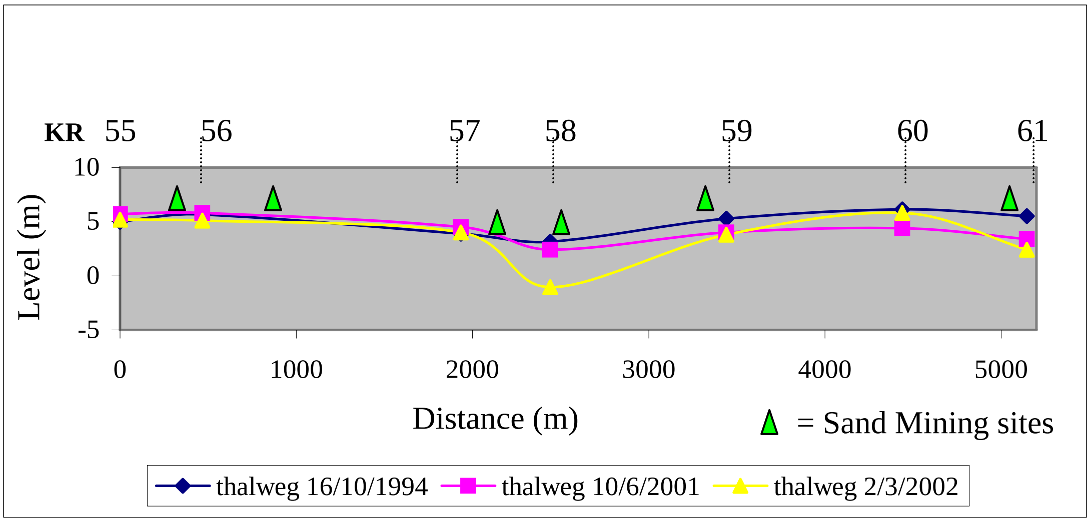


Figure 3.35 River Bed Profile for 1994, 2001 & 2002

Table 3.11 Thalweg and Water Level Data

Station		2001		2002	
	Distance(m)	Thalweg (m)	Water Level (m)	Thalweg (m)	Water Level (m)
KR 55	100	5.722	7.762	5.291	6.256
KR 56	567	5.843	7.863	5.104	6.234
KR 57	2034	4.505	7.765	4.053	6.439
KR 58	2541	2.435	7.655	-1.03	6.494
KR 59	3540	4.06	7.72	3.871	6.616
KR 60	4539	4.436	7.816	5.808	6.758
KR 61	5246	3.422	7.822	2.422	6.959
		So = 0.0004	Sw = 0.00001	So = 0.0006	Sw = 0.0001

Figure 3.36 shows the degradation of the river bed during the study period of the present study.

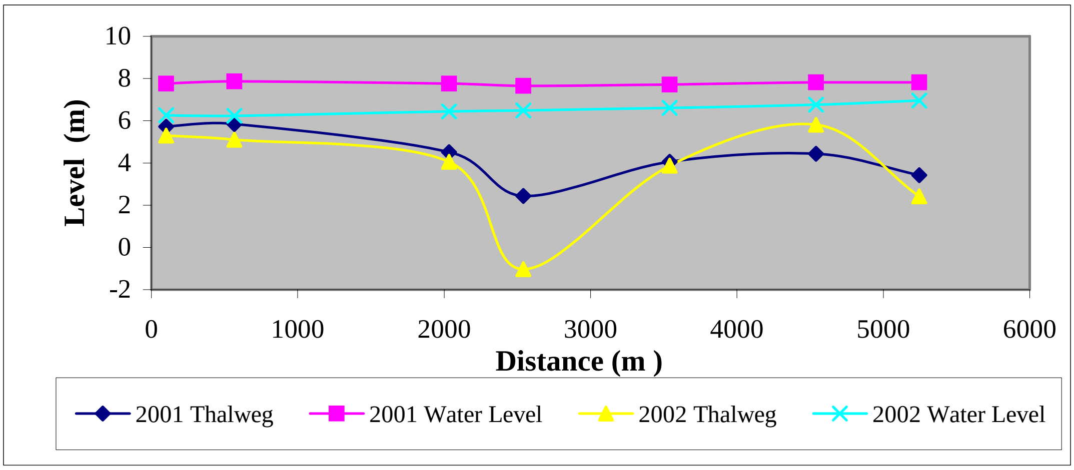
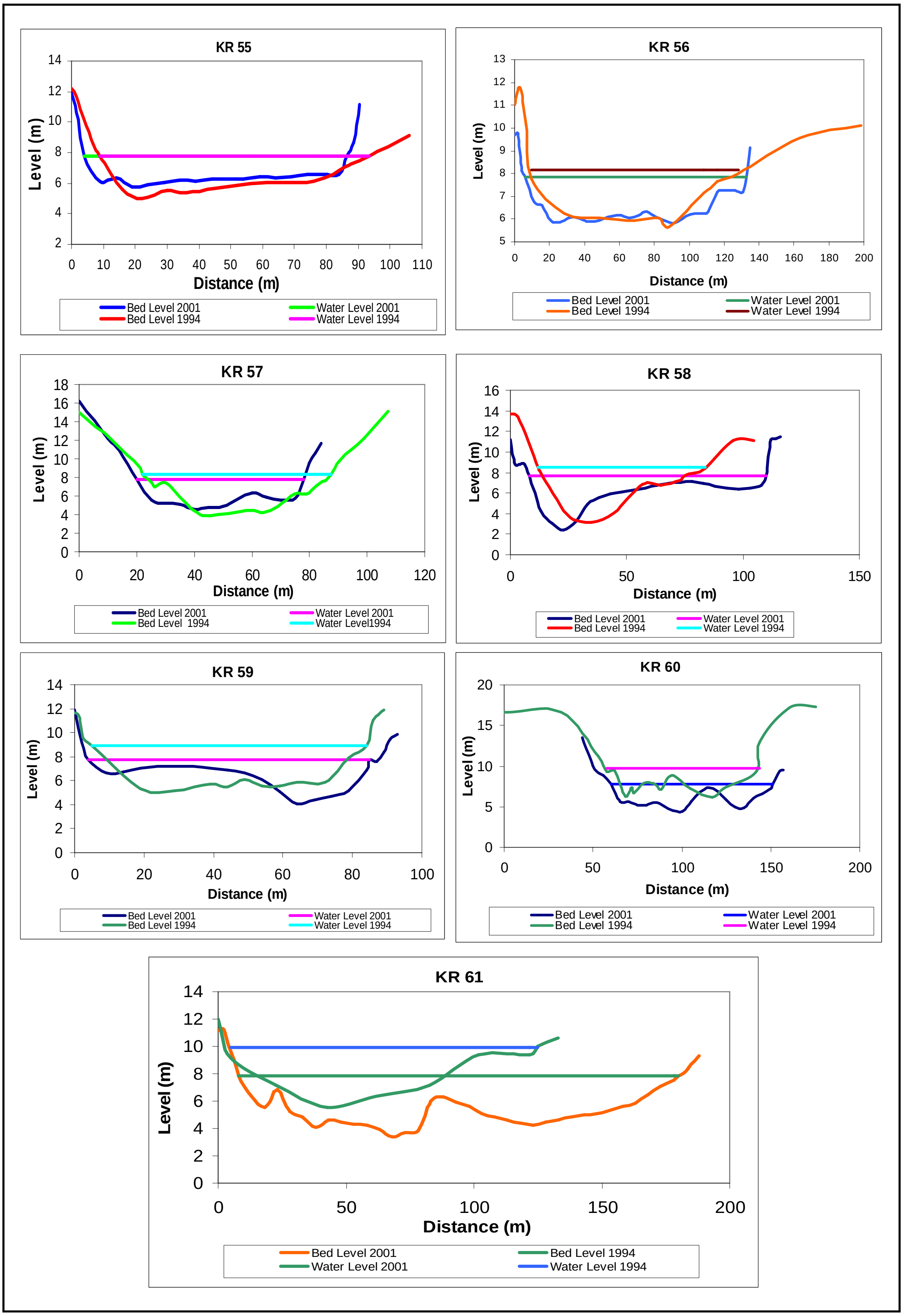


Figure 3.36 Thalweg Levels for 2001 and 2002

The changes that occur between 1994 (JICA, 1995) and 2001 is given in Figure 3.37. In general, degradation occurs while at KR 61 lateral movement has occurred.



Rajah 3.37 Cross Section Comparisons for 1994 & 2001

River Bed Material

Bed materials were collected at five sampling sites (Figure 3.38). Table 3.12 gives a summary of the bed materials at the chosen sites. The sediment sizes vary between 0.62 mm to 3.85 mm (Figure 3.39) confirming the river bed of Sg. Muda is made up of sand and gravel. This explains the so many sand mining operations along Sg. Muda (Figure 3.40 and Figure 3.41).

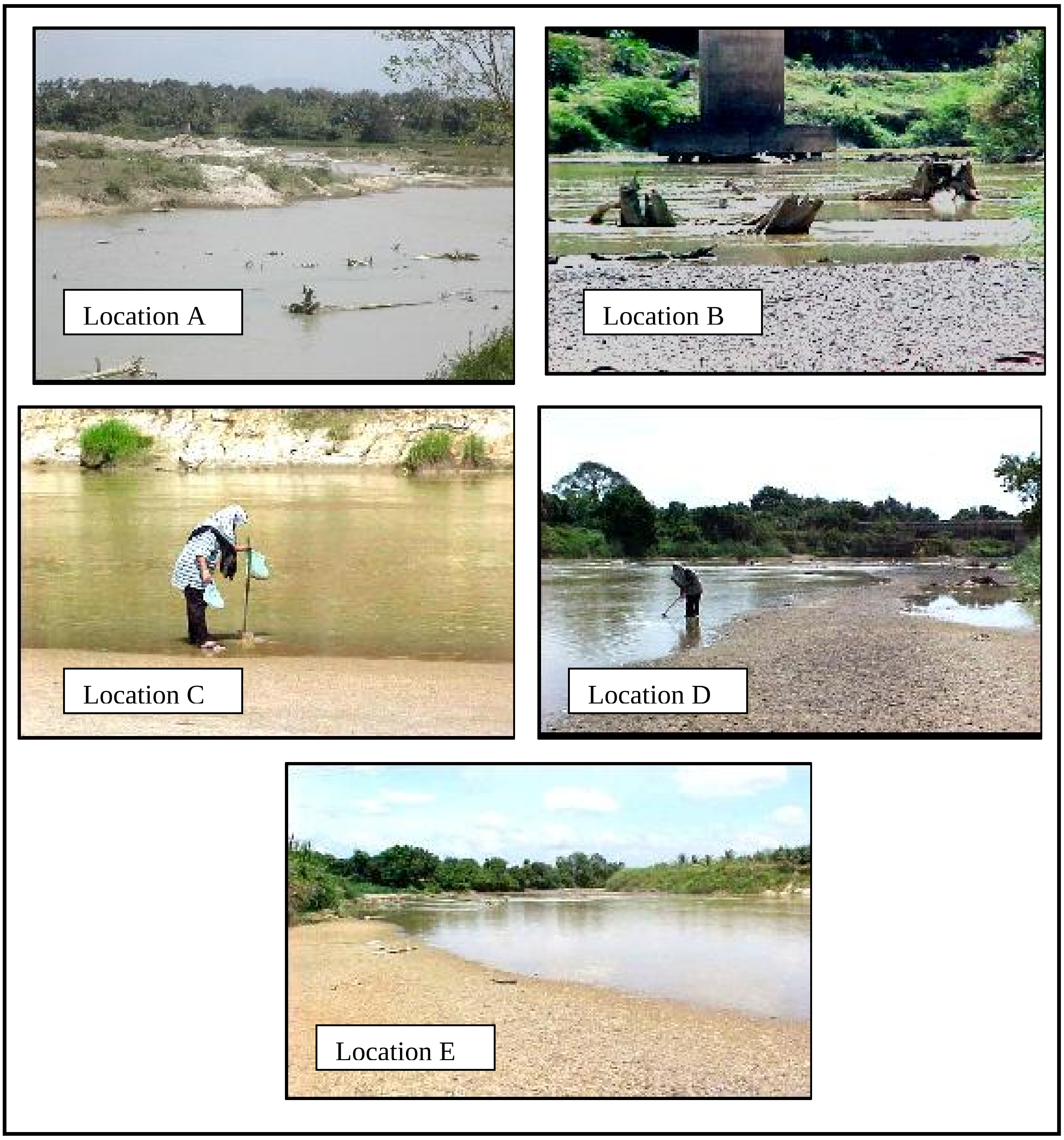


Figure 3.38 Bed Material Sampling Sites

Table 3.12 Bed Material Sizes

Date	Location	Sediment Size (mm)			
		Sample 1	Sample 2	Sample 3	Average
19/2/2001	A (US)	2.42	2.35	2.36	2.38
	B	1.21	1.23	1.19	1.21
	C	1.91	1.86	2.11	1.96
	D	2.61	2.45	2.57	2.54
	E (DS)	1.19	1.16	1.11	1.15
18/3/2001	A (US)	2.54	2.72	2.58	2.61
	B	1.15	1.2	0.96	1.10
	C	1.87	2.03	1.91	1.94
	D	2.72	2.56	2.53	2.60
	E (DS)	1.19	1.12	1.03	1.11
19/5/2001	A (US)	3.27	3.14	3.19	3.20
	B	0.92	0.73	0.84	0.83
	C	1.49	1.27	1.31	1.36
	D	3.52	3.61	3.07	3.40
	E (DS)	1.82	1.78	1.26	1.62
30/6/2001	A (US)	4.41	4.55	4.23	4.40
	B	1.23	1.31	1.09	1.21
	C	1.56	1.45	1.31	1.44
	D	3.81	3.81	3.93	3.85
	E (DS)	0.56	0.72	0.58	0.62
4/8/2001	A (US)	3.02	2.87	3.03	2.97
	B	1.03	1.25	1.4	1.23
	C	1.53	1.27	1.49	1.43
	D	3.13	3.14	3.17	3.15
	E (DS)	1.48	1.49	1.46	1.48

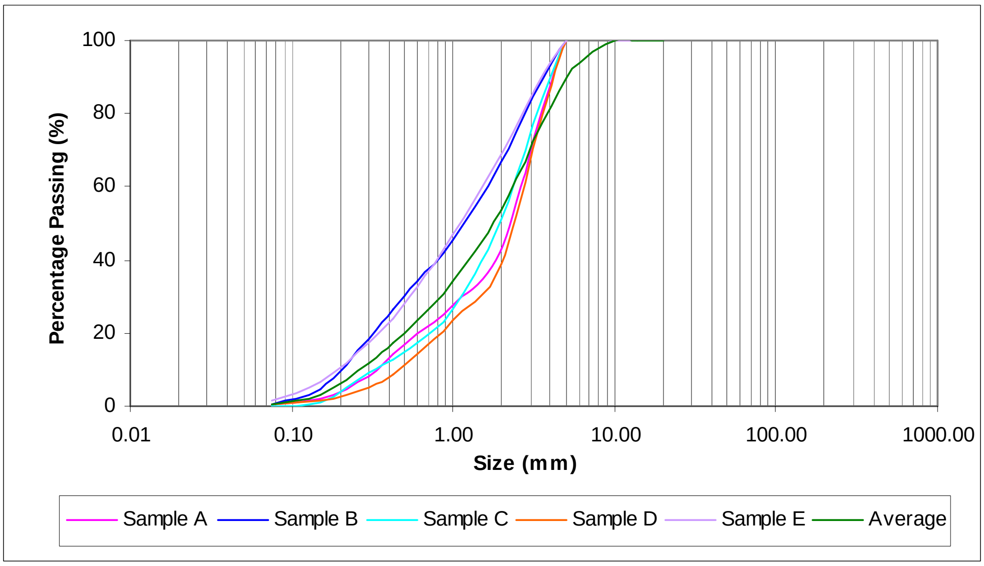


Figure 3.39 (a) Sediment Distribution Curves (19 February 2001)

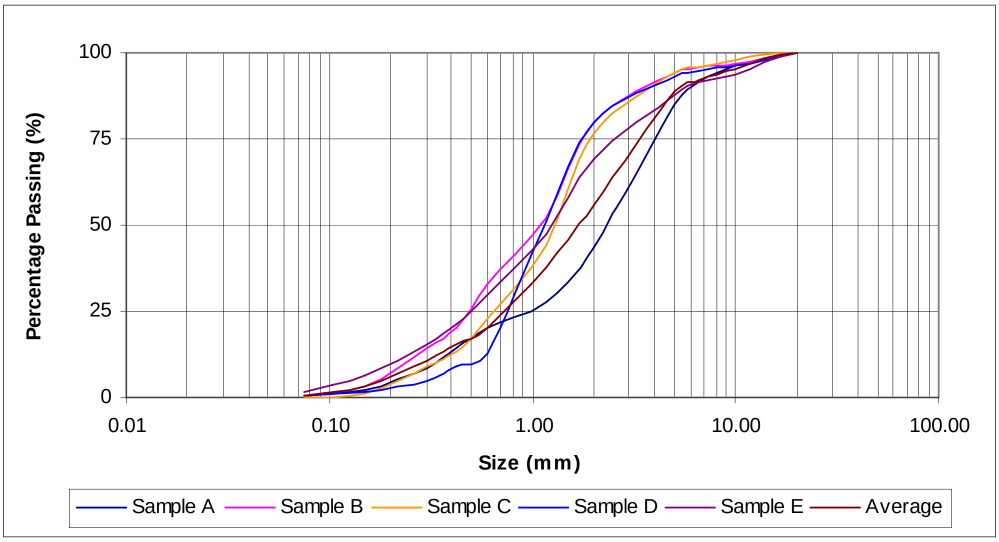


Figure 3.39 (b) Sediment Distribution Curves (18 March 2001)

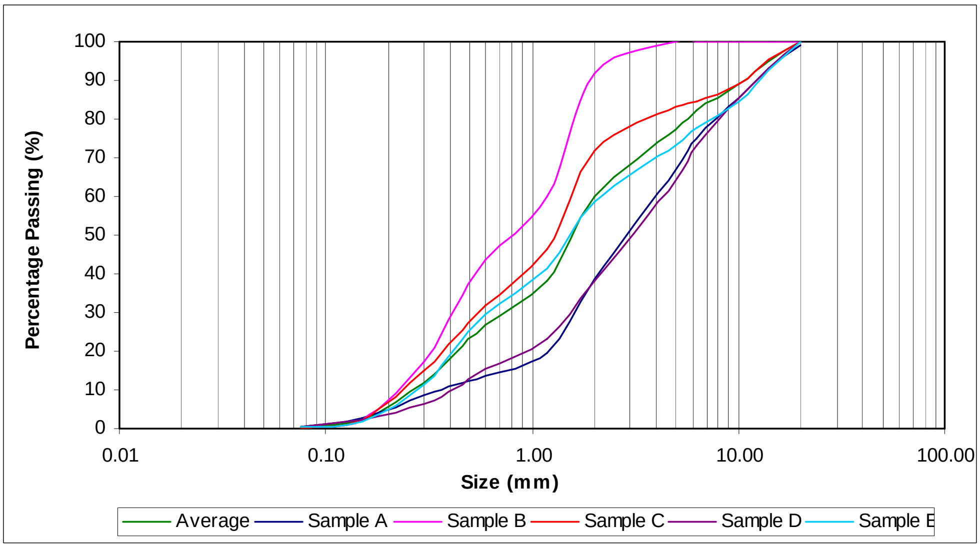


Figure 3.39 (c) Sediment Distribution Curves (19 May 2001)

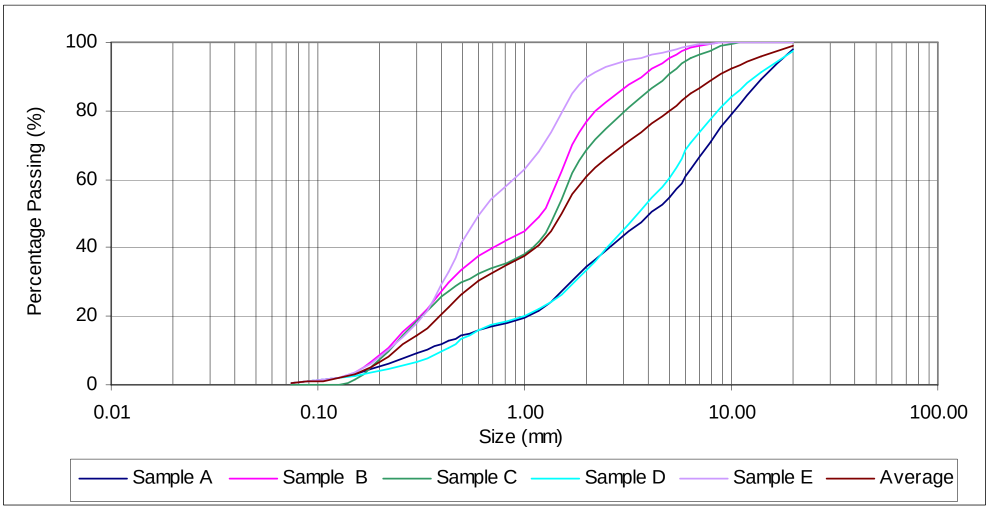


Figure 3.39 (d) Sediment Distribution Curves (30 June 2001)

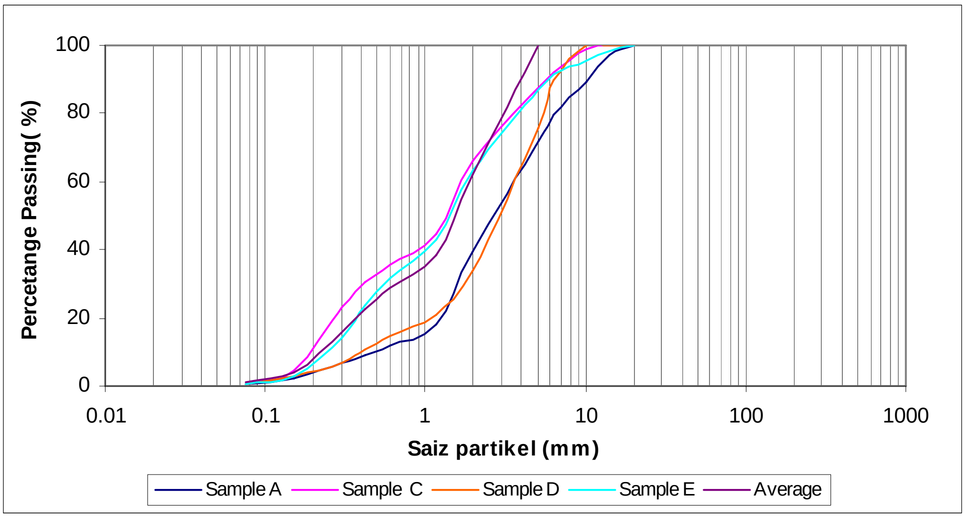


Figure 3.39 (e) Sediment Distribution Curves (4 August 2001)

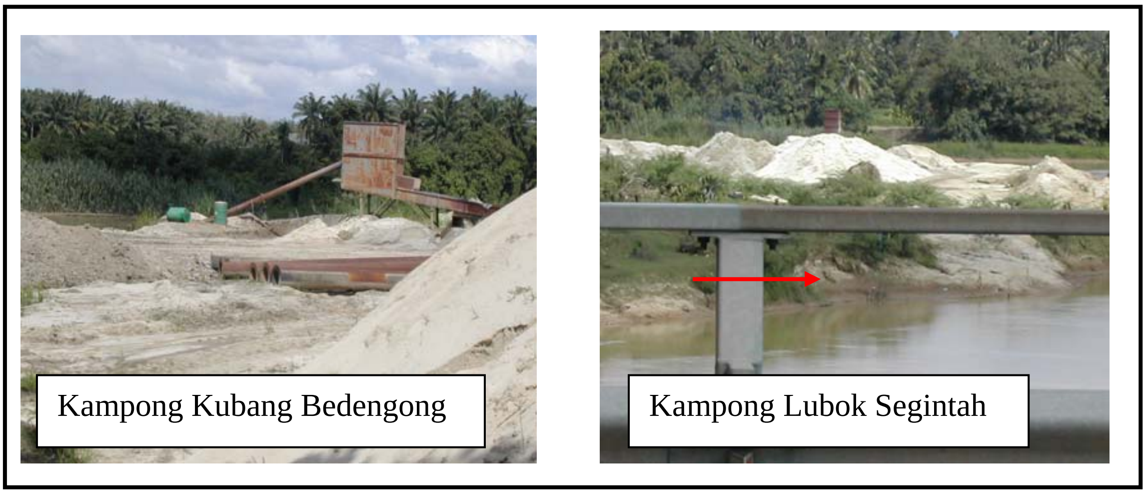


Figure 3.40 Sand Mining Sites (June 2001)

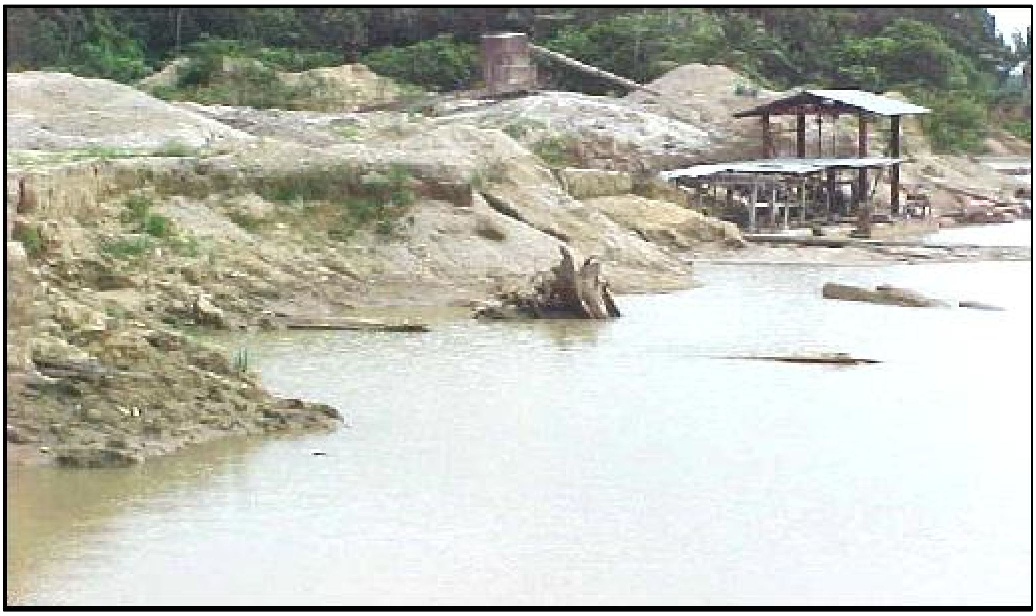


Figure 3.41 Sand Mining Pumping Activity

3.3 Jurutera Perunding Zaaba (JPZ, 2000)

A summary of the proposed alternatives and the recommendation for the lower reach of Sg. Muda is given herein.

3.3.1 Configuration of Flood Mitigation Alternatives

The river system (Sg. Muda), which is subjected to the flood mitigation works, were configured accordingly to perform the hydraulic analysis (modeling) to verify the suitability of design flood level obtained through the rainfall runoff modeling. The lower stretch of Sg. Muda (until 41 km from the river mouth) is severely affected by flood every year. The width of inundation area varies from 1 km to as high as 5 km. Due to the presence of developed areas; only six alternatives were studied for the stretch starting from the river mouth to 50 km upstream of Sg. Muda as mentioned in the Table 3.13:

Table 3.13 Flood Mitigation Alternatives for Lower Reaches of Sg. Muda

Alternative	Details	Recommended Alternative
0	To keep the river conditions same as per existing condition (e.g existing cross-section and gradient).	
1	Construction of bunds along both riverbanks maintaining the existing river section and gradient.	
2	To construct bunds at both sides of the river along the proposed river improvement works (river widening with new gradient).	✓
3	To construct bunds at both sides of the river at a distance of 50m from the river banks along with proposed river improvement works (river widening with new gradient).	
4	To construction bunds at both sides of the river along the proposed river improvement works (deepening and widening only at km 23 to 43) and Sg. Merbok Floodway.	
5	To construct bunds at both sides of the river along the proposed river improvement works (deepening and widening only at km 23 to 43) Sg. Merbok Floodway and Gubir dam.	

3.3.2 Selection of Flood Mitigation Alternatives

Figure 3.42 and Figure 3.43 shows the design flood profile under existing conditions and comparison of design flood profiles of Sg. Muda for 50-year ARI under six alternatives respectively. These alternatives were studied include the existing river condition, existing river with proposed bund, proposed river improvement works with bund and Sg. Merbok Floodway and proposed river improvement works with bund and Sg. Merbok Floodway including construction of Gubir Dam. Figure 3.44 shows that the design flood profile of different return period under proposed conditions. This figure show that water level under proposed condition is well below the existing condition.

From the six alternatives mentioned above, Alternative 2 was recommended by the consultant to implement for the flood mitigation purpose at Sg. Muda floodplains after consideration the risk, safety and consequences of any possible breach of the bunds during floods. The others alternatives were not selected because of several factors.

Construction of bund and maintaining the existing river conditions as mentioned in Alternative 1 will require high bund height where it increases the threat to the people living outside the bund. While Alternative 3 is the modified JICA proposed alternative, which considers uniform alignment of bund along the river at a distance of 50 m from both of the riverbanks. Figure 3.43 shows that the alternative 3 resulted in flood level higher than the Alternative 2, even though the proposed river cross sections are same for both alternatives. Alternative 4 and 5 will involves the higher cost in spite of the construction of the dam for Alternative 5 will create the water resources enhancement for the basin.

Figure 3.45 shows the simulated flood profiles for alternative 2 under 50-year and 100-year ARI with proposed bund levels along Sg. Muda. Although this alternative shall require some extra areas but it will result in optimum cost for construction of bund and minimum resettlement issues. The selection of the Alternative 2 that can solve the flood problem in Sg. Muda, several factors will be consider such as flood profiles, site conditions, sensitive issues and the selecting of optimum size of the proposed river sections.

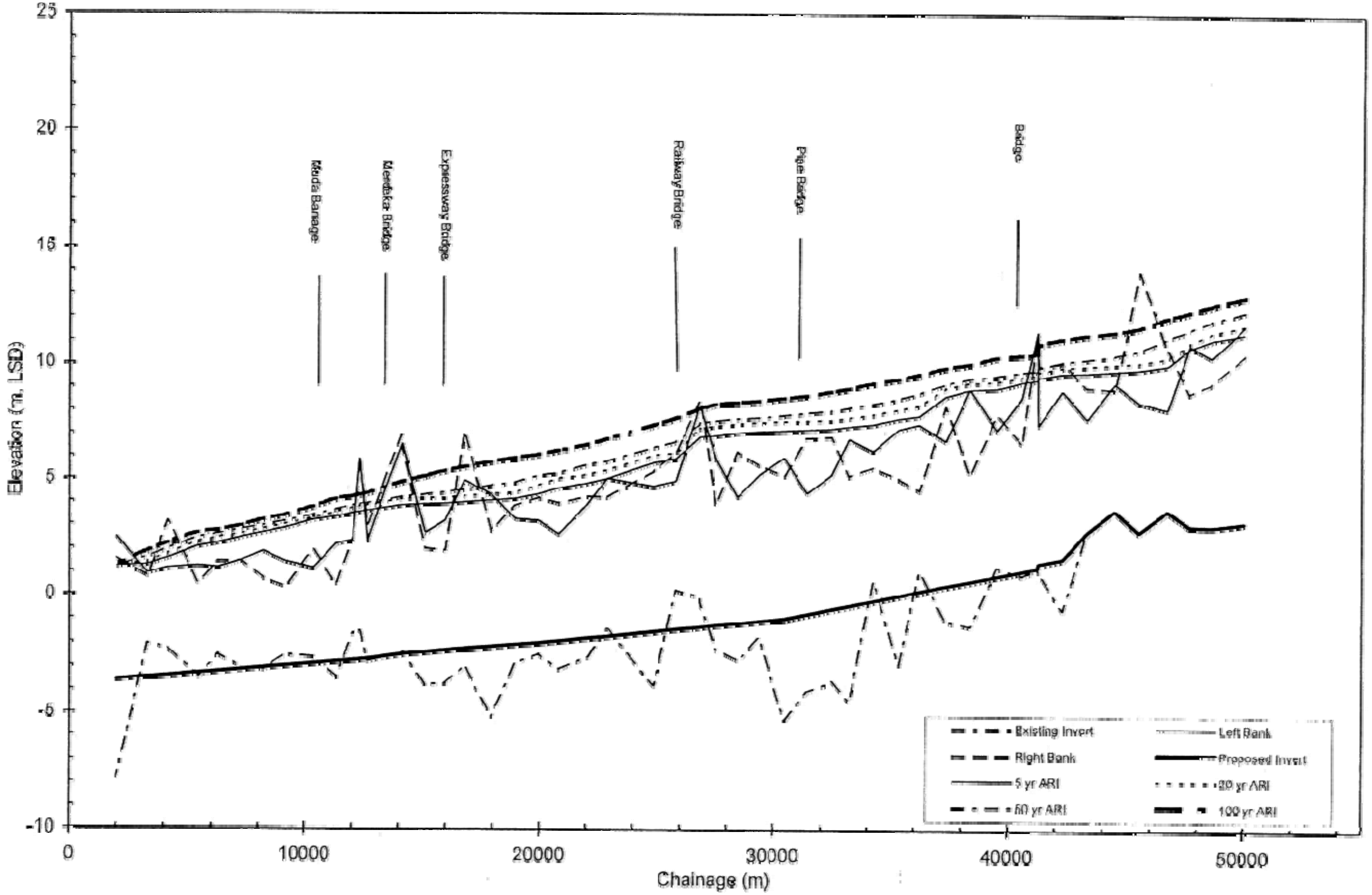


Figure 3.42 Design Flood Profiles of Different Return Period under Existing Condition for Sg. Muda

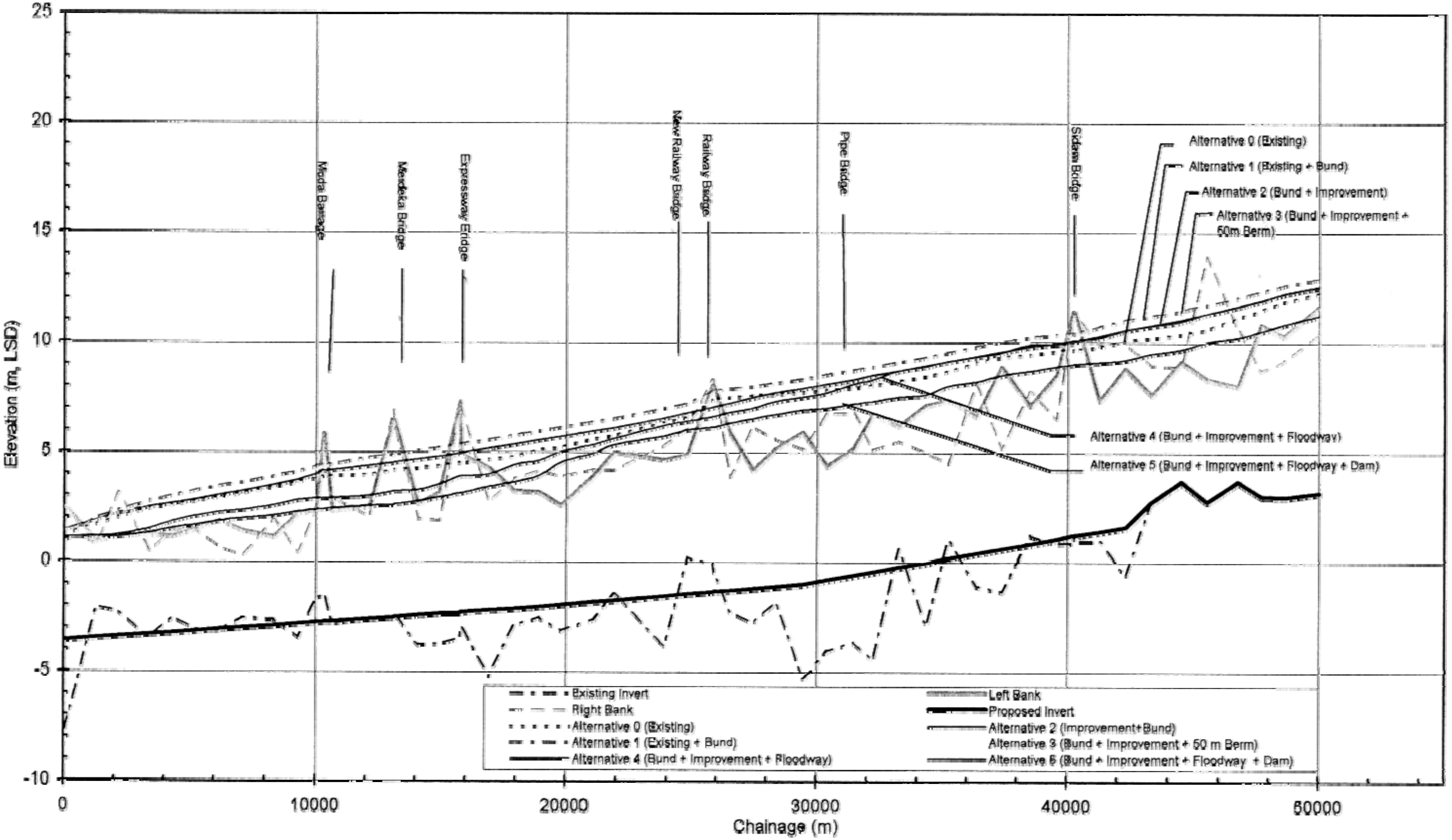


Figure 3.43 Comparison of Design Flood Profiles of Sg. Muda for 50-year ARI under Various Alternatives under Proposed Condition

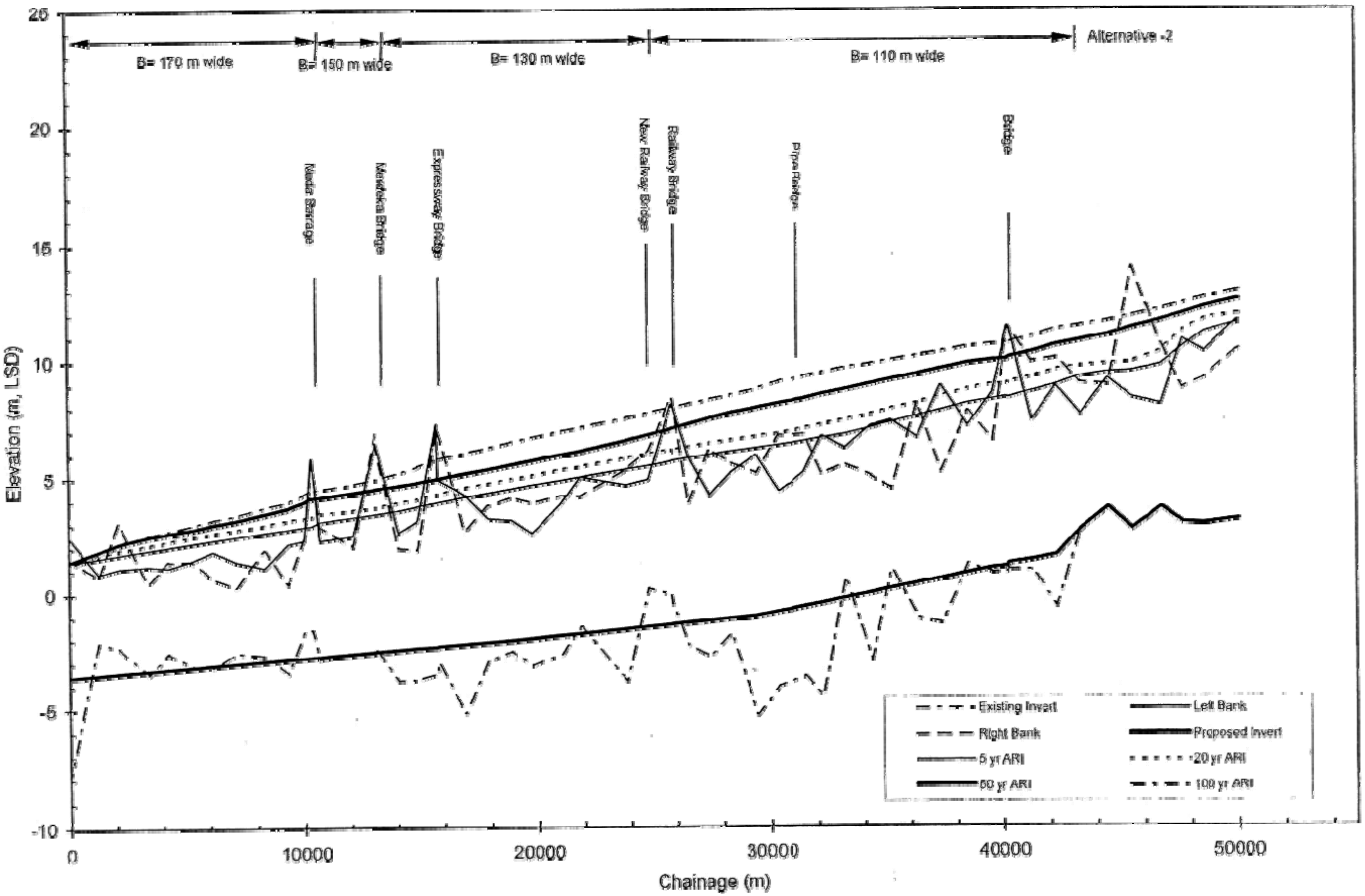


Figure 3.44 Design Flood Profiles of Different Return Period under Proposed Condition for Sg. Muda (Alternative 2)

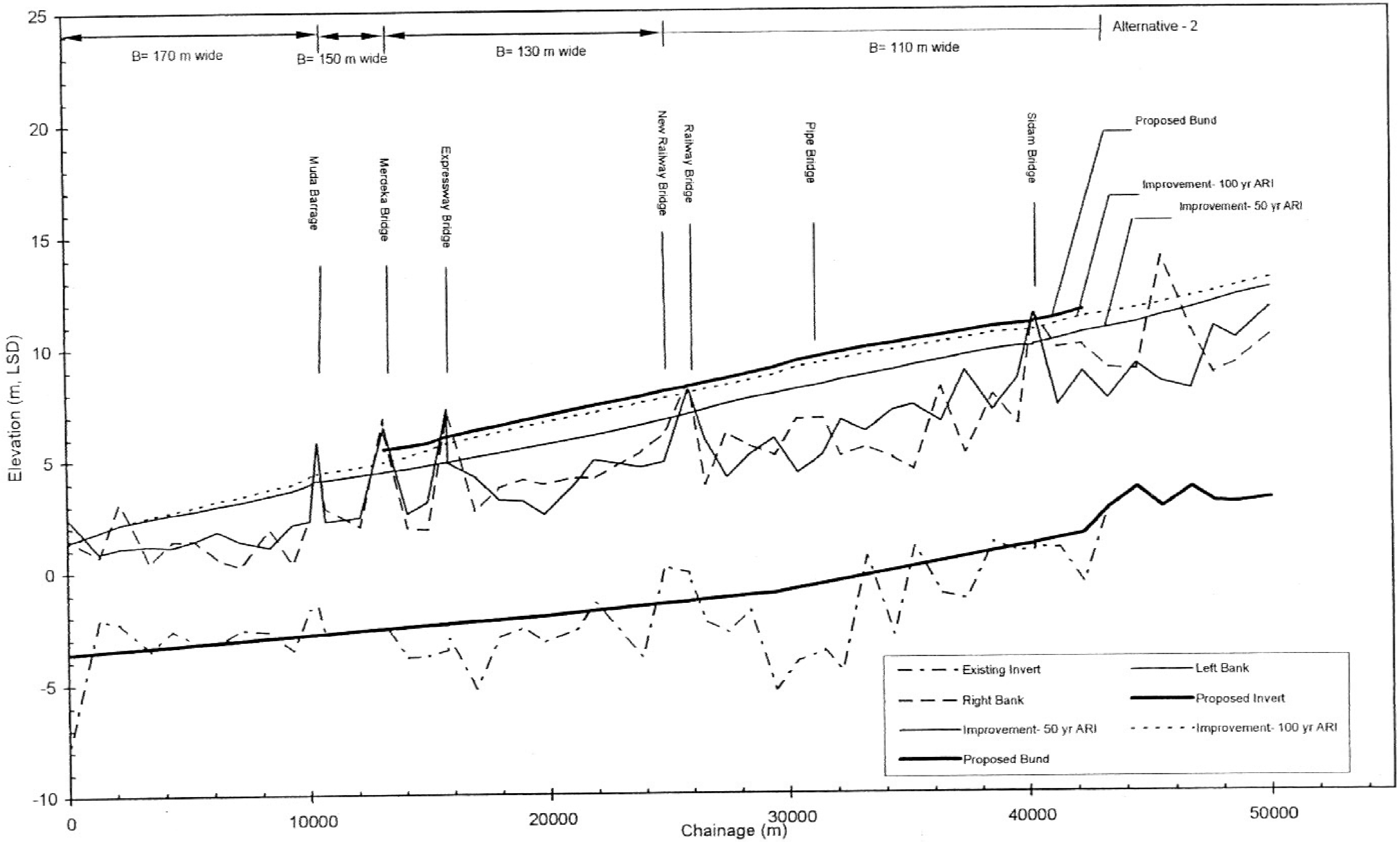


Figure 3.45 Simulated Flood Profiles for Alternative 2 under 50-year and 100-year ARI with Proposed Bund Levels along Sg. Muda.

Chapter 4

Hydrological Modelling

4.1 HEC-HMS Modelling

For the hydrologic modeling for the Sungai Muda catchment, the HEC-HMS model is used as a tool. The Sungai Muda catchment has been divided into four (4) subcatchments, that is, Nami catchment, Sik-Ketil catchment, Sedim catchment, and Sungai Muda downstream catchment. There are four (4) automatic rainfall stations, and two (2) discharge stations with observed discharge data. Figure 4.1 shows the subcatchment areas of Sungai Muda catchment.

4.1.1 Hydrological Data

All hydrological data and previous reports such as the Annual Flood Reports used in this study were provided by the Department of Irrigation and Drainage.

4.1.2 Rainfall

Four (4) automatic rainfall stations located inside the catchment area have been selected for this study. Other rainfall stations within catchment area are observed manually. These rainfall data were collected for the modeling works of Sg Muda catchment using HEC-HMS model. The inventory and locations of these rainfall stations are shown in the Table 4.1 and Figure 4.1 respectively.

Table 4.1 Inventory of Automatic Rainfall Stations

No.	Station Number	Station Name	State
1.	6108001	Komplek Rumah Muda	Kedah
2.	5806066	Jeniang Klinik	Kedah
3.	5808001	Batu 61 Jln. Baling	Kedah
4.	5507076	Batu 27 Jln. Baling	Kedah

4.1.3 Water Level and Streamflow

A total of six (6) streamflow gauging stations have been identified which are located in the study area. The stations are Jambatan Syed Omar, Nami, Lengkuas, Jeniang, Ladang Victoria and Kuala Pegang. The locations of these stations are shown in Figure 4.1. However, only two (2) streamflow gauging stations at Jambatan Syed Omar (5806066) and Ladang Victoria (5505412) were selected for this study.

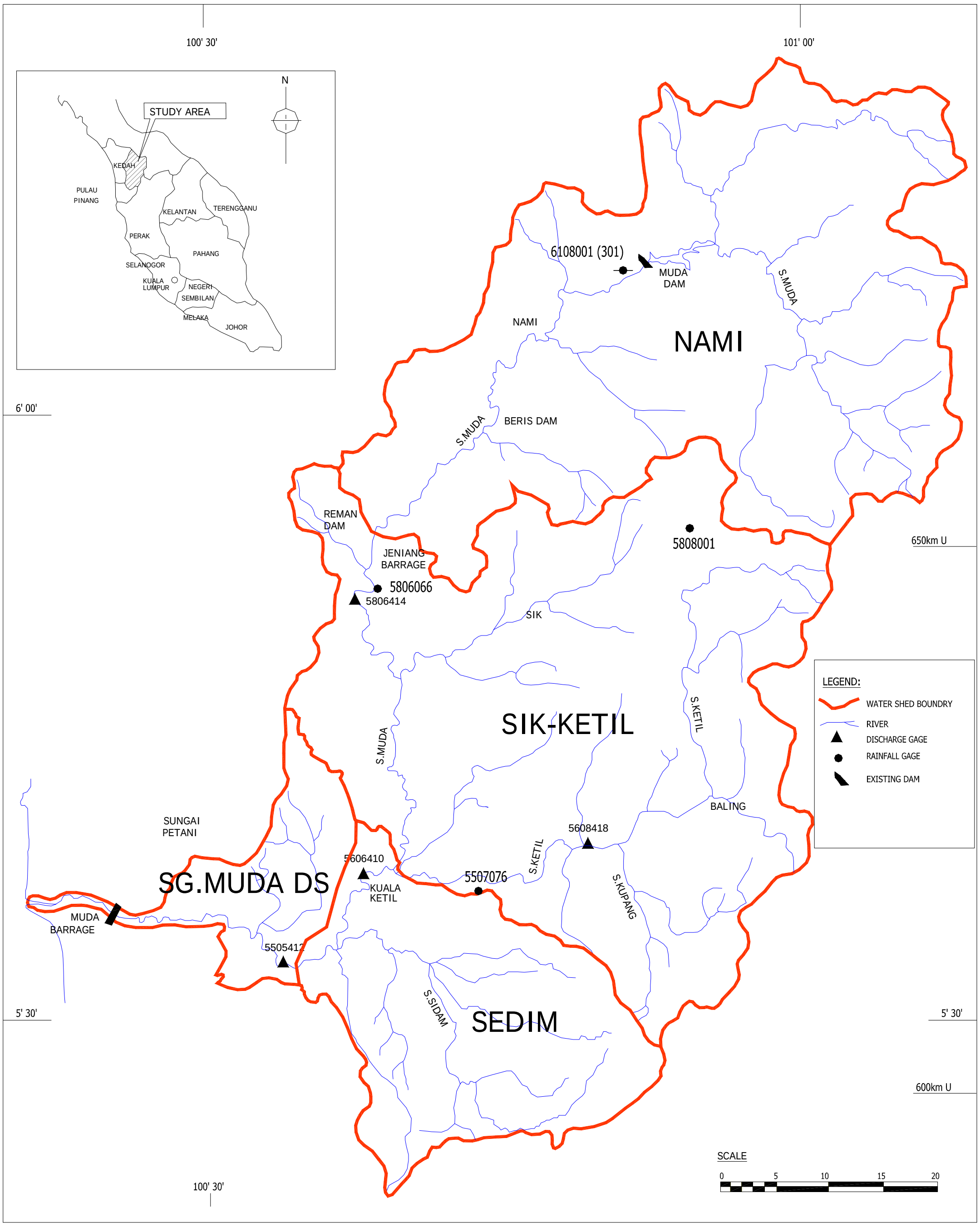


Figure 4.1 Locations of Rainfall Stations and Discharge Stations for Sg. Muda Catchment

4.1.4 Calibration and Validation

This model is calibrated and validated by using the October 2003 and November 1998 rainfall-runoff data respectively. The calibration and validation went through two processes, viz.:

- Calculation of the average rainfall throughout the catchment area by using the weighted Thiessen Polygon method.
- Determination of parameters as such as the losses, catchment routing (transform) and channel routing, and the baseflow discharge.

The weighted rainfall factors and the Thiessen Polygon method are depicted in Table 4.2 and Figure 4.2 respectively.

Table 4.2 Weighted Rainfall Factor

Catchment	Area (sq.km)	Weighted Rainfall Stations			
		6108001	5808001	5806066	5507076
Nami	1661	0.61	0.27	0.12	-
Sik-Ketil	1718	-	0.34	0.25	0.41
Sidam	616	-	-	-	1.00
Sg.Muda DS	215	-	-	0.07	0.93

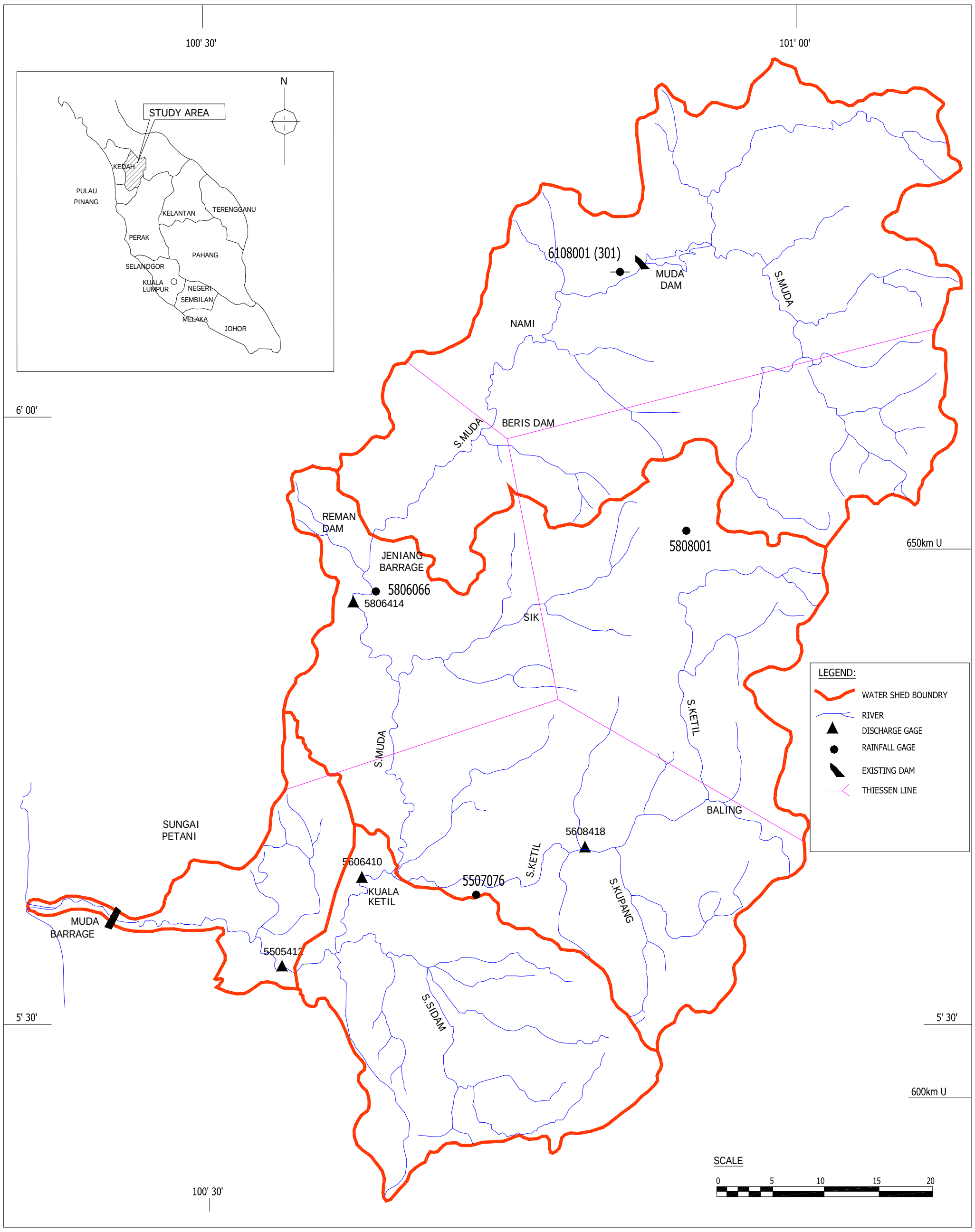


Figure 4.2 Thiessen Polygon Method

The configuration HEC-HMS for Sungai Muda model is depicted in Figure 4.3. There are seven (7) nodes used for the flows from every subcatchments and channels. The observed discharge data recorded at the node at Jambatan Syed Omar (station no.5606410) and Ladang Victoria (station no.5505412) were used in calibration and validation.

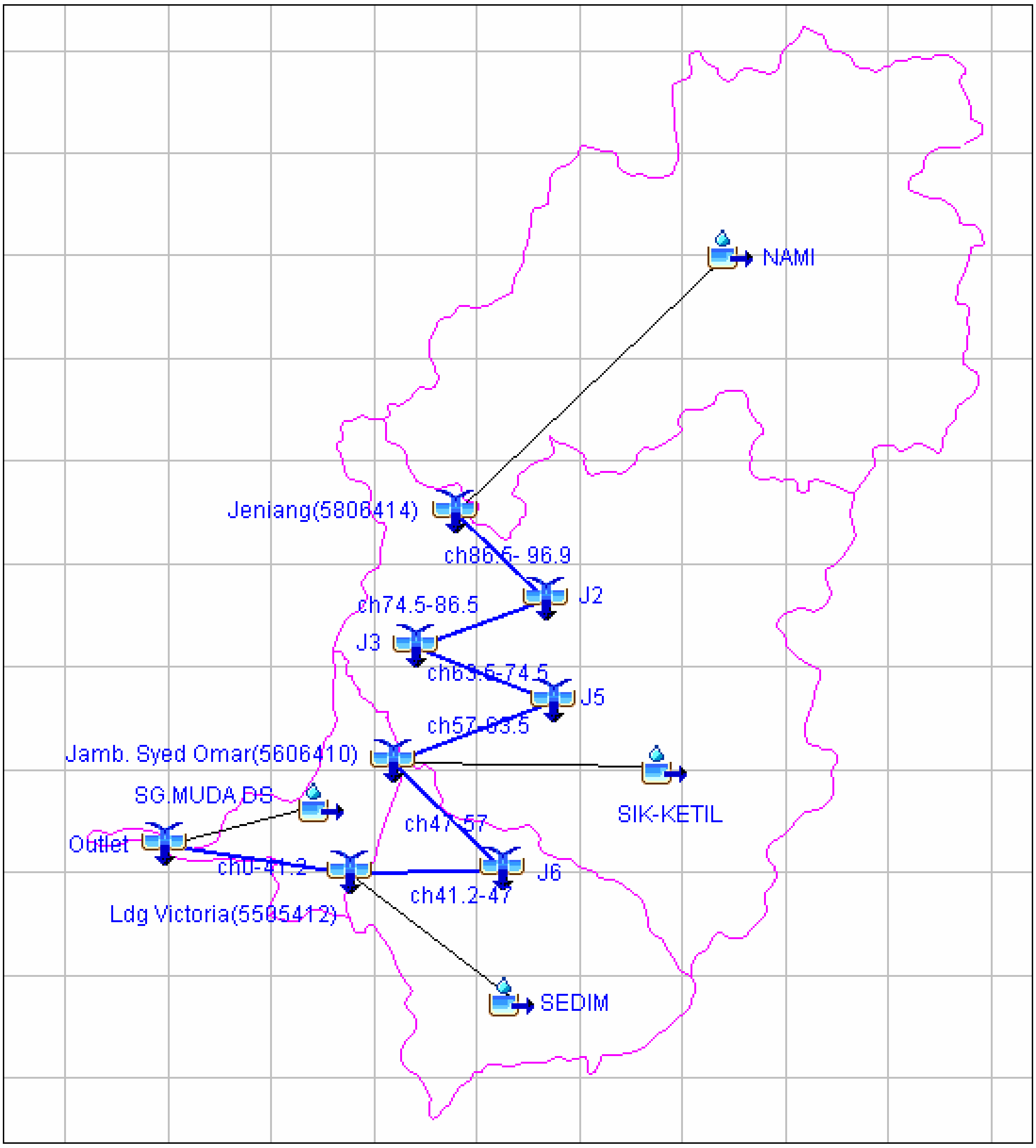


Figure 4.3 HEC-HMS Layout Model

There are seven (7) channel reaches included in this model; CH86.5-96.9, CH74.5-86.5, CH63.5-74.5, CH57-63.5, CH47-57, CH41.2-47, CH0-41.2. The Nami catchment is linked to the Jeniang station (no.5806414), the Sik-Ketil catchment is linked to the Jambatan Syed Omar station (no.5606410), and the Sedim catchment is linked to the Ladang Victoria station (no.5505412). Finally the channel (CH0-41.2) is linked to the outlet or the river mouth.

Calibration is a process to determine the properties or parameters which describe a system. Some parameters such as initial loss, constant loss rate, and storage coefficient are determined through calibration process, in this case the parameters are adjusted until the observed and simulated hydrograph are almost fitted well. Some parameters such as imperviousness percentage, time of concentration, baseflow, the kinematic wave parameters in channel routing (slope of channel, cross section of channel, manning number) are either obtained from available topographic maps or survey data. The time of concentration is calculated by using the Bransby William method and these values are similar to the values from the JPZ study. All channel geometry data are obtained from the survey data. The baseflow is calculated based on the average baseflow from a number of hydrograph records in each month in a calendar year. The calibrated parameters for the Sungai Muda catchment are shown in the Table 4.3. The channel parameters are shown in Table 4.4. The hourly interval rainfall event starts from 01 October 2003 (00:00 time) to 14 October 2003 (23:00 time) are used for the calibration.

Table 4.3 Calibrated Subcatchment Parameters

Parameter for Subcatchments	**NAMI**	**SIK-KETIL**	**SEDIM**	**SG.MUDA Downstream**
Losses (Exponential)				
Initial range (mm)	15	15	15	15
Initial coef. (mm/h)^(1-x)	1.65	1.85	1.75	1.75
Coef. Ratio	1.0	1.0	1.0	1.0
Exponent	0.22	0.22	0.22	0.22
Imperviousness (%)	10	10	10	10
Transform (Clark UH)				
Time of concentration (h)	48	36	38	10
Storage coefficient (h)	45	60	45	45
Baseflow (Constant Monthly)				
November baseflow (cms)	92	92	92	92

Table 4.4 Channel Parameters

Channel Parameters	**CH 86.5-96.9**	**CH 74.5-86.5**	**CH 63.5-74.5**	**CH 57-63.5**	**CH 47-57**	**CH 41.2-47**	**CH 0-41.2**
Length (km)	10.4	12	23	6.5	10	5.8	41.2
Slope	0.003	0.002	0.003	0.003	0.003	0.003	0.003
Manning’s n	0.025	0.025	0.025	0.025	0.025	0.025	0.025
Subreach	2	2	2	2	2	2	2
Shape	Trap.	Trap.	Trap.	Trap.	Trap.	Trap.	Trap.
Bottom width	22.59	50	52.46	97	29.12	90	112
Side slope (xH:1V)	2	2	2	2	2	5	2

The model calibration results are shown in Figure 4.4 and Figure 4.5 for the discharge station at Jambatan Syed Omar (Station no.5606410) and Ladang Victoria (5505412), respectively. Figure 4.6 depicts the simulated hydrograph at the catchment outlet.

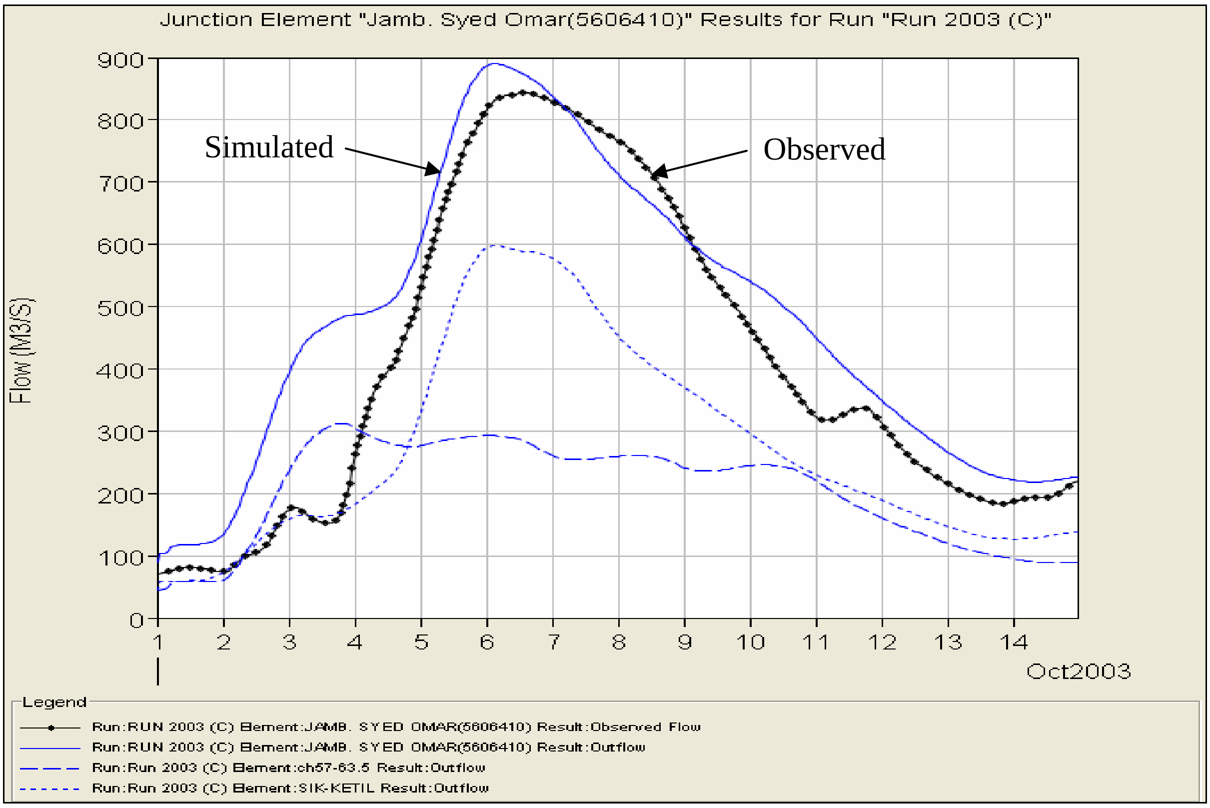


Figure 4.4 Runoff Hydrograph at Jambatan Syed Omar Discharge Station (Calibration)

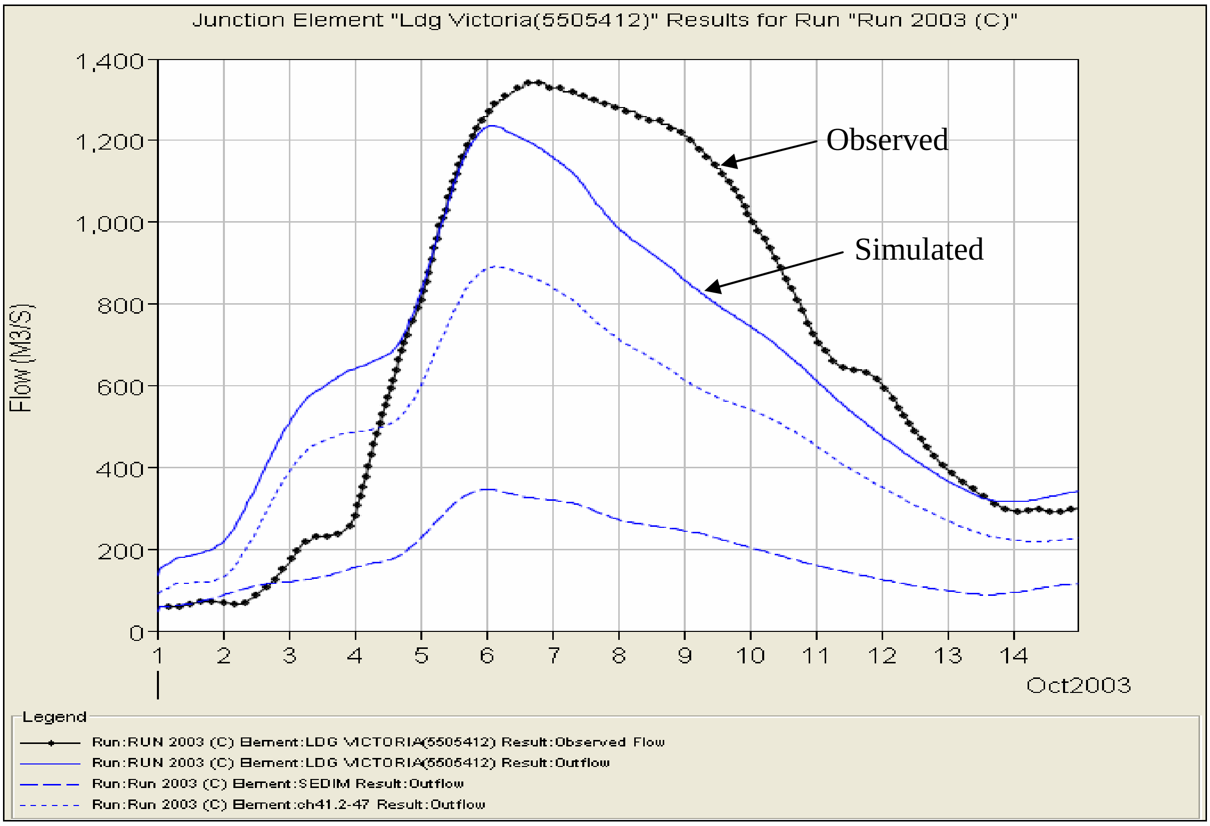


Figure 4.5 Runoff Hydrograph at Ladang Victoria Discharge Station (Calibration)

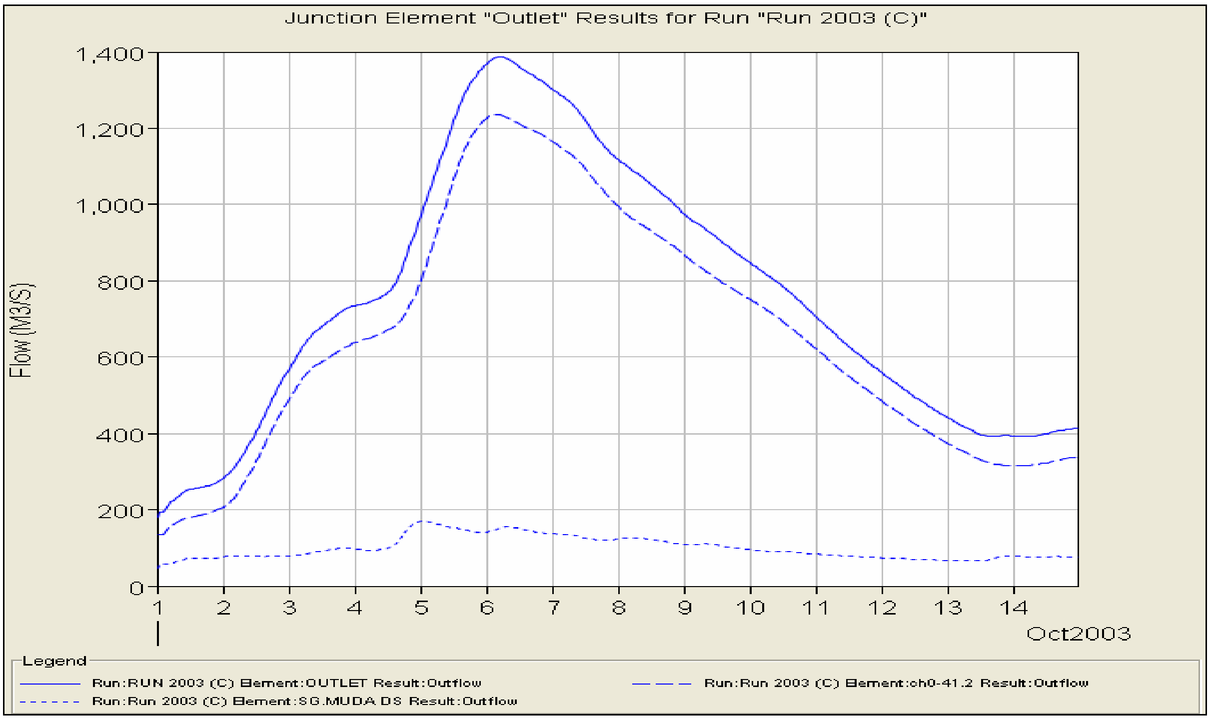


Figure 4.6 Runoff Hydrograph at the Catchment Outlet (Calibration)

The calibrated model parameters are validated by using the hourly interval event rainfall starts from 14 November 1998 (00:00 time) to 26 November 1998 (23:00 time). The parameters are shown in Table 4.3 and 4.4. The validation results are shown in Figure 4.7, 4.8 and 4.9 for the discharge stations at Jambatan Syed Omar, Ladang Victoria and the catchment outlet respectively.

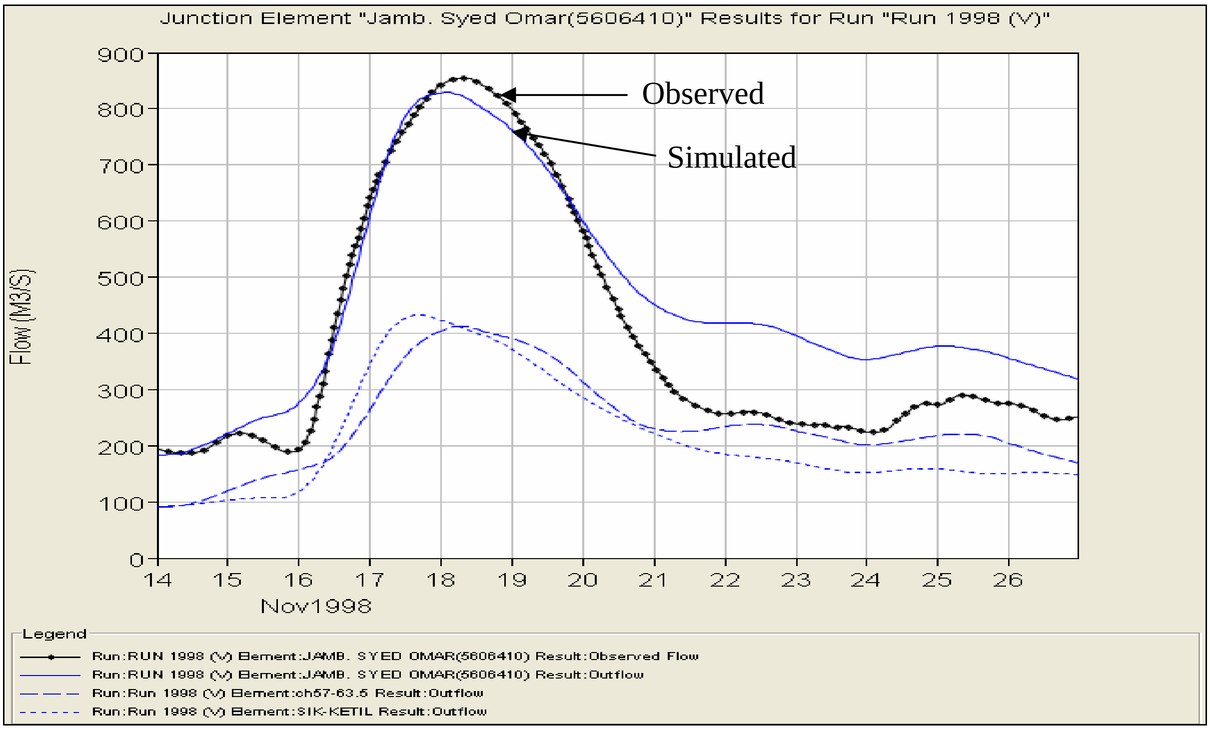


Figure 4.7 Runoff Hydrograph at Jambatan Syed Omar Discharge Station (Validation)

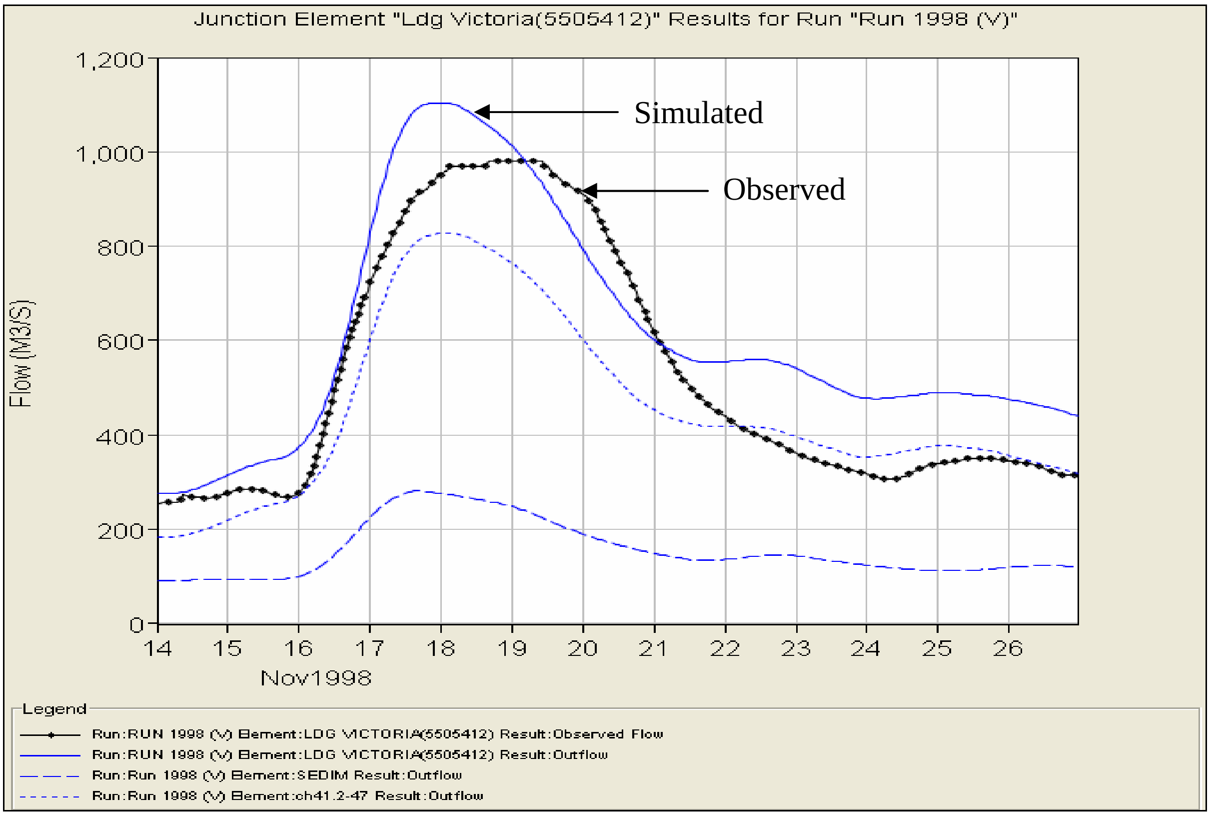


Figure 4.8 Runoff Hydrograph at Ladang Victoria Discharge Station (Validation)

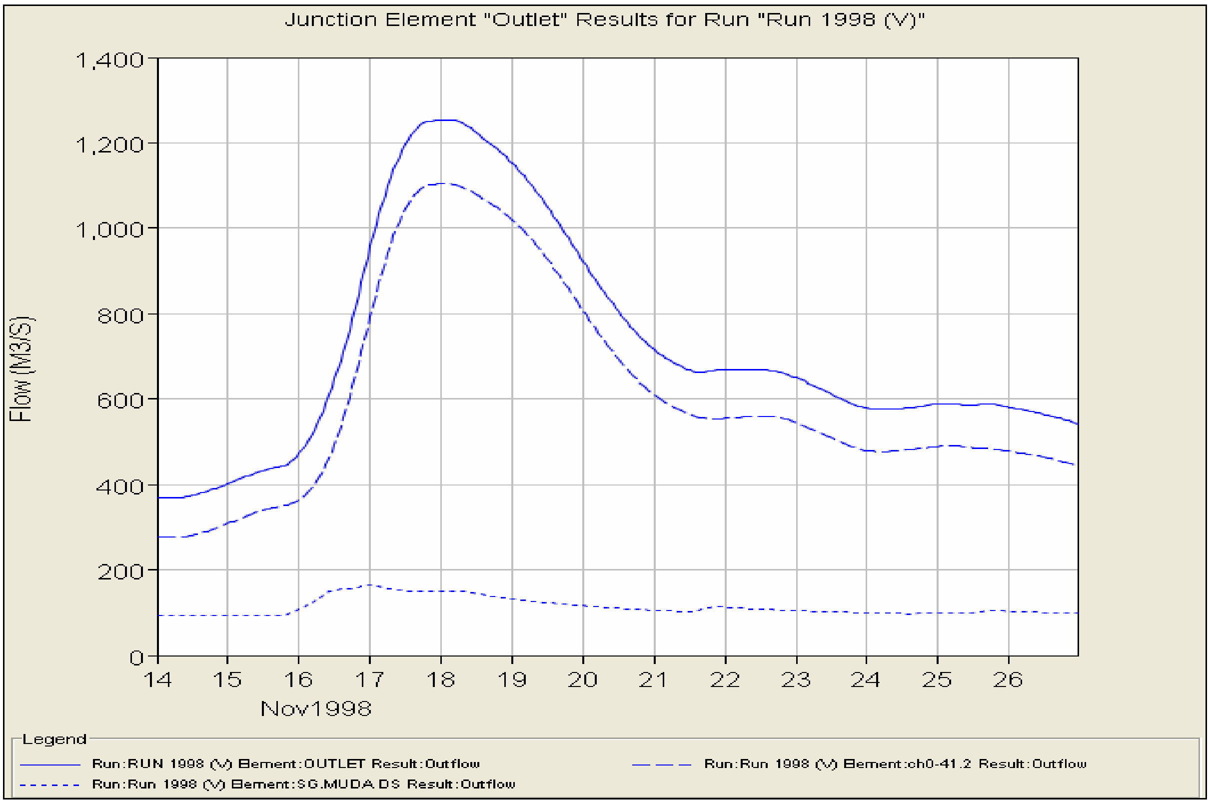


Figure 4.9 Runoff Hydrograph at the Catchment Outlet (Validation)

A larger level of uncertainty was noticeable in the calibration and validation of these results. Indeed, the calibration and validation results are in very good agreement with the 2003 and 1988 observations at Syed Omar, there are several hundred cumecs of difference between the calibration and validation results obtained by the same model when applied at Ladang Victoria. The reason for these discrepancies is not obvious, but the analysis is based on only four rain gauges and this seems to be a rather limited number to represent the spatial variability of rainfall on this relatively large watershed. Also, two important tributaries in Sg Sedim and Karangan bring surface runoff from relatively steep mountainous region in the southern part of the watershed. The 2003 flood should serve as the design discharge for the bund height plus freeboard.

4.1.5 Design Flood Hydrograph

The design flood hydrograph was estimated by the HEC-HMS model on the basis of the design rainfall from the isoyethal map of 50-year and 100-year, which has been produced by the study conducted by JPZ (2000).

The hourly temporal pattern distribution was calculated according to the Hydrological Procedure no.1 (HP.1) for the 75 hours rainfall duration pattern. The three-day rainfall precipitations of 260 mm (Jeniang), 300 mm (Jambatan Syed Omar) and 350 mm (Ladang Victoria) were used to determine 50-year and 100-year peak discharges (Table 4.5). These value of rainfall data are similar to the ones used by JPZ (2000).

There are three reference points within the Sungai Muda catchment representing the subcatchment average design rainfall, they are, Jeniang Gage Station (for Nami catchment), Jambatan Syed Omar Gage Station (for Sik-Ketil catchment), and Ladang Victoria Gage Station (for Sedim catchment). The 50-year and 100-year rainfall temporal pattern distributions for the catchments are shown in Figure 4.10 and 4.11 respectively, while the 50-year and 100-year design hydrograph for each subcatchment outlet are shown in Figure 4.12.

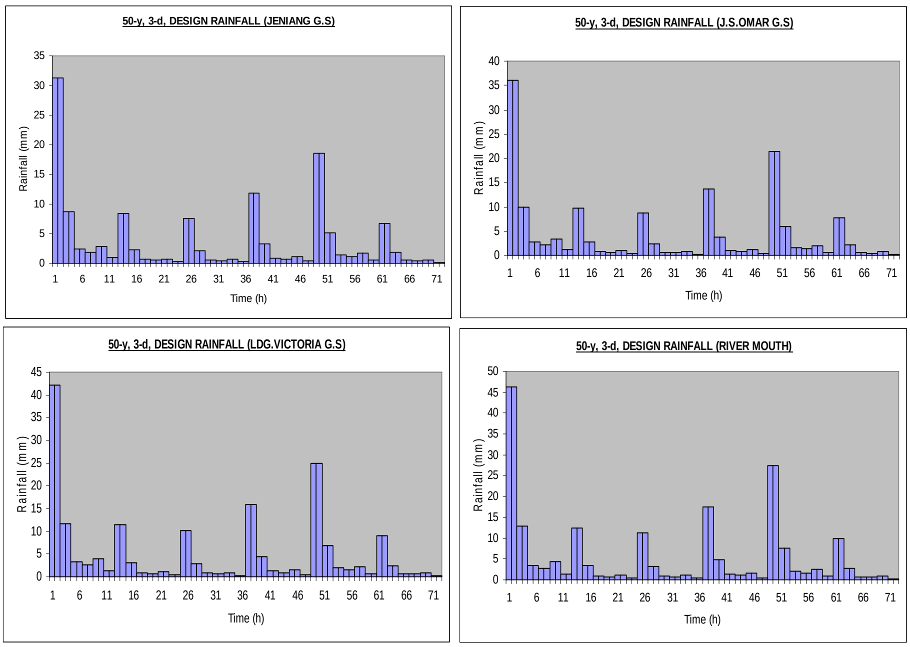


Figure 4.10: The 50-year Design Rainfall

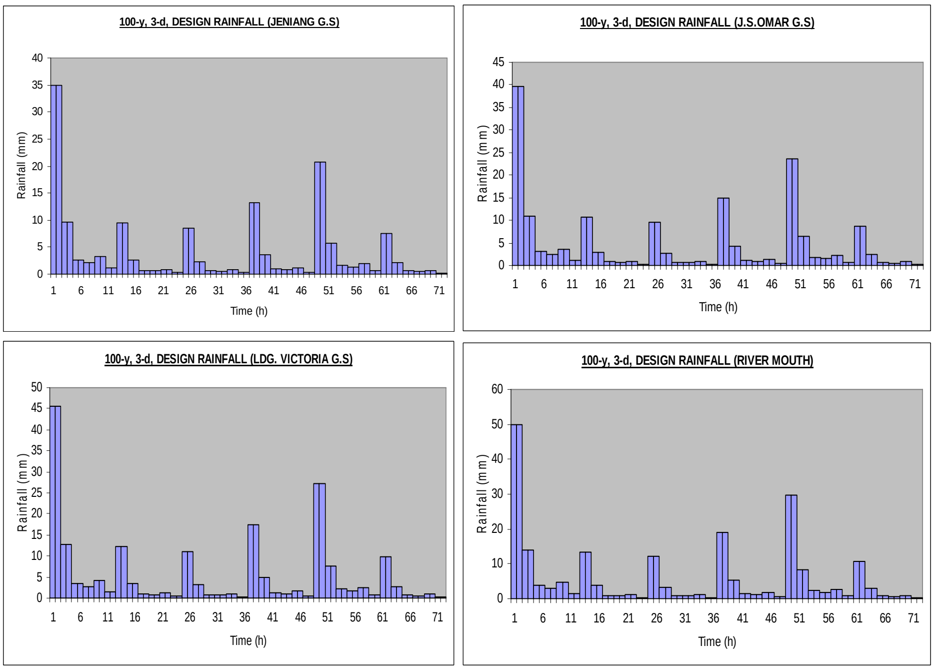


Figure 4.11: The 100-year Design Rainfall

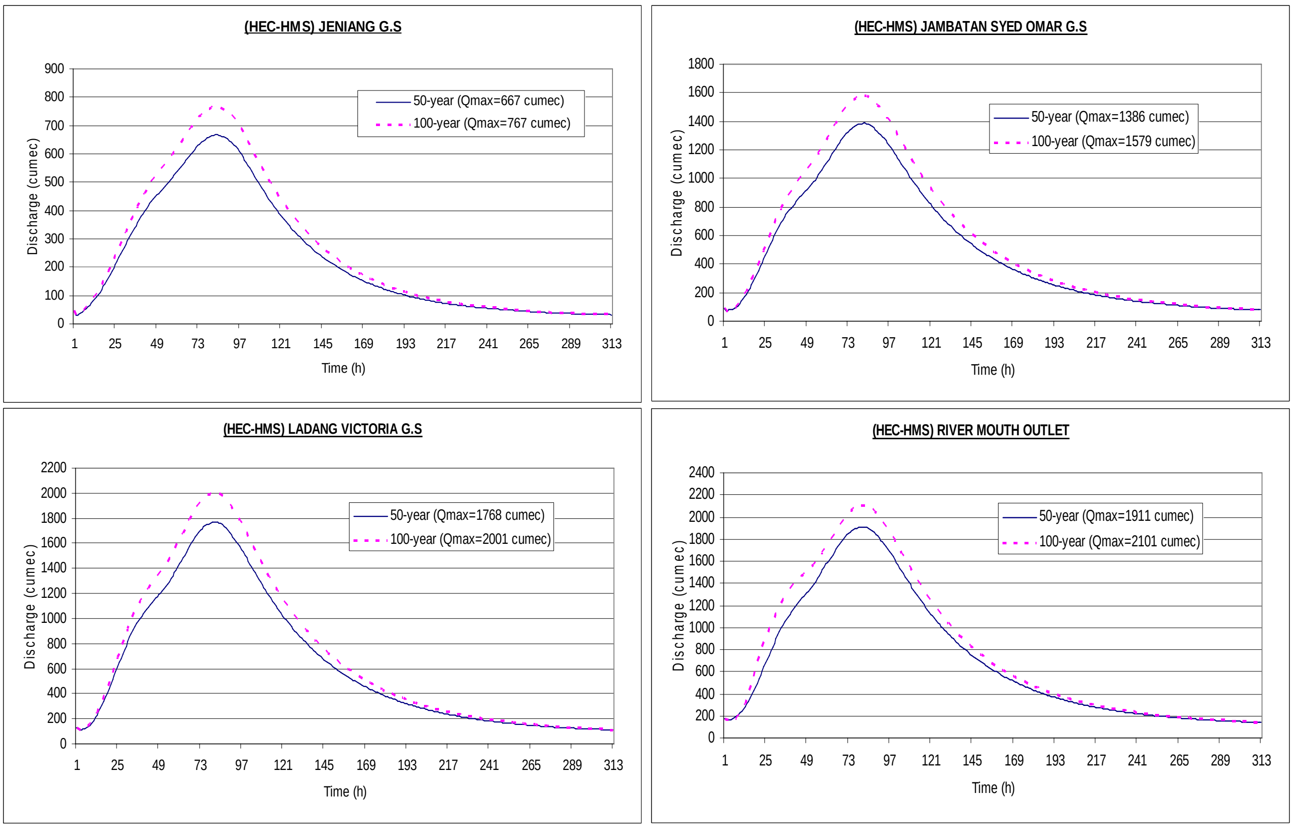


Figure 4.2: The 50-year and 100-year Design Hydrographs (HEC-HMS)

Table 4.5 Design Flood Hydrograph Comparison

REF. LOCATION	RIVER'S NAME	AREA (Sq.km)	MAR (mm)	Tc (h)	RAINFALL (mm)		DESIGN FLOOD HYDROGRAPH (cumec)												OBSERVED HISTORICAL FLOOD 2003
							JICA		NWRS		RAFTS-XP		HP-4		HP-11		HEC-HMS		
					50-yr	100-yr	50-yr	100-yr	50-yr	100-yr	50-yr	100-yr	50-yr	100-yr	50-yr	100-yr	50-yr	100-yr	(cumec)
Jeniang G.S	Sg.Muda	1740	2300	48	**260**	**290**	986	1118	1125	1397	1527	1858	595	660	1109	1286	667	767	-
Jambatan Syed Omar G.S	Sg.Muda	3330	2300	72	**300**	**330**	1275	1403	1890	2348	1936	2396	994	1102	1951	2114	1386	1579	831
Ladang Victoria G.S	Sg.Muda	4010	2300	84	**350**	**380**	1338	1477	2180	2709	1815	2130	1151	1276	2120	2358	1768	2000	1340
River Mouth (Outlet)	Sg.Muda	4210	2325	96	**385**	**415**	-	-	2274	2825	2030	2510	1199	1330	2028	2170	1910	2100	-

When using the same high rainfall precipitation as JPZ (2000), the HEC-HMS results are very consistent with JPZ's design hydrographs (Figure 4.13). However, the three-day rainfall precipitation of 260 - 350 mm used to determine a 50 year peak discharge of 1,815 cumecs is viewed as excessively large. The results of these rainfall-runoff models are highly variable and less reliable than the measured flood discharges at Ladang Victoria. It is concluded that the 50-year design hydrograph with peak discharge of 1,815 cumecs is excessively large. The value of 2003 peak discharge of 1,340 cumecs should be used for the design. The design discharge reduction by 25% should results in significant cost savings for the FCRP of Sg Muda.

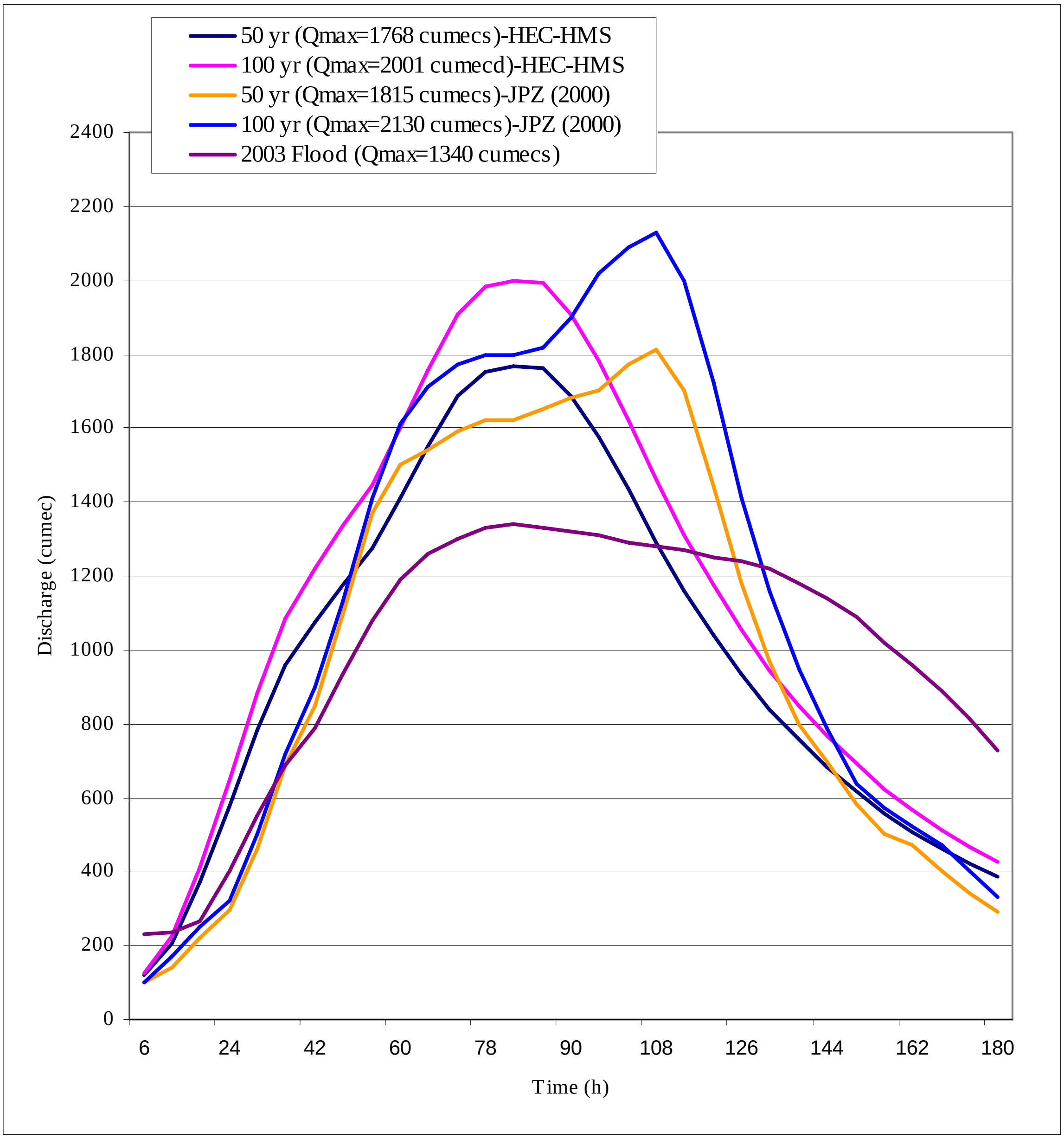


Figure 4.13 Comparison of Design and Observed Hydrograph

4.2 HEC-RAS Modelling

4.2.1 Introduction

The Hydrologic Engineering Centers River Analysis System (HEC-RAS) is an integrated system of software designed to perform one-dimensional hydraulic calculations for a full network of natural and constructed channels and provide input and output information in tabular and graphical formats. This system is capable of performing Steady and Unsteady Flow water surface profile calculations.

The main objective of the hydraulic analysis of the existing river system in the study area is to provide information on the variations of river water levels, discharges, and velocities during flood events. The HEC-RAS Model for this study generates the water surface elevation based on the existing cross section from CH 0 to CH 41.2 of the Sg. Muda. Unsteady flow analysis was used in the HEC-RAS modeling for the chosen hydrographs.

4.2.2 Geometry Data

In order to run the HEC-RAS model, the geometry data consists of existing cross-sections between river mouth (CH 0) and Ladang Victoria (CH 41.2) at the upstream of Sg. Muda. This data, consisting of lateral distance and elevations were obtained from field surveys by Jurutera Perunding Zaaba (JPZ). The plan view of the Sg. Muda in HEC-RAS model is shown in Figure 4.14.

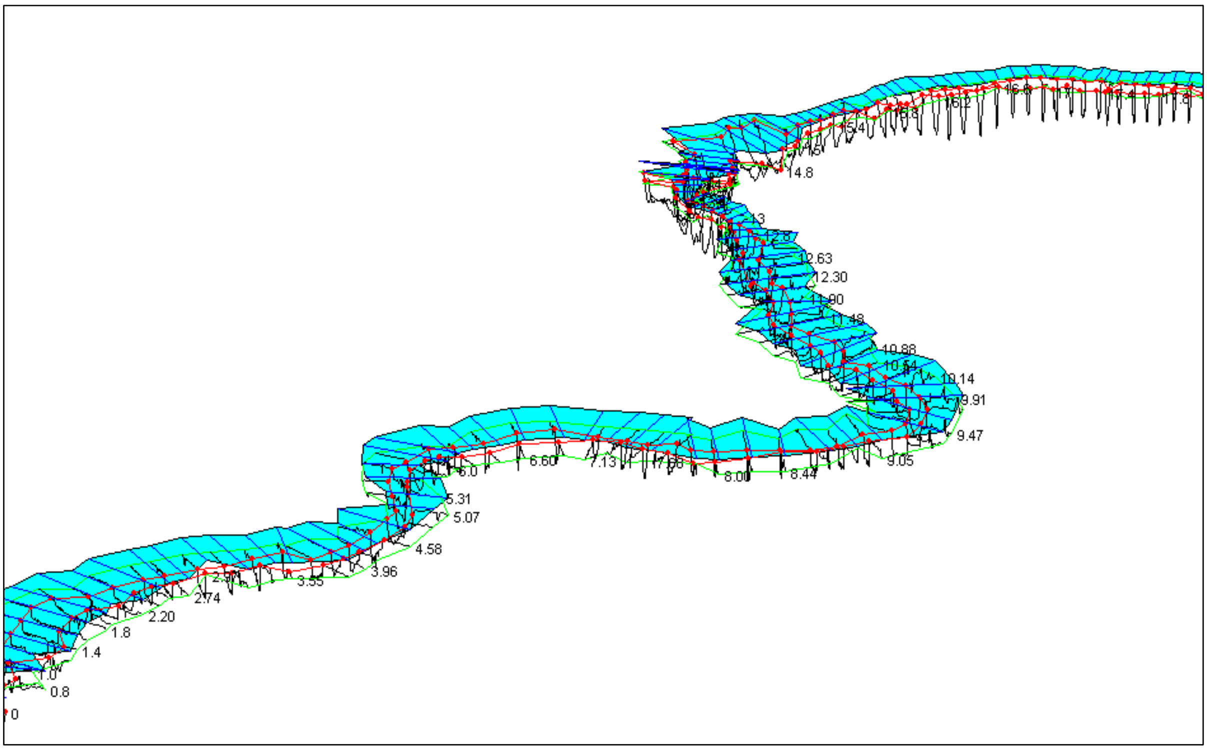


Figure 4.14 Plan View of Sg. Muda in HEC-RAS Model

4.2.3 Stage Hydrograph Data

The stage hydrograph data for October 2003 was obtained using the tidal level data at the Kedah Pier as shown in Figure 4.15. This stage hydrograph is used as a downstream boundary condition at the river mouth (Ch 0).

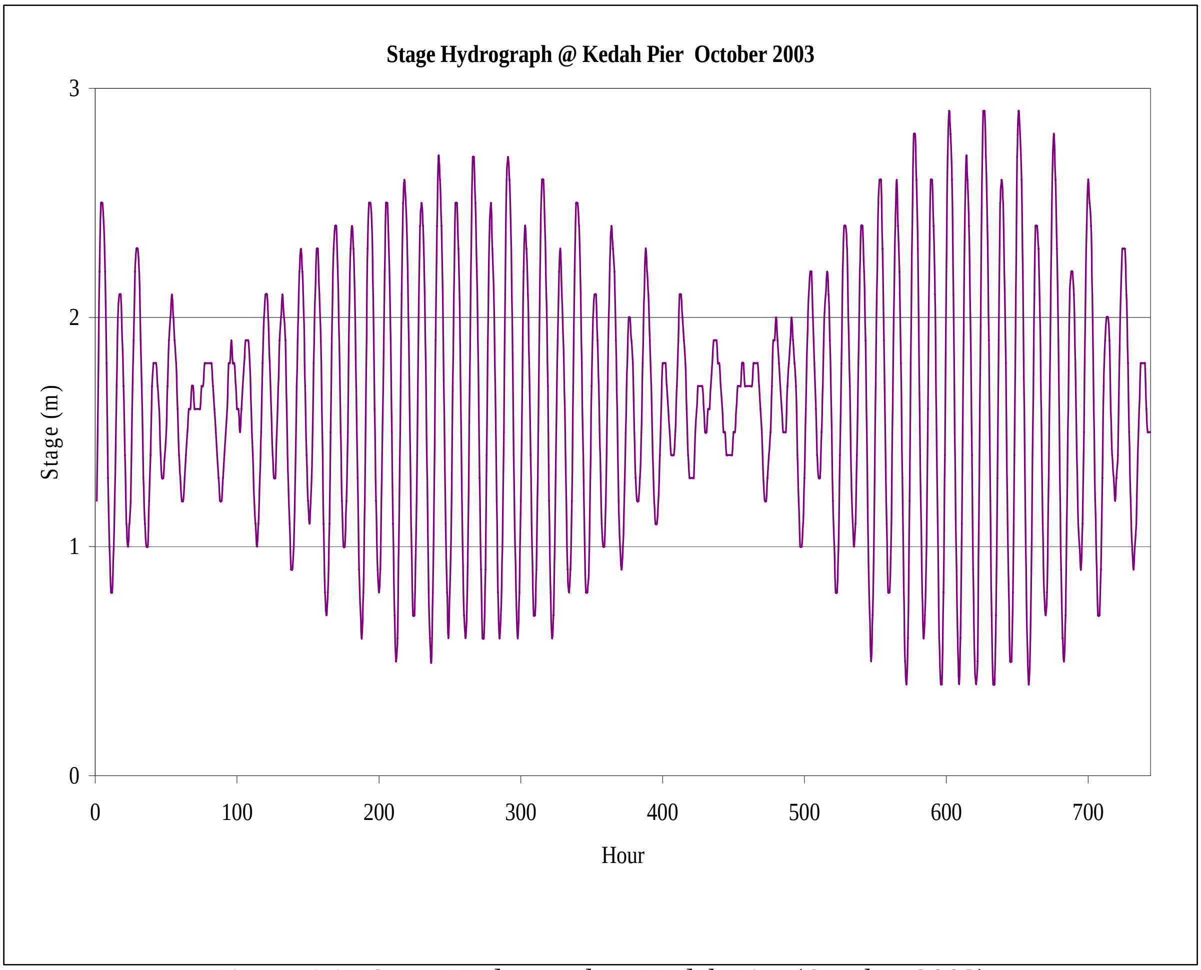


Figure 4.15 Stage Hydrograph at Kedah Pier (October 2003)

4.2.4 Hydrograph

The input hydrograph at Ladang Victoria from 2nd October to 19th October 2003 (Figure 4.16) was used to simulate the 2003 flood that occurred from 3rd to 13th October 2003. The peak flood took place on the 6th October 2003 at 4 p.m. (Figure 4.16) with a value of 1340 m^3/s. For comparison purposes, the proposed bund levels by JPZ (2000) are also plotted.

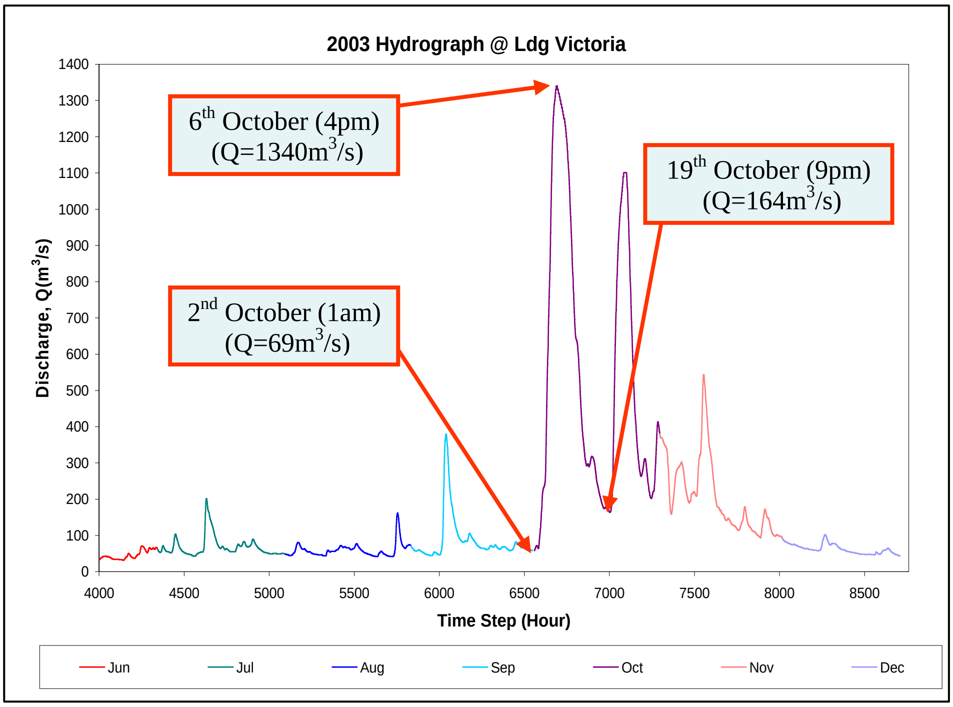


Figure 4.16 Input Hydrograph @ Ladang Victoria for 2003 Flood

4.2.5 Calibration

An example of the predicted water level by the HEC-RAS model is given in Figure 4.18. Three values of Manning's n for the main channel (0.025, 0.030 and 0.035) were used to simulate the 2003 flood level. A value of 0.05 was used for the floodplains. Water level records at three locations (Ladang Victoria, Pinang Tunggal, Bumbong Lima and River Mouth) were used to check the predicted water level by the HEC-RAS model. The results are shown in Table 4.6.

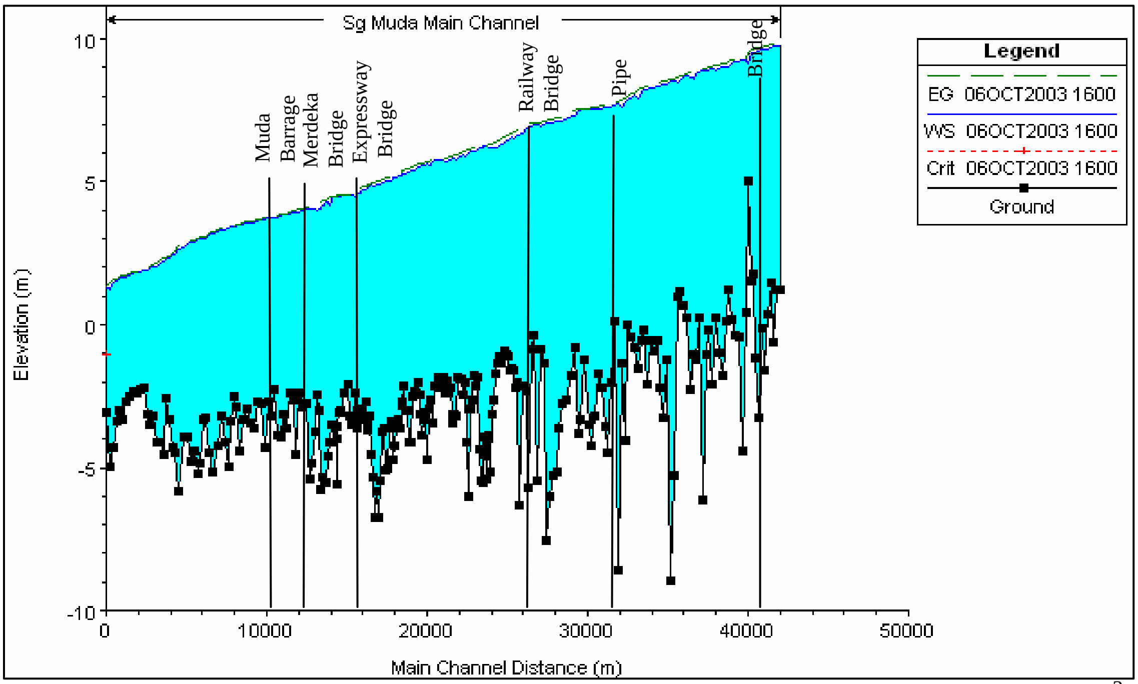
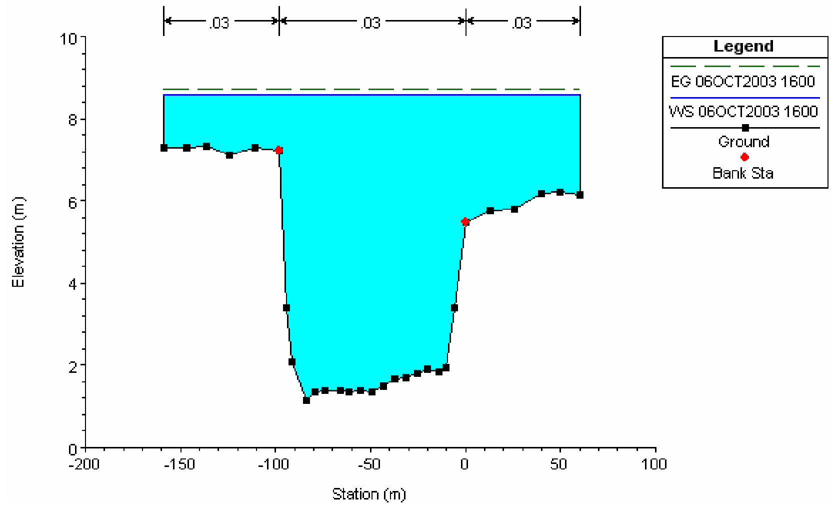
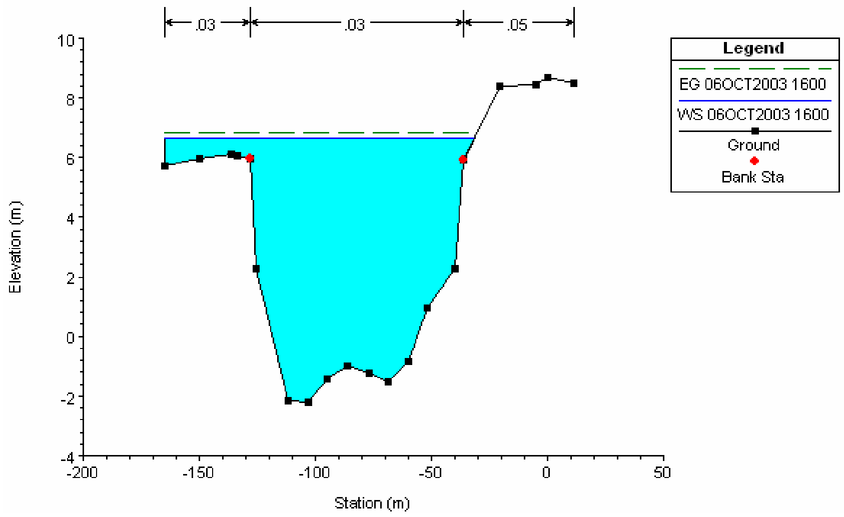


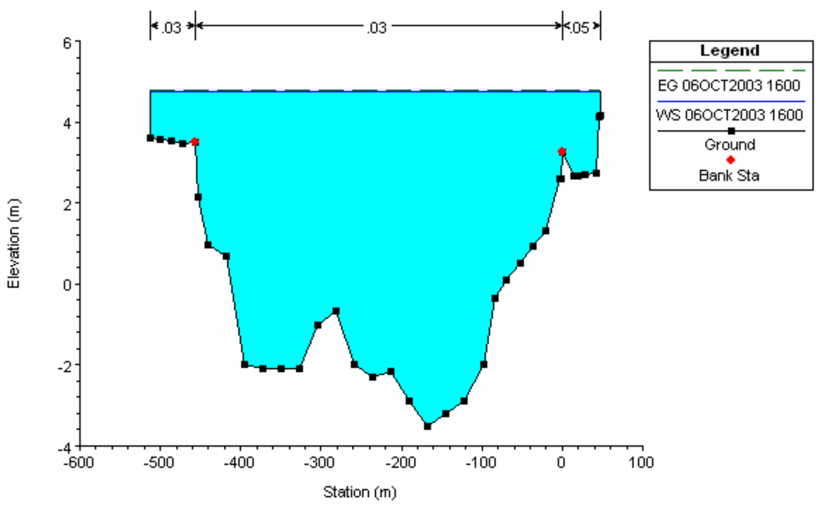
Figure 4.17 (a) Longitudinal Flood Profile for Sg Muda in HEC-RAS Model (Q=1340m^3/s)



(a) CH 35.0

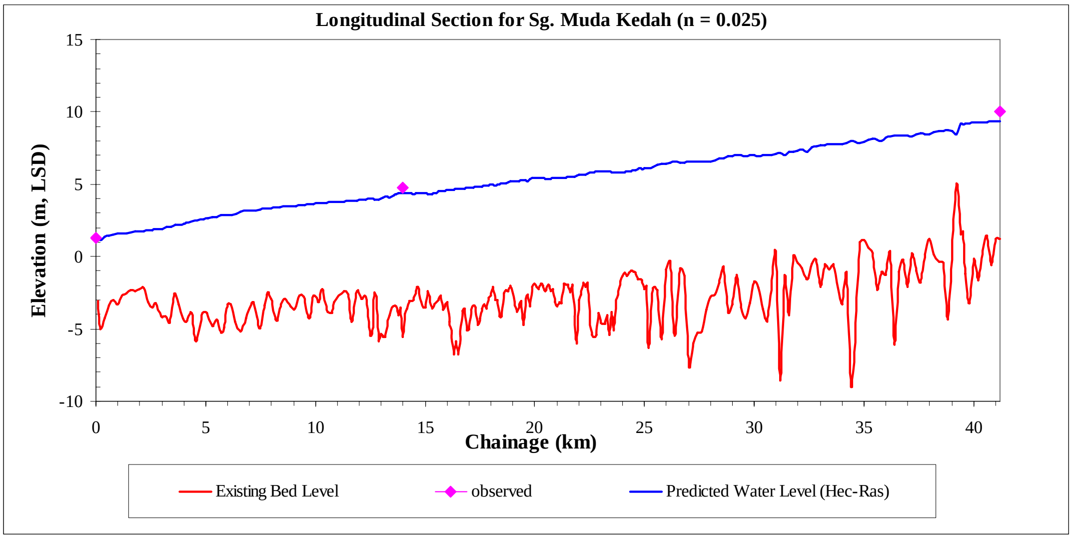


(b) CH 25.0

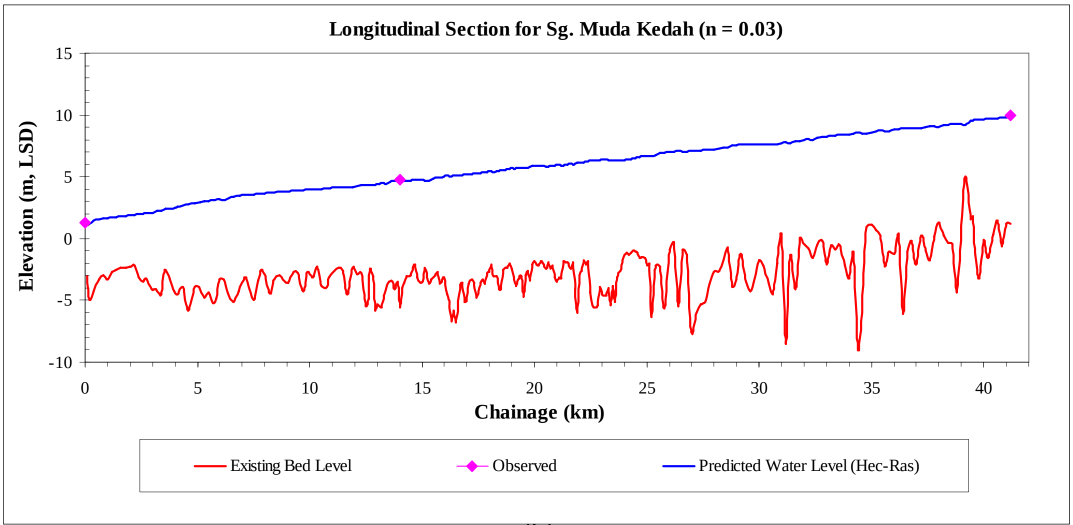


(c) CH 15.0

Figure 4.17 (b) Cross Sections for Sg Muda in HEC-RAS Model (Q=1340m^3/s)



(a)



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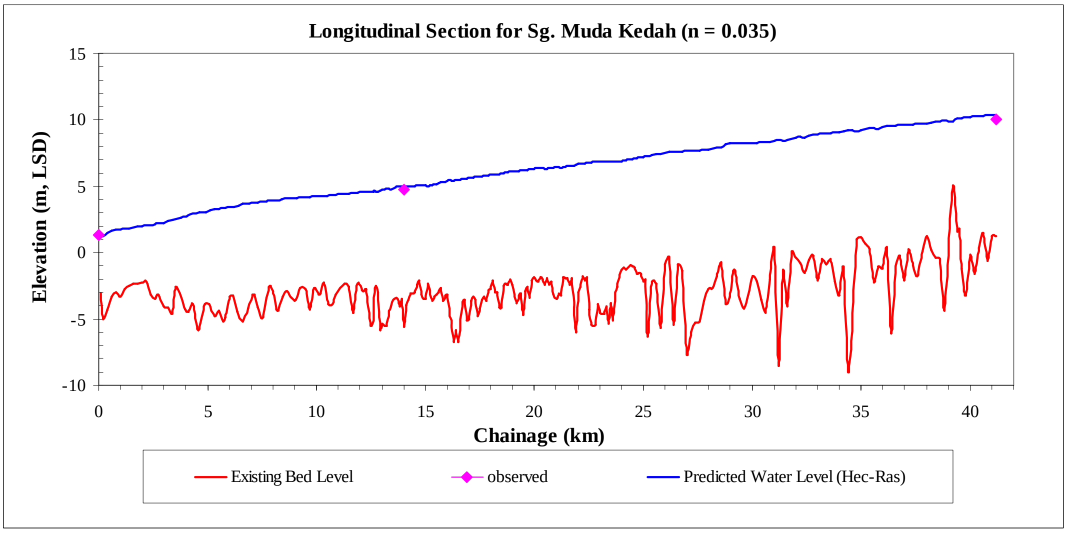


(c)

Figure 4.18 Predicted Water Level by the HEC-RAS Model

Table 4.7 and Table 4.8 give water level comparisons at two locations along Sg. Muda (Ladang Victoria and Bumbong Lima) at the peak water levels as they occurred during the 2003 flood. The results show that with Manning's n of 0.030, the predicted water levels by HEC-RAS model are the nearest to the observed values. Similar results are obtained for the duration of the flood as shown in Figure 4.19 and Figure 4.20. Therefore the Manning's n value of 0.030 will be used for further analysis in the present study.

Table 4.6 Maximum Water Level Discharge Record at Sg. Muda

Station No.	Name of Station	Maximum Water Level (m)							
		Observed	n = 0.025		n = 0.030		n = 0.035		Date and Time of Maximum Reading
			HEC – RAS	Difference	HEC – RAS	Difference	HEC – RAS	Difference	
5505412	Sg Muda @ Ldg. Victoria	9.65	9.37	-0.28	9.82	0.17	10.37	0.72	6.10.2003 @ 1600 Hrs
5505413	Rumah Pam Pinang Tunggal	7.43	6.11	-1.32	6.72	-0.71	7.28	-0.15	7.10.2003 @ 0600 Hrs
5504401	Rumah Pam Bumbong Lima	4.82	4.41	-0.41	4.76	-0.06	5.09	0.27	7.10.2003 @ 0300 Hrs
	River Mouth		2.70		2.70		2.70		11.10.2003 @ 0200 Hrs

Table 4.7 Maximum Water Level at Ladang Victoria (CH 41.2)

No.	Maximum Water Level(m)								
	Observed	n = 0.025		n = 0.03		n = 0.035		Date	Time (Hours)
		HEC-RAS	Difference	HEC-RAS	Difference	HEC-RAS	Difference		
1	9.26	9.22	-0.04	9.58	0.32	10.05	0.79	6.10.2003	24:00
2	9.42	9.29	-0.13	9.70	0.28	10.21	0.79		6:00
3	9.35	9.32	-0.03	9.76	0.41	10.32	0.97	7.10.2003	12:00
4	9.35	9.22	-0.13	9.61	0.26	10.13	0.78	8.10.2003	12:00
5	9.32	9.18	-0.14	9.56	0.24	10.06	0.74		21:00
6	9.35	8.96	-0.39	9.23	-0.12	9.65	0.30	9.10.2003	18:00
7	9.35	8.68	-0.67	8.62	-0.73	8.83	-0.52	10.10.2003	18:00

Table 4.8 Maximum Water Level at Bumbung Lima (CH 14.0)

No.	Maximum Water Level(m)								
		n=0.025		n = 0.03		n = 0.035		Date	Time (Hours)
	Observed	HEC-RAS	Difference	HEC-RAS	Difference	HEC-RAS	Difference		
1	4.27	3.68	-0.59	3.94	-0.33	4.16	-0.11	5.10.2003	12:00
2	4.41	3.90	-0.51	4.19	-0.22	4.45	0.04		18:00
3	4.55	4.11	-0.44	4.42	-0.13	4.69	0.14		24:00
4	4.55	4.11	-0.44	4.42	-0.13	4.69	0.14	6.10.2003	24:00
5	4.66	4.24	-0.42	4.57	-0.09	4.86	0.20		6:00
6	4.74	4.32	-0.42	4.66	-0.08	4.97	0.23		12:00
7	4.75	4.35	-0.40	4.71	-0.04	5.02	0.27		18:00
8	4.75	4.41	-0.34	4.76	0.01	5.09	0.34	7.10.2003	3:00
9	4.75	4.33	-0.42	4.69	-0.06	5.02	0.27		18:00
10	4.76	4.30	-0.46	4.66	-0.10	4.98	0.22	8.10.2003	6:00
11	4.71	4.24	-0.47	4.59	-0.12	4.91	0.20		18:00
12	4.70	4.18	-0.52	4.54	-0.16	4.86	0.16		21:00
13	4.66	4.19	-0.47	4.54	-0.12	4.85	0.19	9.10.2003	6:00
14	4.44	3.84	-0.60	4.16	-0.28	4.45	0.01	10.10.2003	6:00
15	4.22	3.54	-0.68	3.85	-0.37	4.12	-0.10		18:00

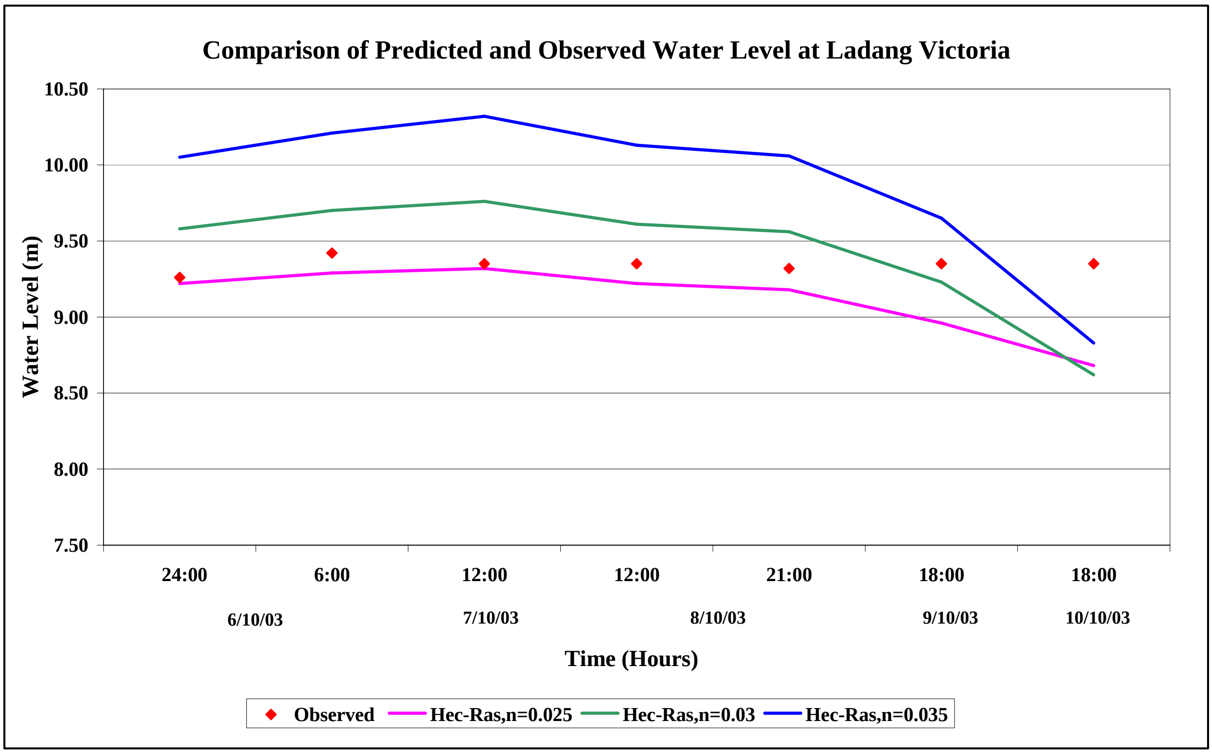


Figure 4.19 Comparison of Water Level at Ladang Victoria Using HEC-RAS for Different Values of Manning's n

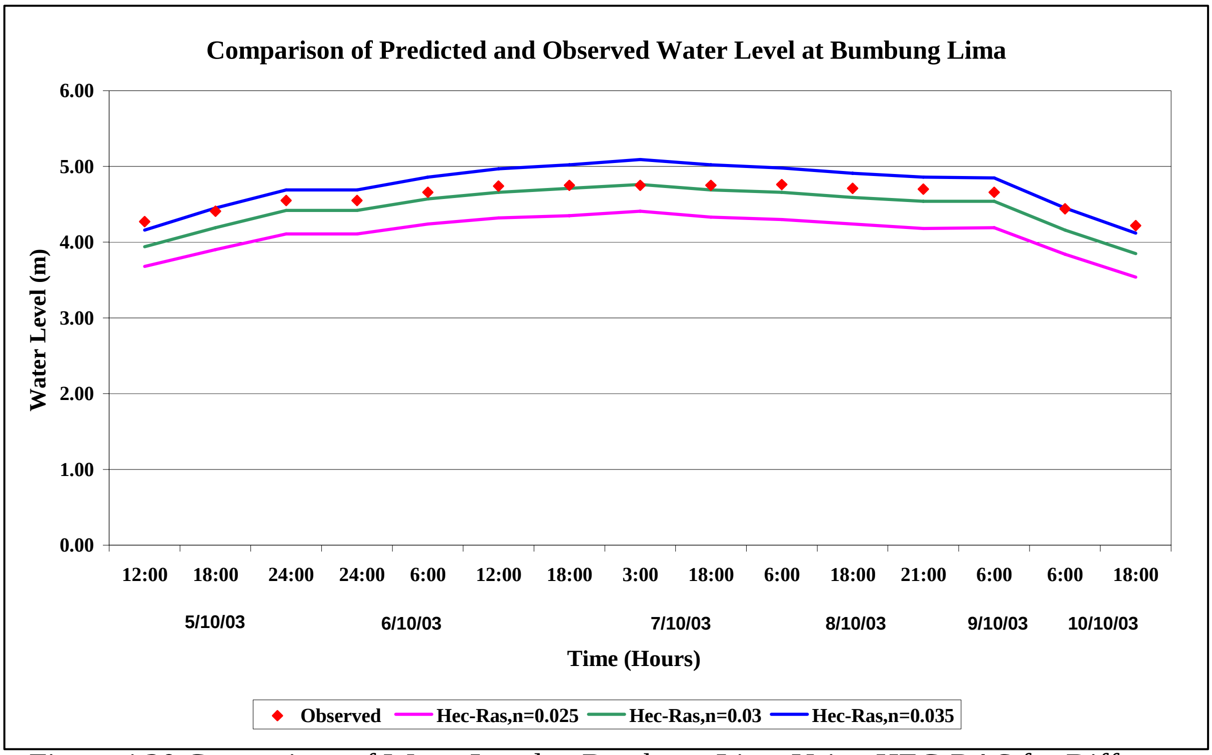


Figure 4.20 Comparison of Water Level at Bumbung Lima Using HEC-RAS for Different Values of Manning's n

4.2.5 Simulation

Referring to the flood frequency analysis in Section 2.3, the 2003 flood is chosen as the design flood. Figure 4.21 and Table 4.9 shows the predicted water levels with existing cross sections in comparison with the proposed bund height by JPZ (2000). The comparisons between the bund height determined by JPZ and the water level of the 2003 flood without channel widening indicate that the proposed bund height is typically 1-2 meters higher than the 2003 flood level. Further widening of the channel cross section would result in further lowering of the bund elevation. If the option to widen the channel is retained for the final design, it is strongly recommended to determine the new elevation of the bund height from the design discharge of 1,340 cumecs plus 1 meter of freeboard. The resulting bund elevation should be much lower than proposed in the design. Such analysis would result in significant cost savings.

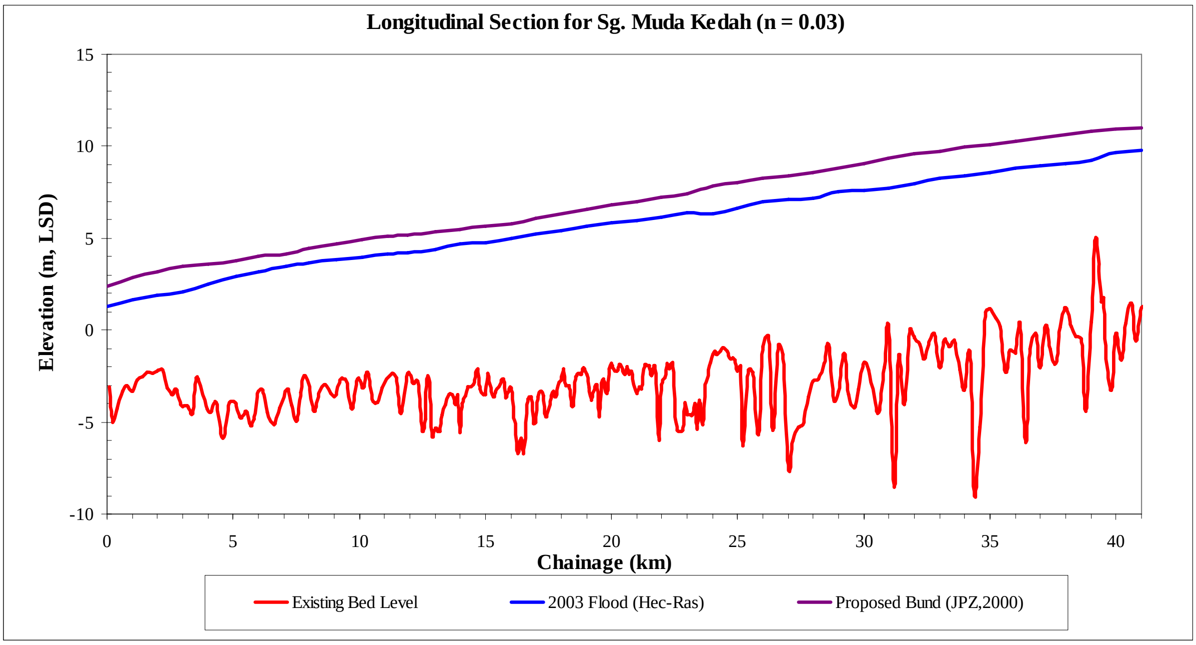


Figure 4.21 Comparison of Design Water Level and Proposed Bund Height

Table 4.9 Comparisons of Water Levels and Proposed Bund Height

Node	Cumulative Distance	Existing Invert	Flood Profiles				Difference between 2003 Flood and Proposed Bund Levels (m)
			Proposed Cross Section (Alternative 2); EXTRAN-XP (JPZ, 2000)			Existing Cross Section; HEC-RAS	
			50-yr ARI Level (m)	100-yr ARI Level (m)	Bund Level (m)	Flood 2003 Level (m)	
CH41	40275	1.09	10.01	10.68	11.01	9.79	1.22
CH40	39589	0.81	9.95	10.64	10.95	9.65	1.30
CH39	38535	1.18	9.82	10.53	10.83	9.26	1.57
CH38	37382	-1.34	9.58	10.32	10.62	9.05	1.57
CH37	36361	-1.10	9.36	10.15	10.45	8.96	1.49
CH36	35223	0.97	9.13	9.96	10.26	8.81	1.45
CH35	34344	-2.91	8.94	9.81	10.11	8.58	1.53
CH34	33248	0.57	8.70	9.65	9.95	8.41	1.54
CH33	32214	-4.48	8.50	9.44	9.74	8.26	1.48
CH32	31459	-3.66	8.30	9.28	9.58	7.95	1.63
CH31	30414	-4.09	8.10	9.07	9.37	7.70	1.67
CH30	29447	-5.30	7.90	8.74	9.04	7.60	1.44
CH29	28374	-1.82	7.70	8.49	8.79	7.56	1.23
CH28	27460	-2.78	7.47	8.27	8.57	7.15	1.42
CH27	26541	-2.29	7.21	8.09	8.39	7.12	1.27
CH26	25853	-0.34	7.04	7.95	8.25	6.98	1.27
CH25	24821	0.17	6.77	7.72	8.02	6.64	1.38
CH24	23879	-3.83	6.53	7.51	7.81	6.33	1.48
CH23	21901	-1.48	6.08	7.11	7.41	6.37	1.04
CH22	21039	-2.65	5.93	6.95	7.25	6.17	1.08
CH21	19806	-3.16	5.69	6.68	6.98	5.93	1.05
CH20	18951	-2.53	5.52	6.49	6.79	5.86	0.93
CH19	17946	-2.92	5.32	6.25	6.55	5.67	0.88
CH18	16946	-5.19	5.14	6.03	6.33	5.41	0.92
CH17	15801	-3.01	4.92	5.77	6.07	5.21	0.86
PLUS2	15771	-3.50	4.91	5.77	6.07	5.07	1.00
CH16	14944	-3.76	4.77	5.45	5.77	5.00	0.77
CH15	14097	-3.80	4.63	5.17	5.63	4.76	0.87
CH14	13142	-2.47	4.50	4.92	5.50	4.71	0.79
MB2	13112	-2.55	4.49	4.92	5.49	4.52	0.97
CH13	12123	-2.62	4.34	4.71	5.34	4.40	0.94
CH12	10665	-2.84	4.15	4.50	5.15	4.19	0.96
CH11	10354	-1.57	4.11	4.43	5.11	4.11	1.00
BARR2	10324	-1.57	4.14	4.47	5.14	4.01	1.13
CH10	10028	-1.67	3.95	4.29	4.95	3.98	0.97
CH9	9314	-3.47	3.68	3.96	4.68	3.82	0.86
CH8	8344	-2.66	3.45	3.74	4.45	3.64	0.81
CH7	7108	-2.56	3.16	3.40	4.16	3.50	0.66
CH6	6184	-3.18	2.99	3.21	3.99	3.17	0.82
CH5	5298	-3.12	2.79	2.98	3.79	2.91	0.88
CH4	4299	-2.56	2.62	2.74	3.62	2.53	1.09
CH3	3413	-3.46	2.46	2.54	3.46	2.09	1.37
CH2	2152	-2.28	2.17	2.19	3.17	1.87	1.30
CH1	1294	-2.09	1.84	1.84	2.84	1.65	1.19
River Mouth		-7.80	1.39	1.39	2.39	1.30	1.09

Chapter 5

River Modelling

5.1 River Sediment Data Collection

The river sediment data collection (Table 5.1) was carried out from June until August 2006 to establish the size distribution of the bed and bank materials of Sg. Muda. The objective of this programme is to study the effects of large flood on the sediment transporting capacity of Sg. Muda. Comparisons with the data from JICA (1995) will be made once the field work and analysis are completed. After several field visits were made, 15 sites (Figure 5.1 to Figure 3.4) were chosen as locations for the samplings of the bed and bank materials (Figure 5.5 to Figure 5.6) as listed in Table 5.1.

The sediment size distribution curves for the main river channel between Sidam Kanan (CH 36) and Merdeka Bridge (CH 12) shows that the mean sediment sizes (d_{50}) are between 1.00 mm and 2.00 mm indicating the river bed is made up of coarse sand. However, for other reaches finer sediment sizes are obtained.

Table 5.1 Details of River Bed and Bank Sampling Programme

Site No.	Chainage No.	Name of Location	Total Sample	No. of Samples		
				Bank Material (left)	Bed Material	Bank Material (right)
M1	Ch. 0.20	River Mouth	8	1	7	0
M2	Ch. 0.80	River Mouth	10	1	7	2
M3	Ch. 1.40	Kg. Sg Deraka	10	1	7	2
M4	Ch. 2.97	Kg. Pulau Mertajam	10	1	7	2
M5	Ch. 4.86	Kuala Muda Bridge	13	3	7	3
M6	Ch. 12.64	Merdeka Bridge	13	3	7	3
M17	Ch. 21.90	Kg Lahar Tiang	9	1	7	1
M16	Ch. 23.10	Kg Matang Berangan	9	1	7	1
M9	Ch. 23.60	Kuari 1	3	-	3	-
M7	Ch. 25.20	Pinang Tunggal Bridge	13	3	7	3
M10	Ch. 25.60	Kuari 2	3	-	3	-
M15	Ch. 30.80	Kg Pantai Perai	9	1	7	1
M11	Ch. 31.00	Kuari Kg Pantai Perai	3	-	3	-
M12	Ch. 33.40	Kuari Kg Terat Batu	3	-	3	-
M14	Ch. 33.80	Kg Lubok Ekor	9	1	7	1
M13	Ch. 36.80	Kg Sidam Kanan	9	1	7	1
M8	Ch. 39.50	Ladang Victoria Bridge	13	3	7	3
		Total	**147**	**21**	**103**	**23**

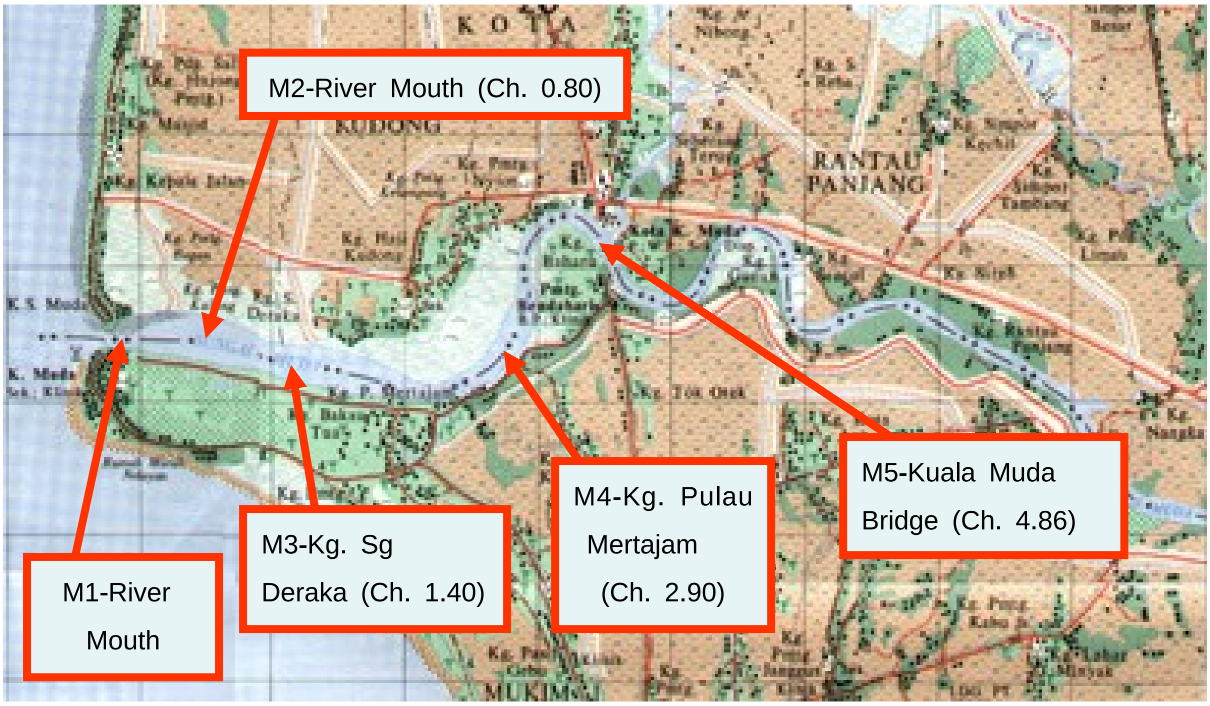


Figure 5.1 Bed Material Sampling Locations at River Mouth

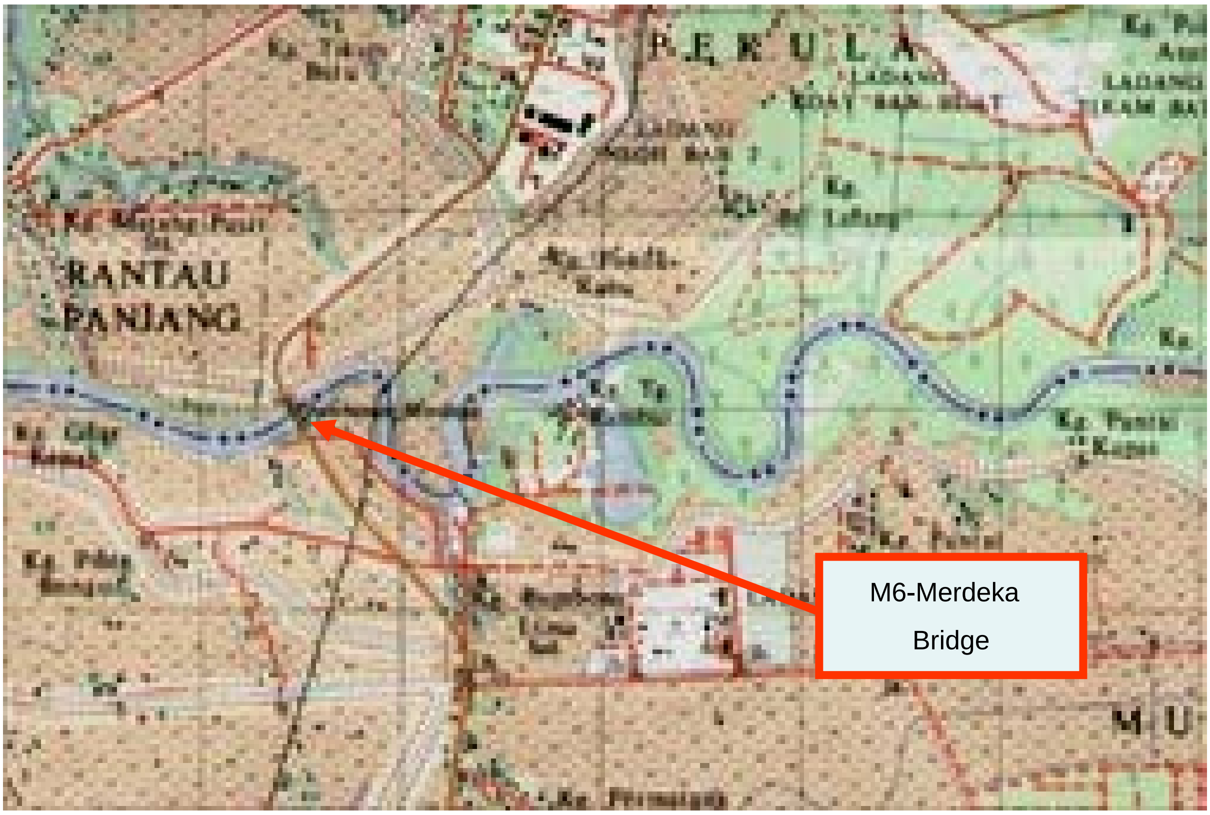


Figure 5.2 Bed Material Sampling Locations at Merdeka Bridge

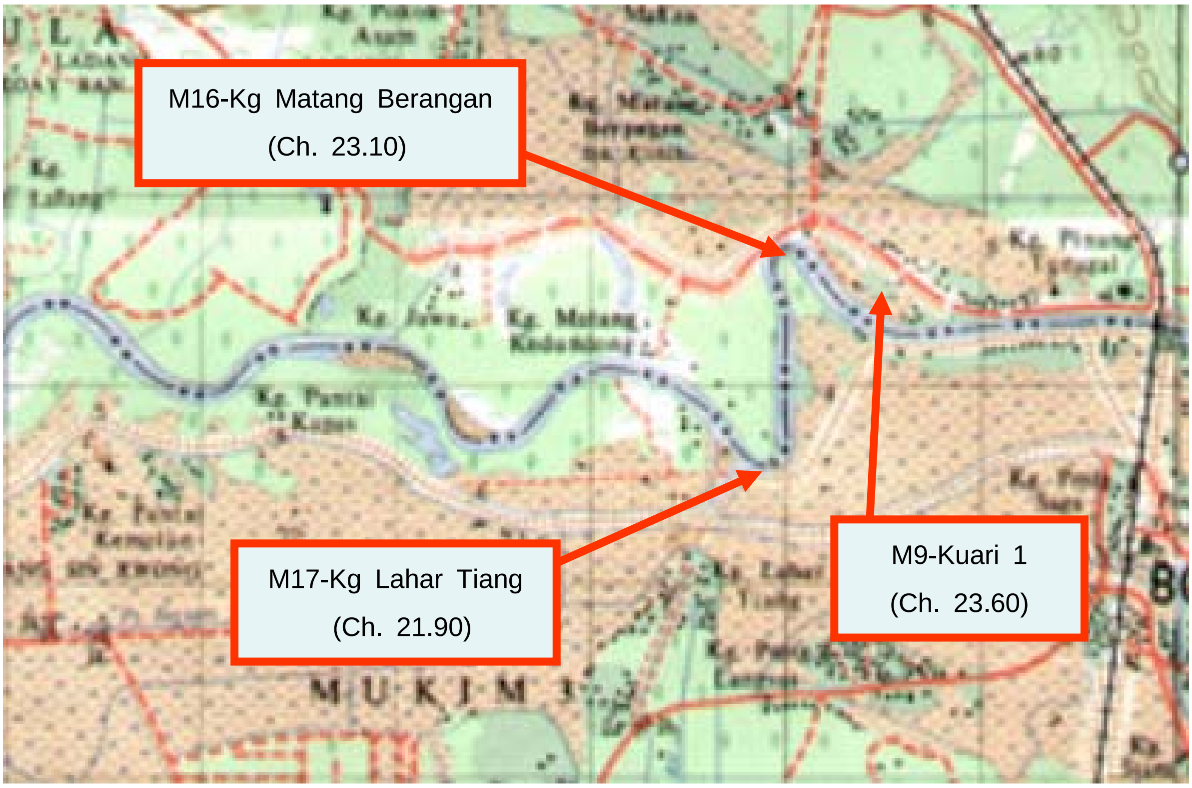


Figure 5.3 Bed Material Sampling Locations near Kg Pinang Tunggal

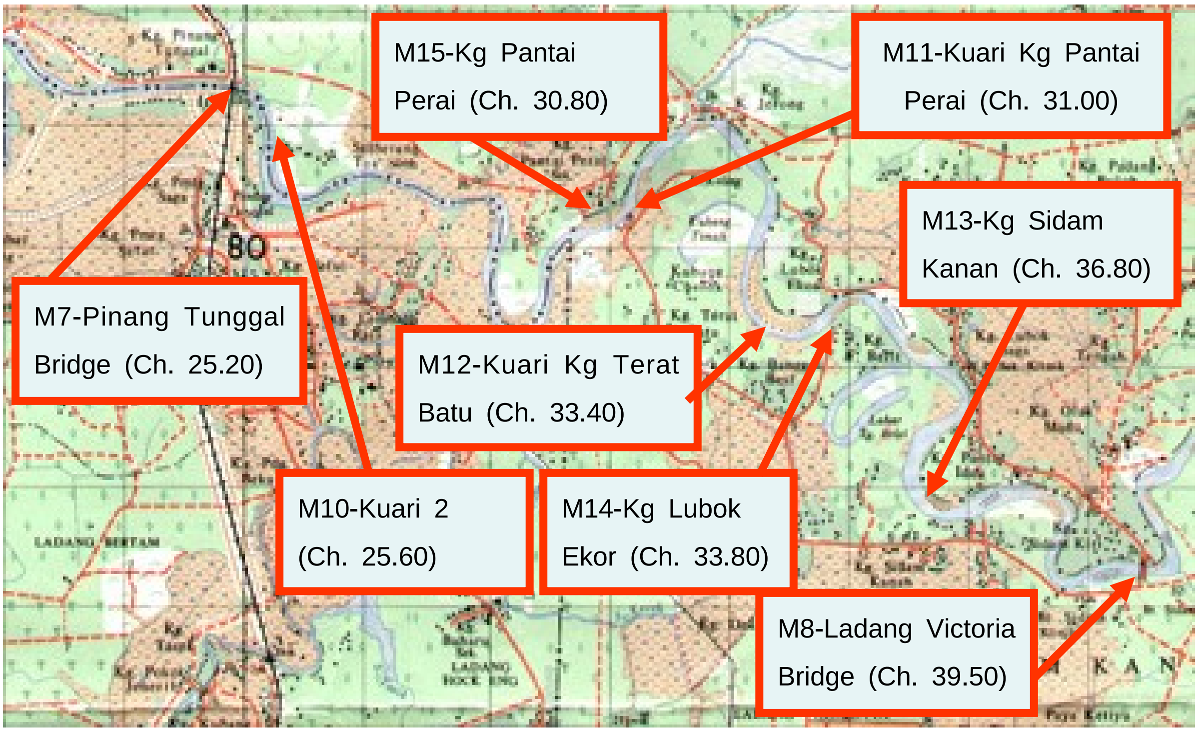


Figure 5.4 Bed Material Sampling Locations between Pinang Tunggal and Ladang Victoria

Figure 5.5 Grab Sampling @ Ch 1.40, Kg. Sg Deraka (5 June 2006)

Figure 5.6 Bank Material Sampling @ Ch 1.40, Kg. Sg Deraka (5 June 2006)

Table 5.2 Mean Sediment Size for Bed Material

Chainage No.	Site No.	Name of Location	D_{50} (mm)		
			Left Bank	Main Channel	Right Bank
Ch. 0.20	M1	River Mouth 1	0.900	0.425	-
Ch. 0.80	M2	River Mouth 2	0.216	0.063	0.600
Ch. 1.40	M3	Kg. Sg Deraka	0.063	0.150	0.040
Ch. 2.97	M4	Kg. Pulau Mertajam	0.300	0.300	0.040
Ch. 4.86	M5	Kuala Muda Bridge	0.150	0.150	0.063
Ch. 12.64	M6	Merdeka Bridge	0.090	1.000	0.050
Ch. 21.90	M17	Kg Lahar Tiang	0.036	0.212	0.070
Ch. 23.10	M16	Kg Matang Berangan	0.036	0.036	0.036
Ch. 23.60	M9	Kuari 1	-	1.180	-
Ch. 25.20	M7	Pinang Tunggal Bridge	0.212	0.425	0.063
Ch. 25.60	M10	Kuari 2	-	1.000	-
Ch. 30.80	M15	Kg Pantai Perai	0.050	0.050	2.000
Ch. 31.00	M11	Kuari Kg Pantai Perai	-	1.500	-
Ch. 33.40	M12	Kuari Kg Terat Batu	-	1.800	-
Ch. 33.80	M14	Kg Lubok Ekor	0.014	0.036	0.020
Ch. 36.80	M13	Kg Sidam Kanan	0.040	1.180	0.036
Ch. 39.50	M8	Ladang Victoria Bridge	0.212	1.800	0.050

5.2. Flow Discharge and Sediment Load Measurements

Flow discharge and sediment transport rates are also being carried out at Ladang Victoria (Figure 5.7 to Figure 5.9) to establish the flow and sediment rating curves. Comparisons of the present cross section (new bridge) and the one in 1993 (old bridge) is given in Figure 5.10. Figure 5.11 shows the water levels and flow discharges for the month of July and August 2006. The summary of flow characteristics is given in Table 5.3.

Figure 5.7 Bed Load Sampling @ Ladang Victoria (20 July 2006)

Figure 5.8 Bed Load Sampling @ Ladang Victoria (20 July 2006)

Figure 5.9 Gauging @ Ladang Victoria (26 July 2006)

The sediment size distribution curve for suspended load for the months of July and August 2006 (Figure 5.12) shows that mean sediment size is much finer than the bed material size. Hence it can be concluded that the suspended load is made up of wash load.

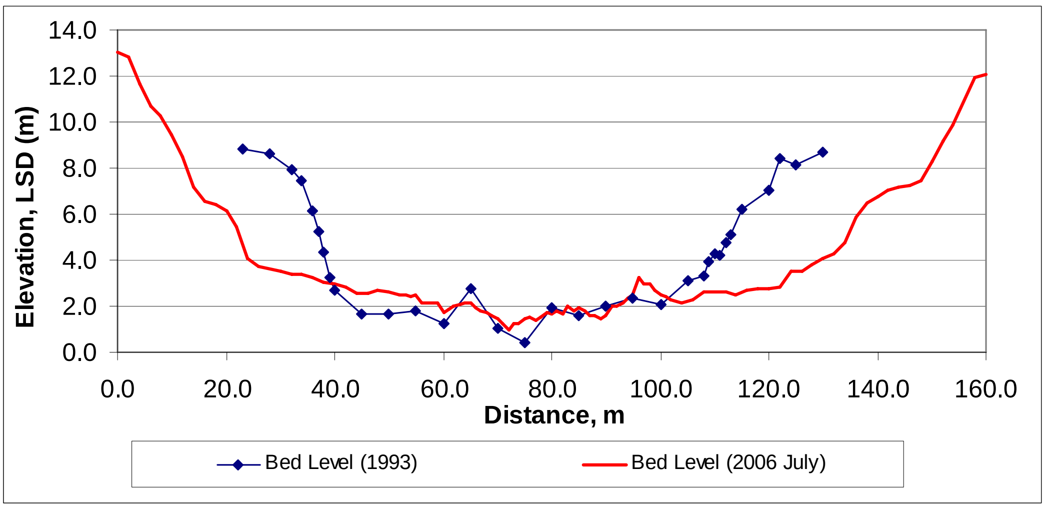


Figure 5.10 Comparisons of the Present Cross Section (New Bridge) and the Cross Section Year 1993 (Old Bridge)

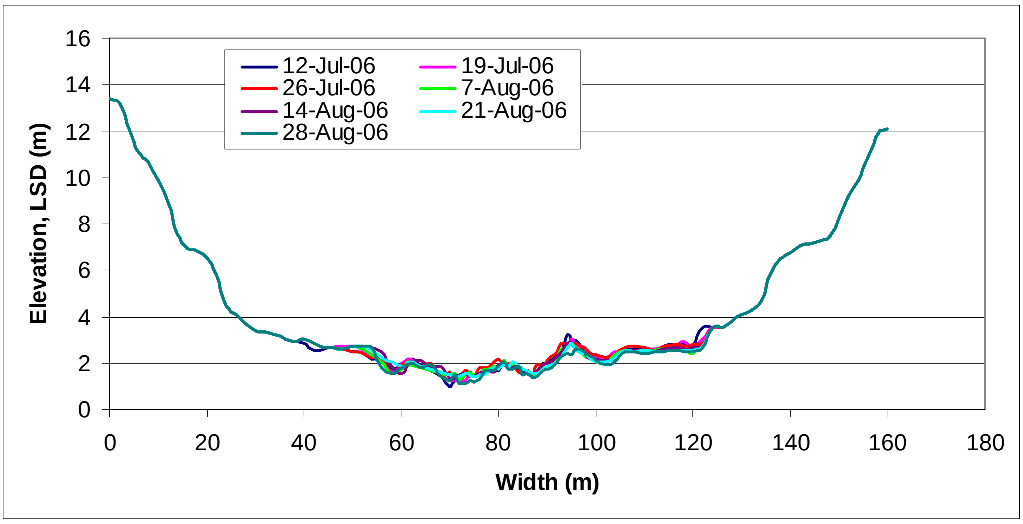
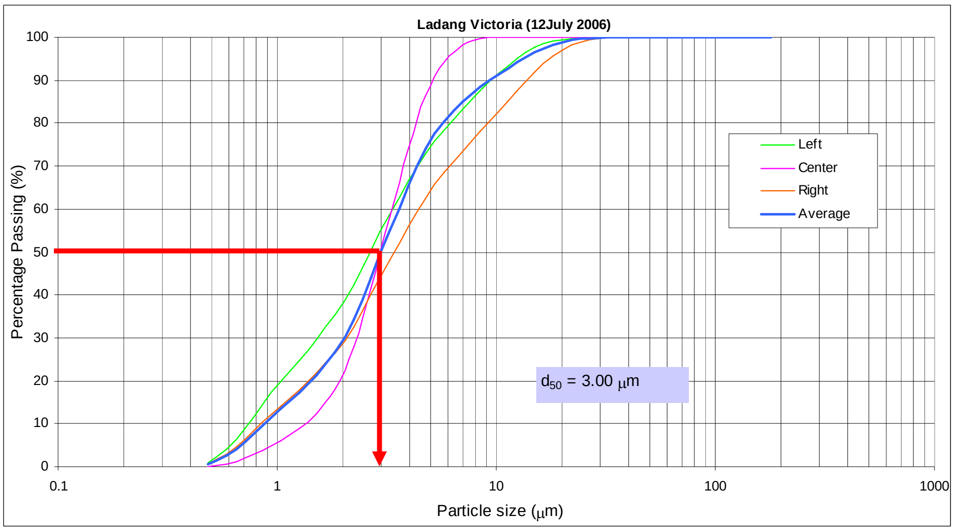
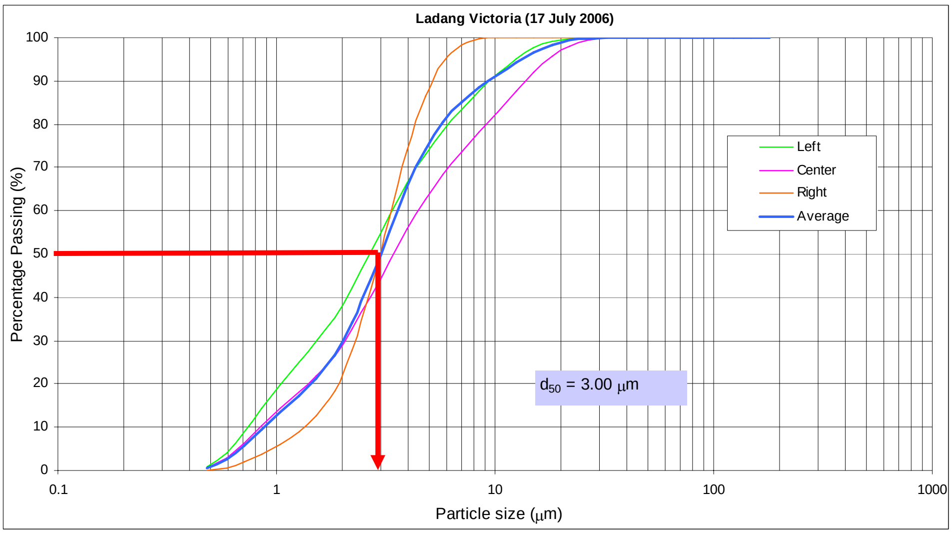


Figure 5.11 Water Level and Flow Discharge@ Ladang Victoria (July 2006)

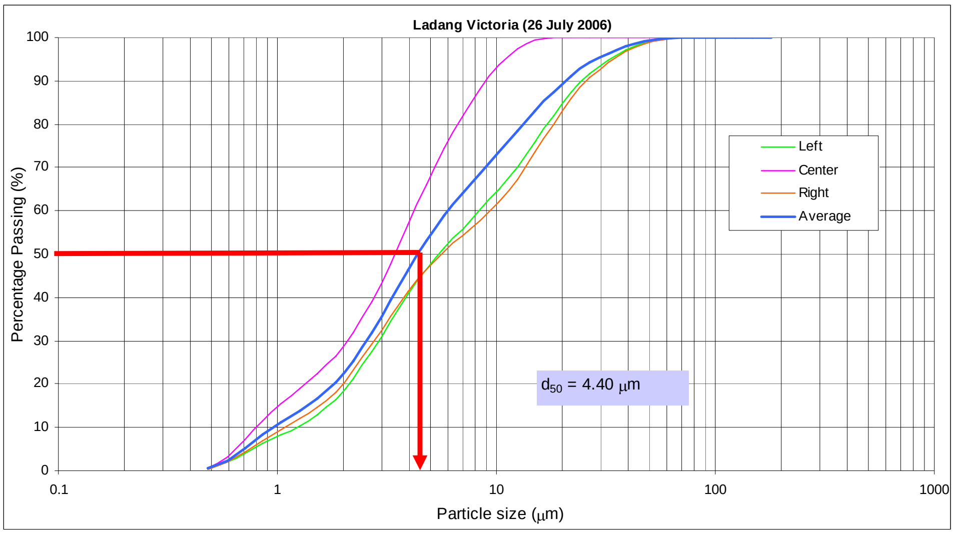


(a) 12 July 2006

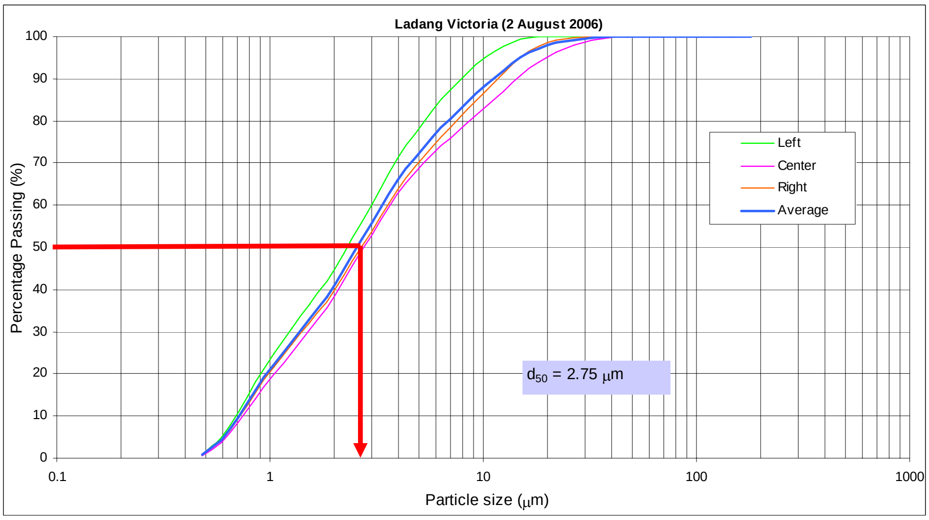


(b) 17 July 2006

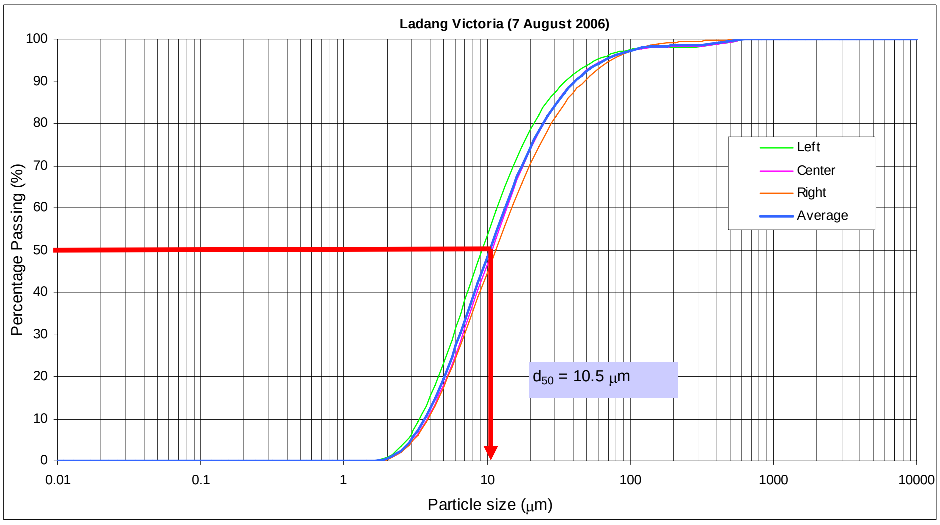
Figure 5.12 S-Curves for the Suspended Load @ Ladang Victoria



(c) 26 July 2006

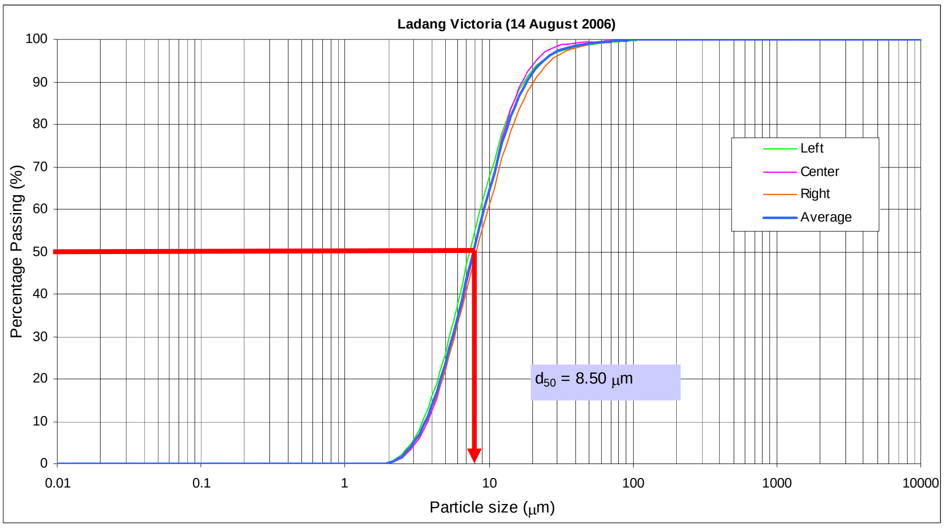


(d) 2 August 2006

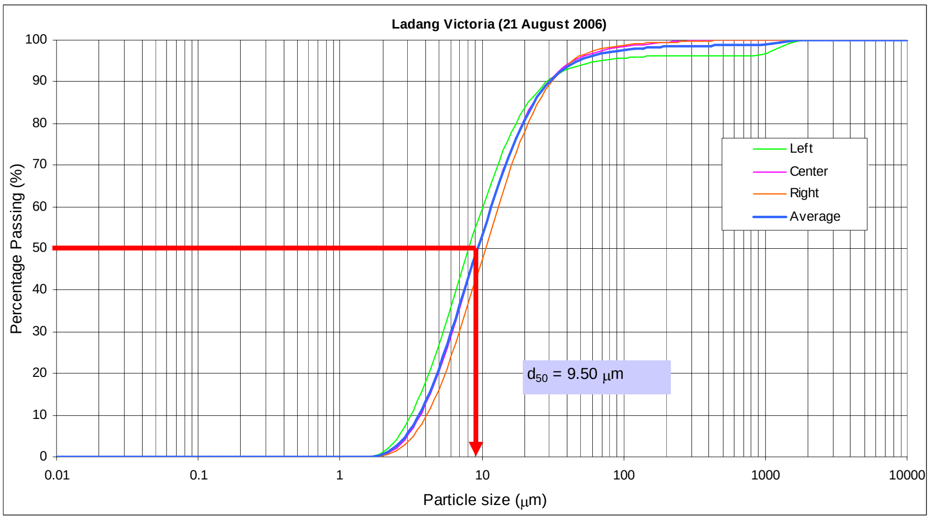


(e) 7 August 2006

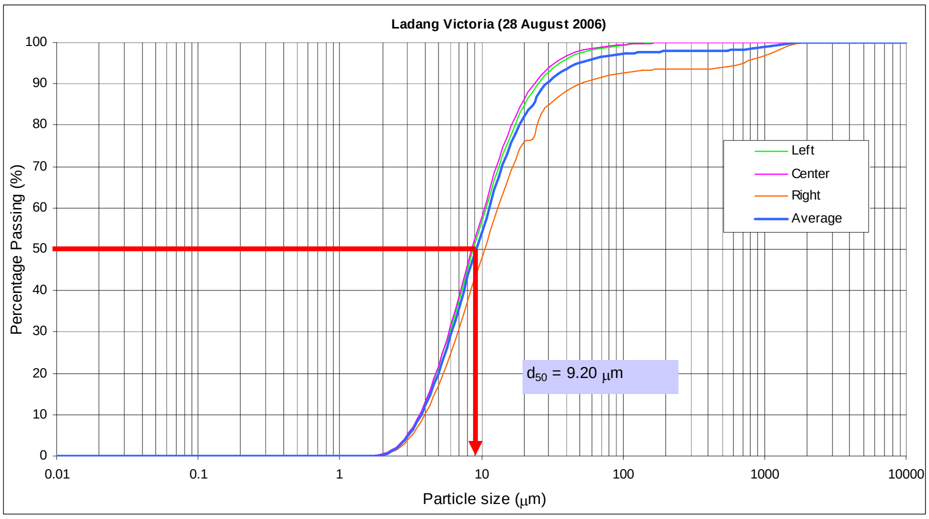
Figure 5.12 S-Curves for the Suspended Load @ Ladang Victoria (Continued)



(f) 14 August 2006



(g) 21 August 2006



(h) 28 August 2006

Figure 5.12 S-Curves for the Suspended Load @ Ladang Victoria (Continued)

Table 5.3 Summary of Flow Characteristics @ Ladang Victoria (July and August 2006)

Sampling No.	Date	Q (m^3/s)	V (m/s)	B (m)	Y_o (m)	A (m^2)	P (m)	R (m)	S_o	n
LV01	12.07.2006	109.89	0.94	94.0	2.52	111.165	95.150	1.17	0.0002	0.0159
LV02	19.07.2006	47.21	0.71	82.0	1.80	66.835	82.808	0.81	0.0002	0.0174
LV03	26.07.2006	33.12	0.59	80.0	1.53	51.400	80.967	0.63	0.0002	0.0162
LV04	07.08.2006	27.78	0.59	72.0	1.41	55.135	72.827	0.76	0.0002	0.0233
LV05	14.08.2006	24.71	0.53	42.0	1.36	41.31	70.5846	0.59	0.0002	0.0165
LV06	21.08.2006	28.35	0.59	46.0	1.33	45.675	70.5251	0.65	0.0002	0.0171
LV07	28.08.2006	27.18	0.54	48.0	1.57	47.085	68.896	0.68	0.0002	0.0190

5.3 Sediment Transport Modelling

This section gives the results of loose boundary modeling of Sg. Muda using FLUVIAL-12 model (Chang, 1993). The modeling will involve simulation of the river bed and cross sections for the 2003 flood. The results of the modeling will identify stretches prone to meandering, hence needing extra protection, and also changes in alluvial river geometry in terms of aggradations and degradation as well as lateral channel migration.

5.3.1 Historical Flood Hydrograph (2003)

The input hydrograph at Ladang Victoria from 16th Jun to 29th December 2003 (Figure 3.13) was used. The 2003 flood occurred from 3rd to 13th October 2003. The peak flood took place on the 6th October 2003 at 4 p.m. (Figure 3.13) with a value of 1340 m^3/s.

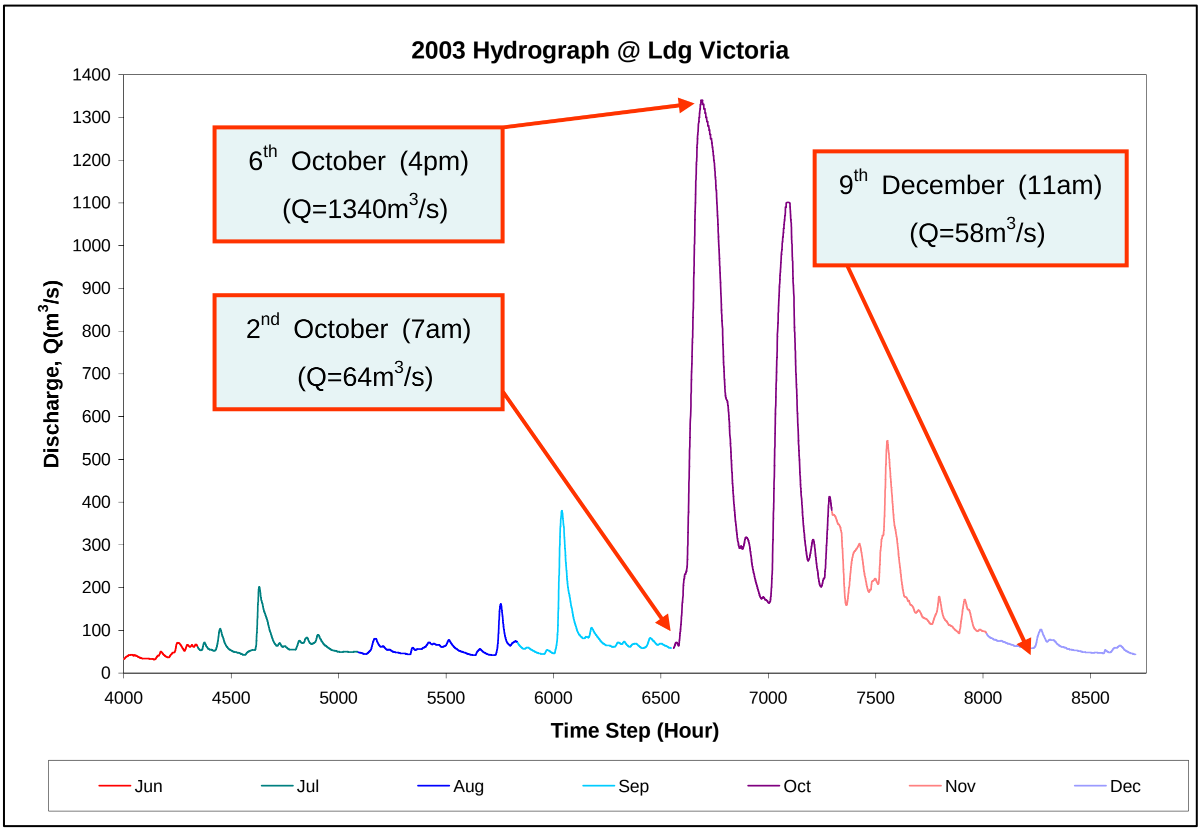


Figure 5.13 Input Hydrograph @ Ladang Victoria for Flood 2003

3.3.2 Tidal Record

The tidal record (Figure 3.14) at the river mouth is used to define time variation of stage (water surface elevation) at a downstream cross section.

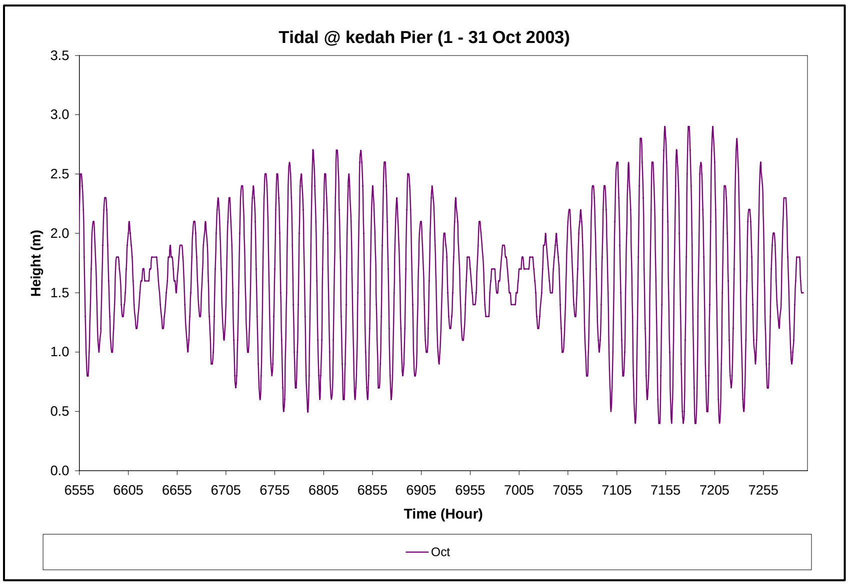


Figure 5.14 Tidal Record for the Month of October 2003

5.3.3 S-Curve

Two S-curves are required at the downstream and upstream cross sections to specify initial bed material compositions in the river bed (Figure 3.15).

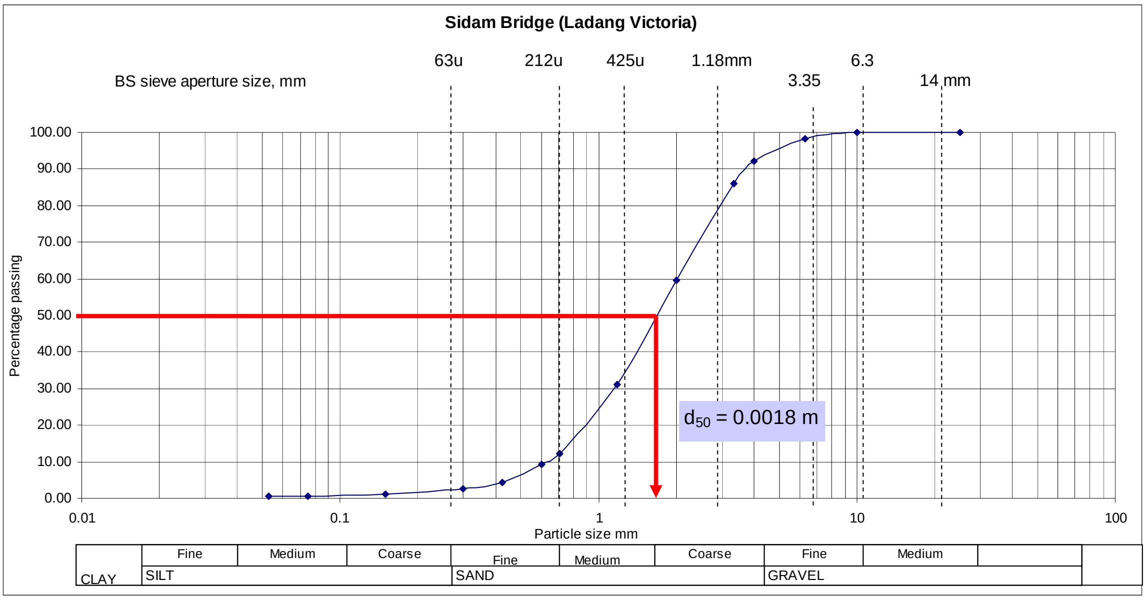


Figure 3.┌ Ldg Victoria – M8 (Upstream)

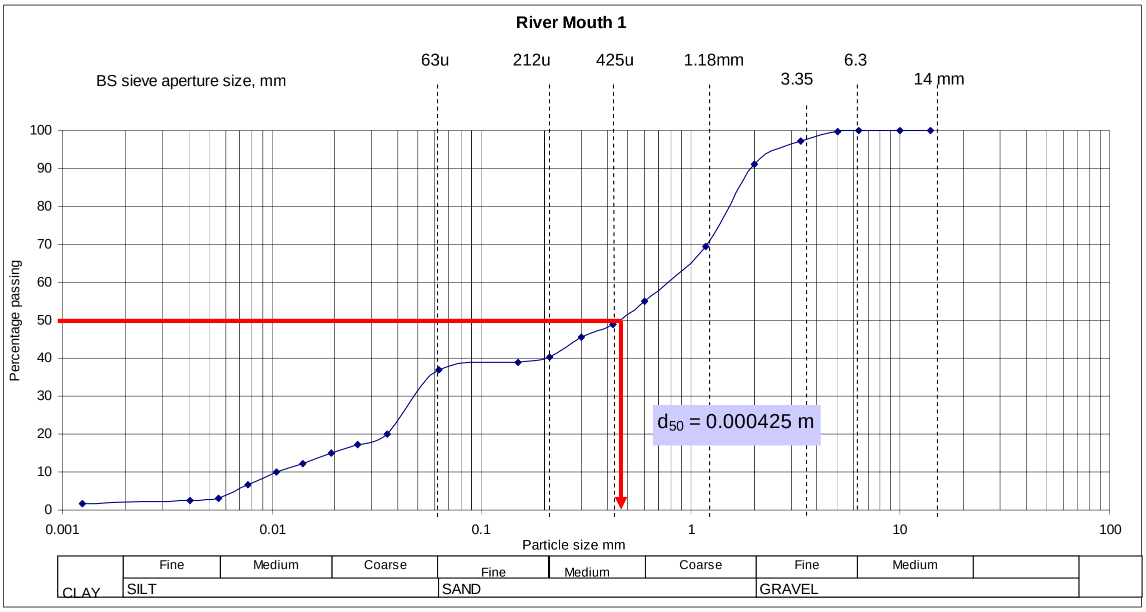


Figure 3.┌ River Mouth, Sg Muda – M1 (Downstream)

Figure 5.15 Initial Bed Material Size Distributions

5.3.4 Geometry Data

The geometry data consists of existing cross-sections between river mouth (CH 0) and Ladang Victoria (CH 41.2) at the upstream of Sg. Muda. This data, consisting of lateral distance and elevations were obtained from field surveys by Jurutera Perunding Zaaba (JPZ).

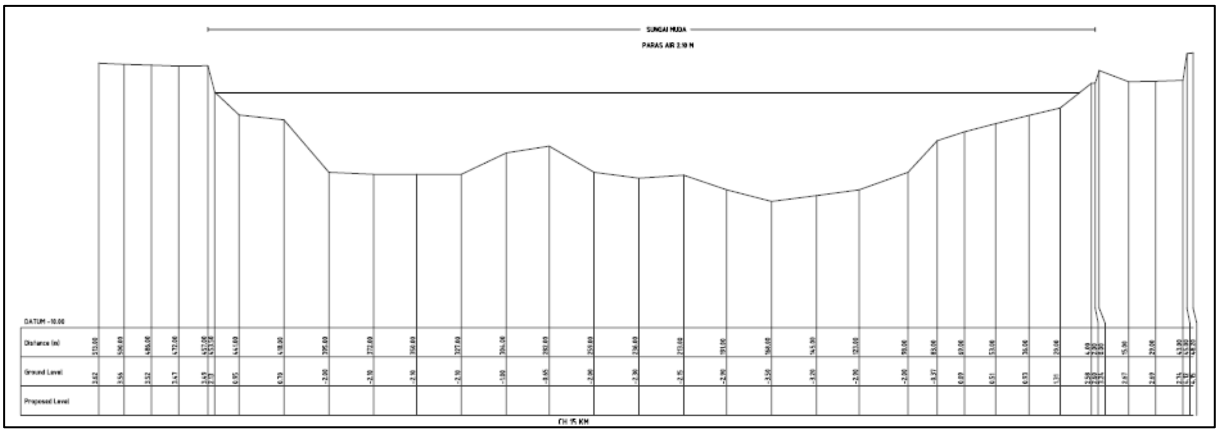


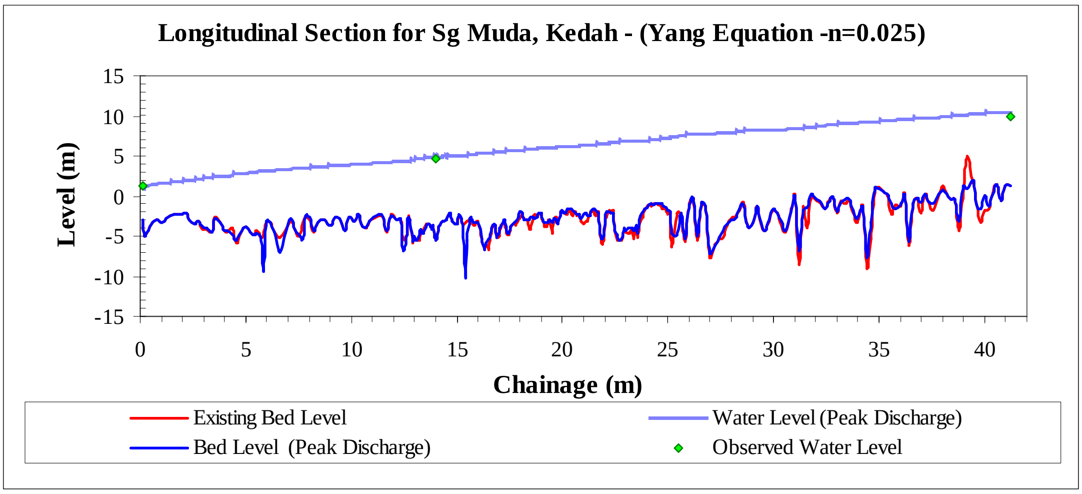
Figure 5.16 Existing Sg Muda Cross Section @ CH 15

5.3.5 Calibration

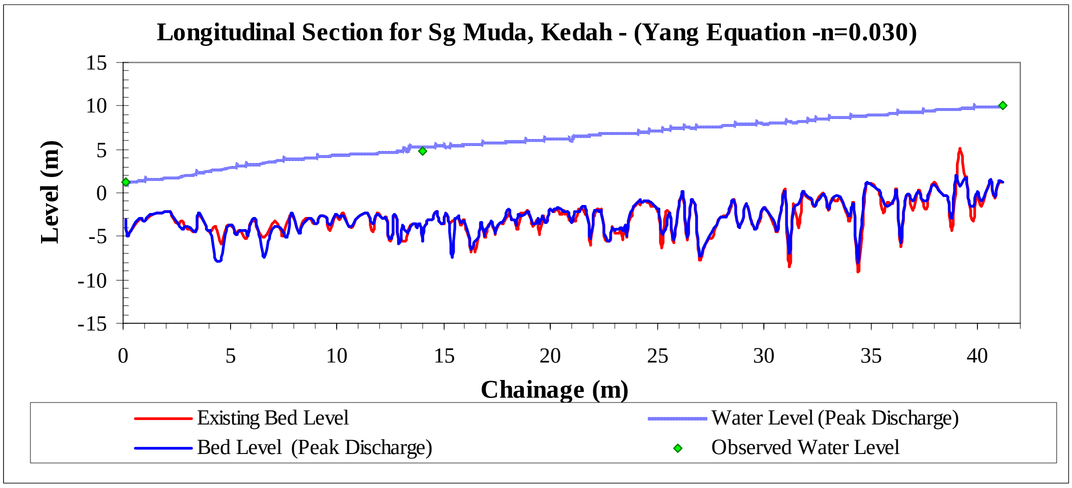
Based on previous applications of FLUVIAL-12 for Kulim River and Pari River and sediment transport equation assessments of existing equations (Ab. Ghani et al., 2003), Yang equation was used to simulate the sediment transport process in the study reach. Manning's values of 0.025, 0.030 and 0.035 were used. Based on measured water levels (Table 5.5 and Figure 5.17) at Bumbung Lima, either 0.025 or 0.030 can be used for modeling. To be consistent with the HEC-RAS modeling, the value of 0.030 was chosen for further analysis.

Table 5.5 Water Level Comparisons at Three Locations Using Yang Equation

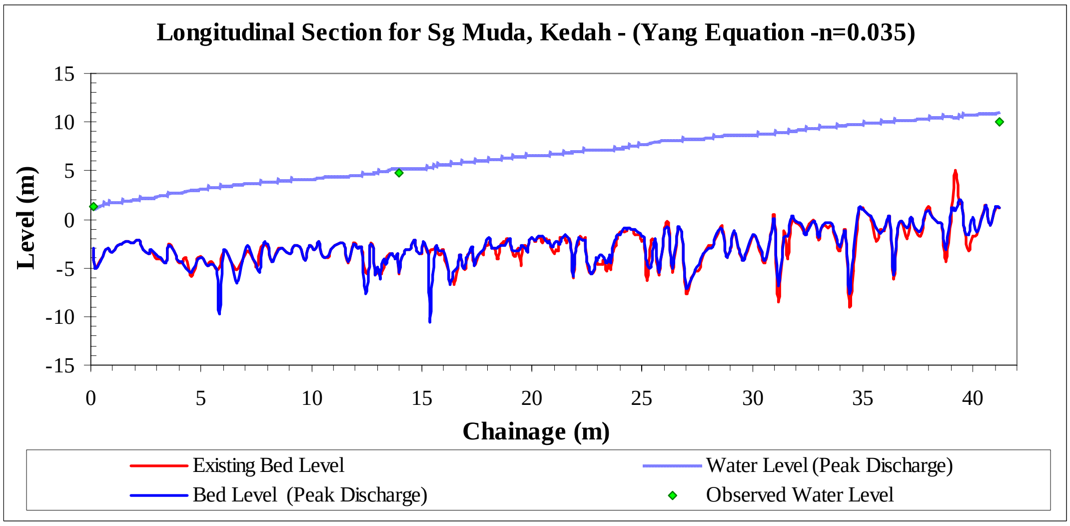
Location	Water Level (n=0.025)		
	Observed	Predicted	Difference
Ch 41.2 (Ldg Victoria)	10.00	9.99	-0.01
Ch 14.0 (Bumbong Lima)	4.74	4.92	+0.18
Ch 0.1 (River Mouth)	1.30	1.06	-0.24
	Water Level (n=0.030)		
Ch 41.2 (Ldg Victoria)	10.00	10.48	+0.48
Ch 14.0 (Bumbong Lima)	4.74	4.92	+0.18
Ch 0.1 (River Mouth)	1.30	1.06	-0.24
	Water Level (n=0.035)		
Ch 41.2 (Ldg Victoria)	10.00	10.90	+0.90
Ch 14.0 (Bumbong Lima)	4.74	5.19	+0.45
Ch 0.1 (River Mouth)	1.30	1.06	-0.24



(a) n = 0.025



(b) n = 0.030



(c) n = 0.035

Figure 5.17 Comparison of Water Level for Manning’s n = 0.025, 0.030 and 0.035

5.3.6 Simulation

The 2003 Flood was chosen as the design flood with existing cross sections. Table 5.6 and Figure 5.18 give the result of the predicted water level using Fluvial-12 in comparison with the proposed bund height. In general, the predicted water level 1m lower than the proposed bund height.

Table 5.6 Comparisons of Water Levels and Proposed Bund Height

Node	Cumulative Distance	Existing Invert	Flood Profiles				Difference between 2003 Flood and Proposed Bund Levels (m)
			Proposed Cross Section; EXTRAN-XP (JPZ, 2000)			Existing Cross Section ; FLUVIAL-12	
			50-yr ARI Level (m)	Flood 2003 Level (m)	Bund Level (m)	2003 Flood Level (m)	
CH41	40275	1.09	10.01	10.68	11.01	9.99	1.02
CH40	39589	0.81	9.95	10.64	10.95	9.83	1.12
CH35	34344	-2.91	8.94	9.81	10.11	8.90	1.21
CH30	29447	-5.30	7.90	8.74	9.04	7.96	1.08
CH25	24821	0.17	6.77	7.72	8.02	7.08	0.94
CH20	18951	-2.53	5.52	6.49	6.79	6.18	0.61
CH15	14097	-3.80	4.63	5.17	5.63	5.35	0.28
CH10	10028	-1.67	3.95	4.29	4.95	4.27	0.68
CH5	5298	-3.12	2.79	2.98	3.79	2.91	0.88
CH4	4299	-2.56	2.62	2.74	3.62	2.41	1.21
CH3	3413	-3.46	2.46	2.54	3.46	1.94	1.52
CH2	2152	-2.28	2.17	2.19	3.17	1.65	1.52
CH1	1294	-2.09	1.84	1.84	2.84	1.44	1.40
River	0	-7.80	1.39	1.39	2.39	1.06	1.33

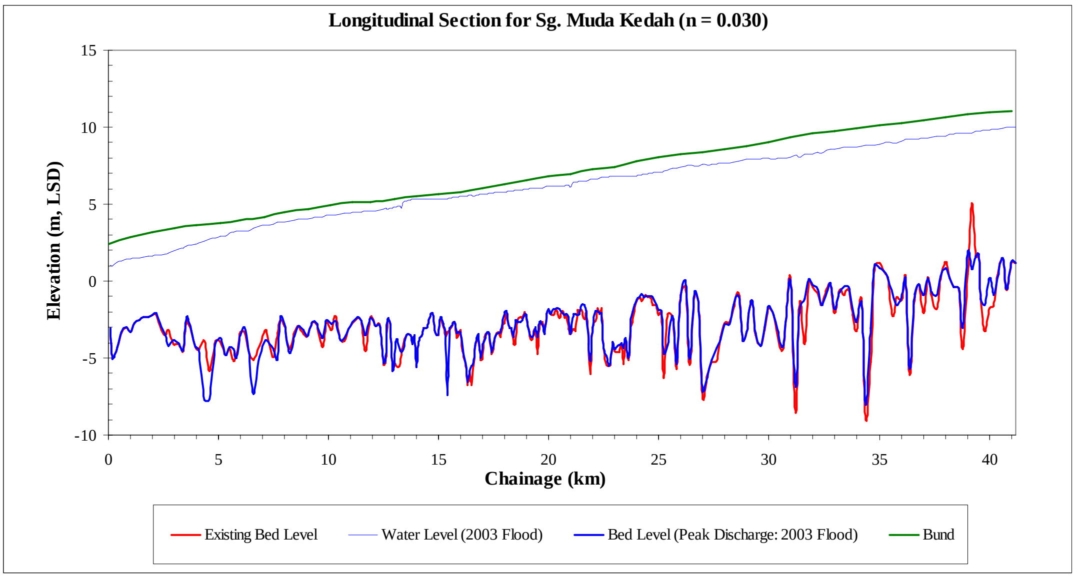
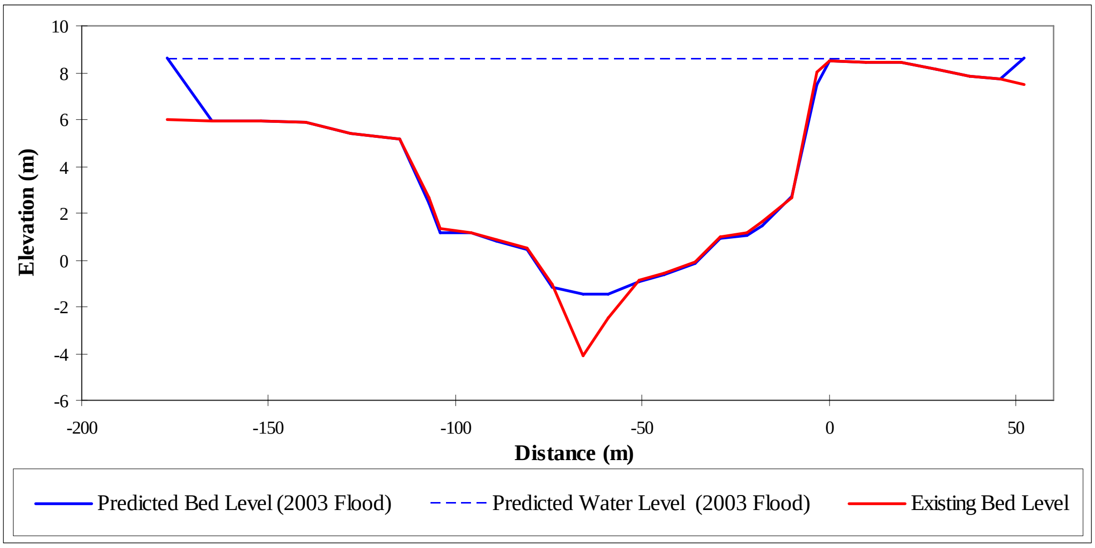
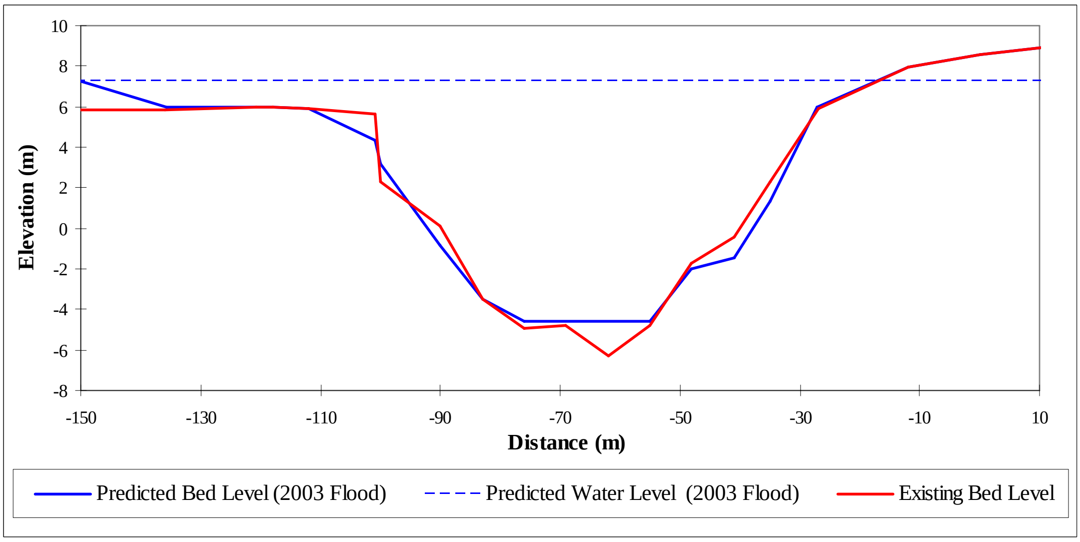


Figure 5.18 Comparisons of Water Levels and Proposed Bund Height

Figure 5.19 shows the cross section changes for several locations along Sg. Muda. In general, the river is stable at most locations with the exception of Kg Lahar Tiang and Bumbong Lima where lateral migration is predicted at these two locations (Figure 5.20 and 5.21). Further recommendation is given in Section 6.2.4 to reduce the possibility of lateral migration at these locations.

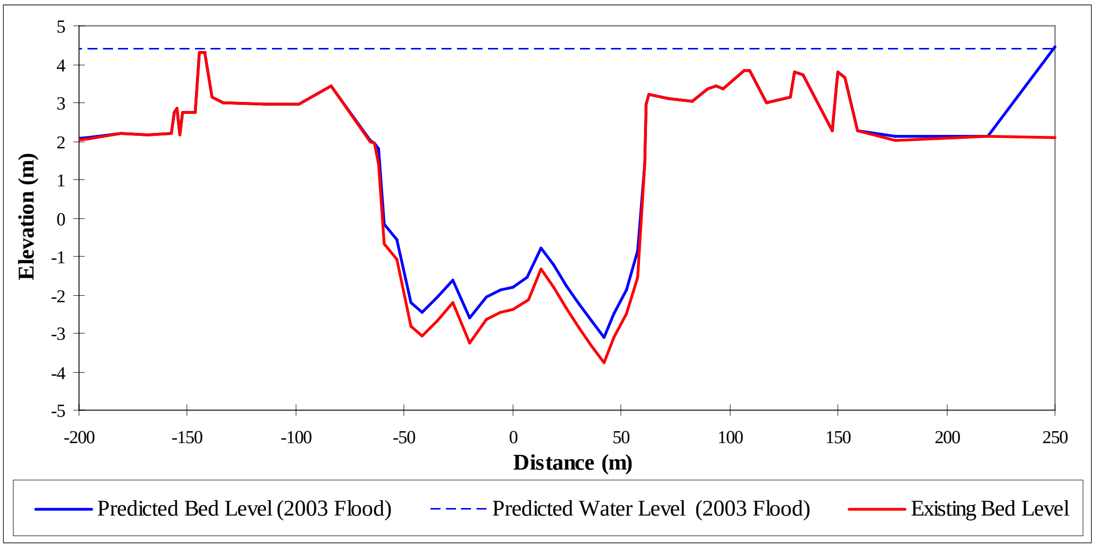


(a) CH 31.6

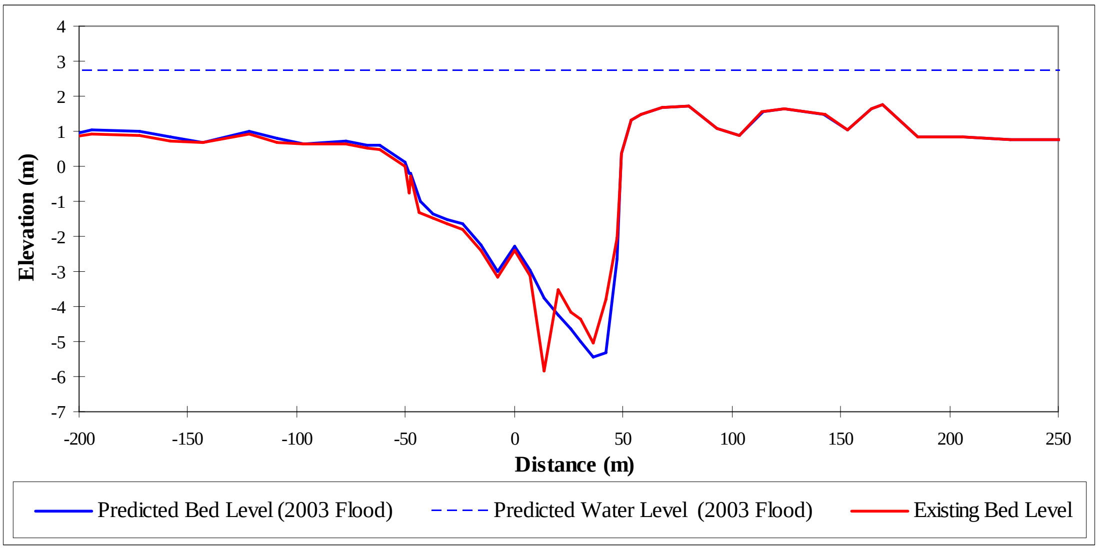


(b) CH 25.2

Figure 5.19 Cross Section Changes

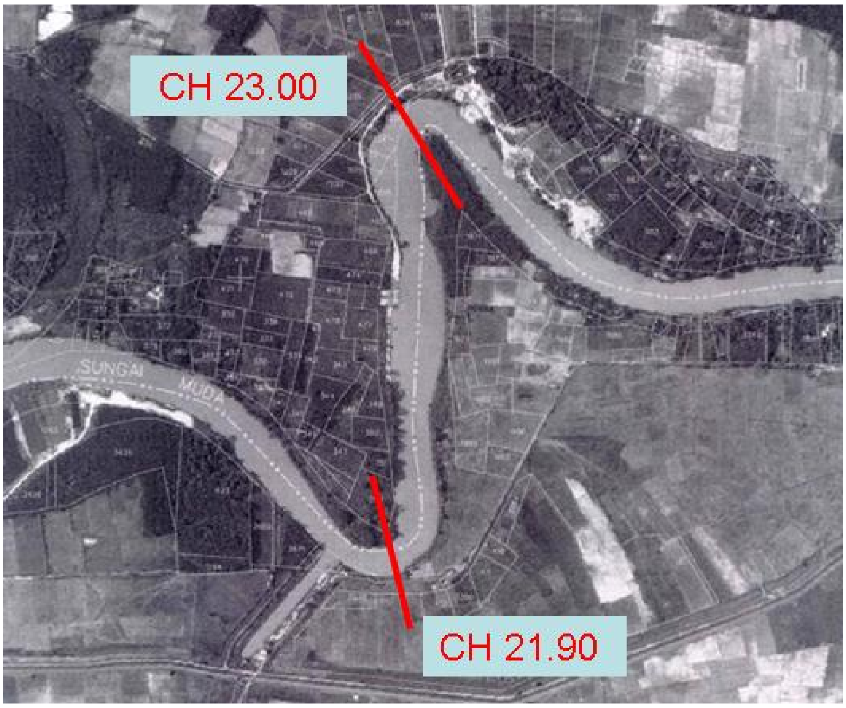


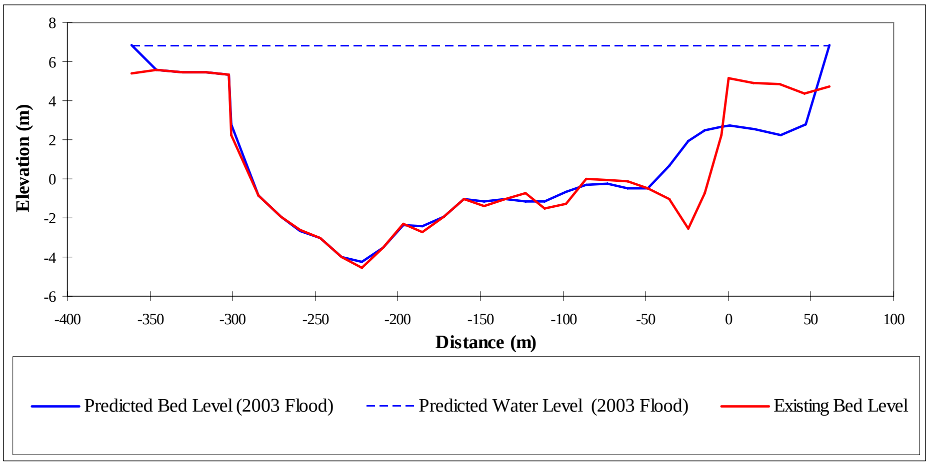
(c) CH 12.64



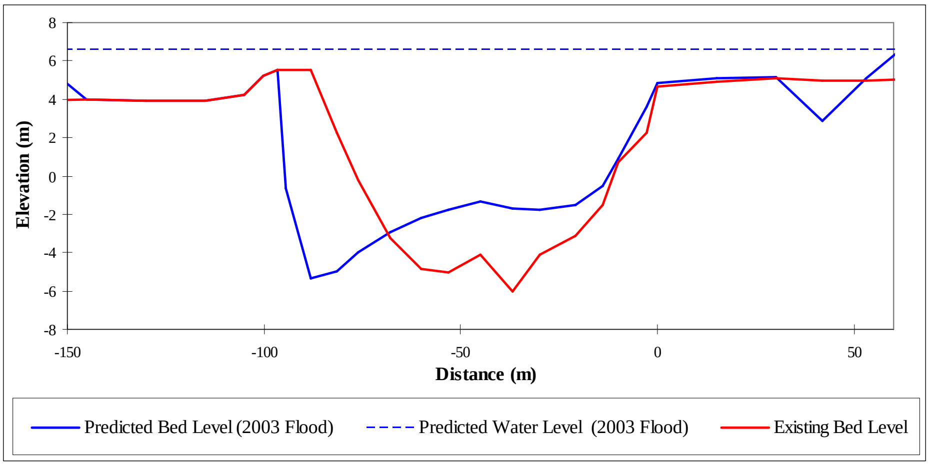
(d) CH 4.58

Figure 5.19 Cross Section Changes (Continued)



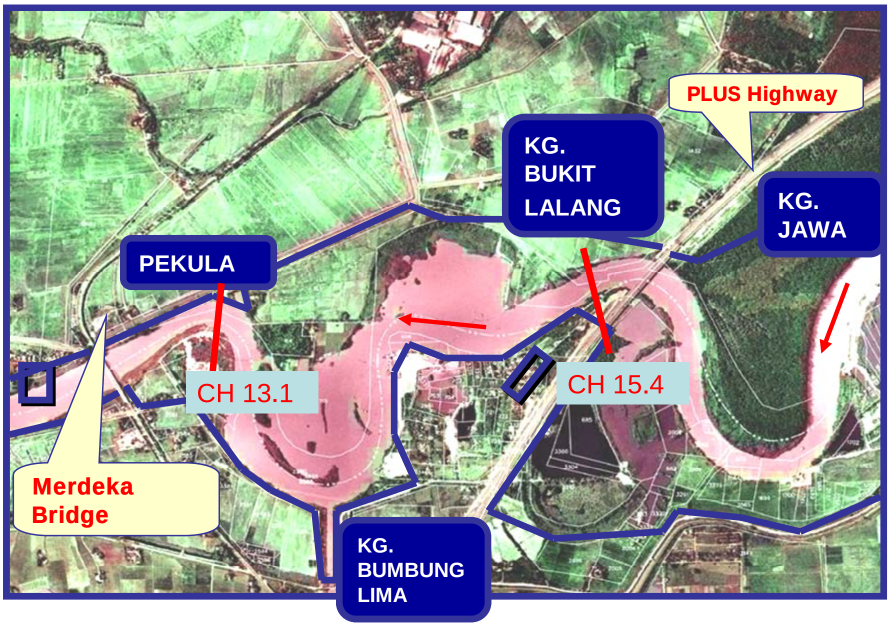


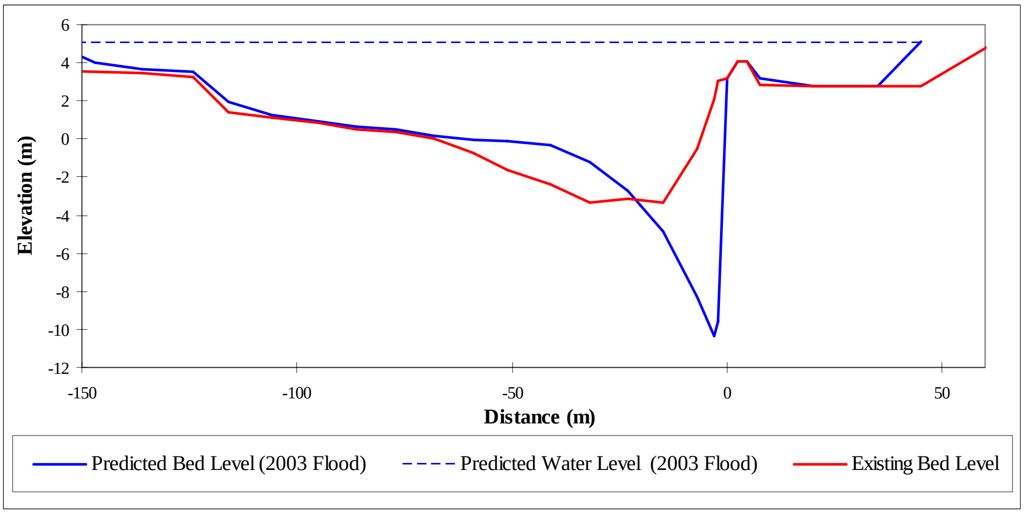
(a) CH 23.0



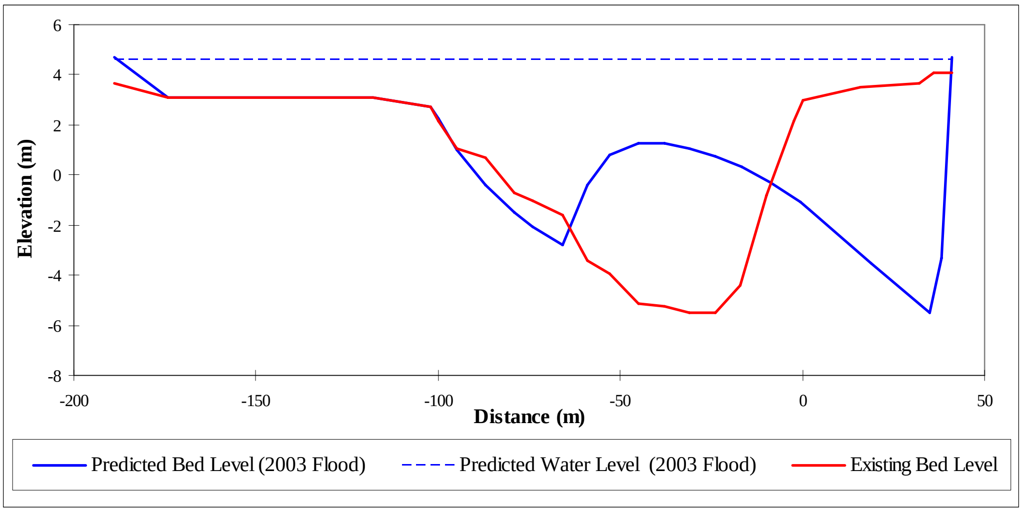
(b) CH 21.90

Figure 5.20 Lateral Migration @ Kg Lahar Tiang





(a) CH 15.4



(b) CH 13.1

Figure 5.21 Lateral Migration @ Bumbong Lima

It can also be considered that the model Fluvial 12 (Figure 5.22) provided sediment transport rates of the bed material of the order of 50,000 tons during the three day simulation of the 2003 flood and 163,000 tons after the flood.

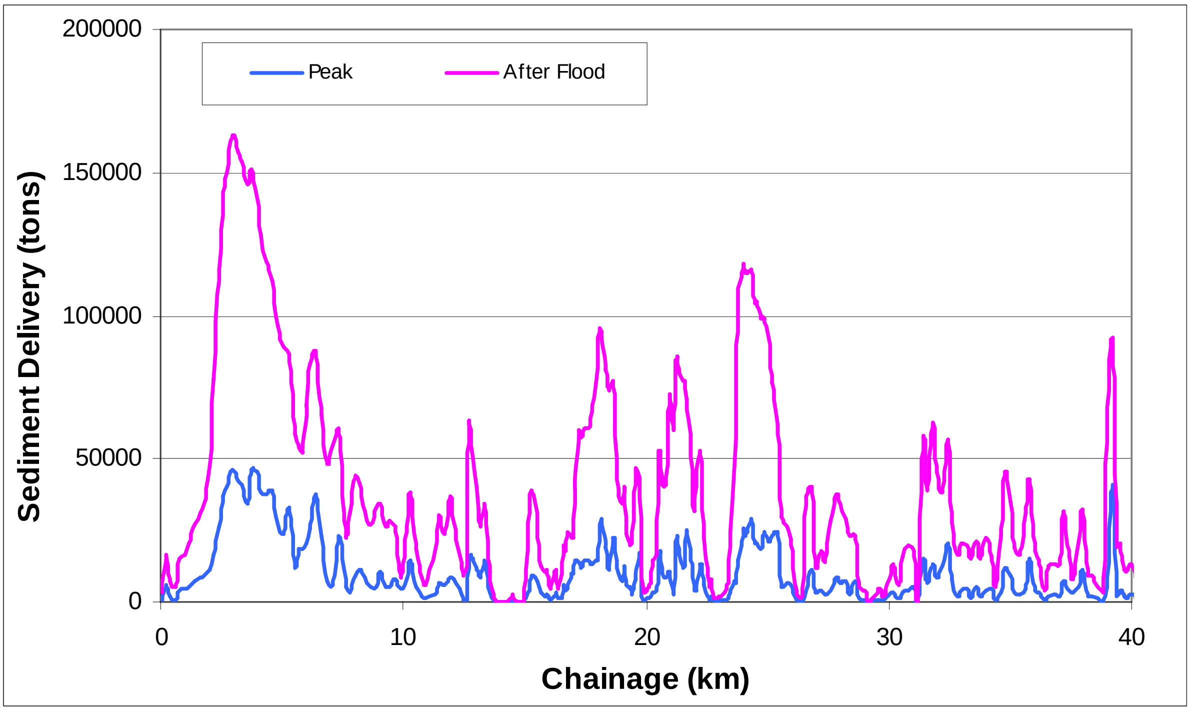


Figure 5.22 Sediment Delivery during October 2003 Flood

Chapter 6

Proposed Design Mitigation and Protection Works

6.1 Regional Storage

Potential sites have been screened for additional flood storage for Sg. Muda. Factors considered in the screening process include:

(a) topography and geotechnical aspect
(b) proximity to flood-prone areas
(c) upstream flooded area
(d) land acquisition sites

The main aspect under consideration has been to examine the topography, soil type and land use of the Sg Muda. As shown in Figure 6.1, the topography of the watershed indicates very steep mountain slopes on the eastern side of the watershed. Some of the important features include the narrow gorge where Muda Dam was constructed. It is noticeable however that the area upstream of Muda Dam does not have very high slopes and the flow seems to gradually converge into the reservoir. The area upstream of Muda Dam is also well forested. On the contrary, the steepest areas were found in the valley north of Baling. It is noticeable that rain in this area would trigger runoff to the Chepir, Ketil and Baling Rivers. This combination may cause significant floods near the confluence of the Ketil and Sg Muda, particularly near Kuala Ketil. There is no other appropriate site with substantial flood storage capacity in the southern part of the watershed.

The possibility of adding storage capacity at Muda Dam has also been explored. The northern part of the watershed experienced large rainfall in 1988, but this was not the case in the 2003 flood. It was thus concluded that adding storage capacity in the northern part of the watershed would not significantly reduce the magnitude of the flood peaks that seem to be rather caused by the confluence of the Muda, Ketil, Sedim and Karangan. The most critical rainstorms affecting the magnitude of large floods in the lower reach of the Muda river will be observed when the rainfall occurs in the southern part of the watershed.

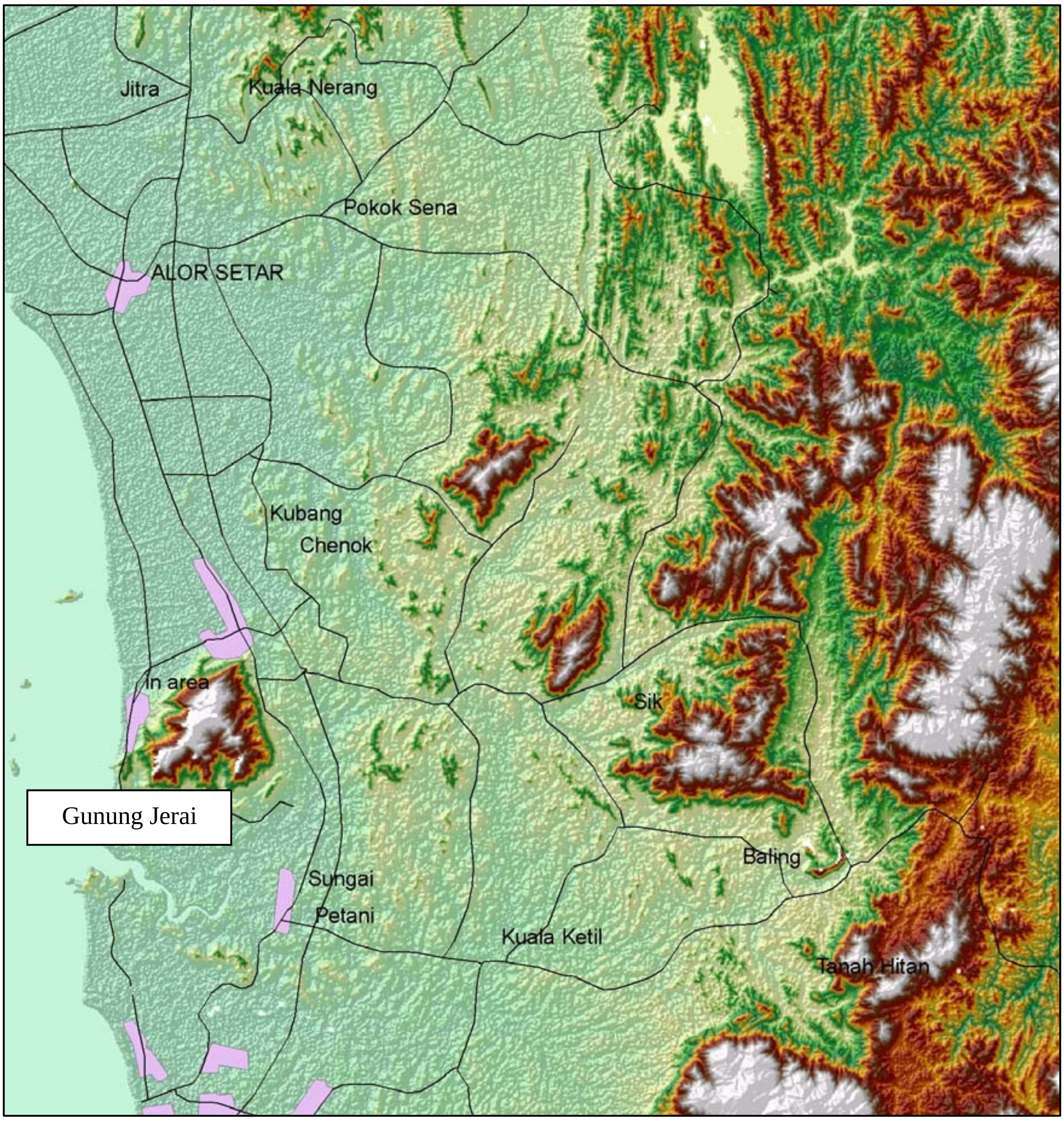


Figure 6.1 Topographic Map for the Sg Muda Area

Some additional views from Google Earth are shown in Figure 6.2 to point out that the area upstream of Muda Dam is well forested. The presence of vegetation should increase infiltration, increase resistance to flow, slow down the drainage and thus attenuate the flood. The increase human activities in the areas downstream of Muda Dam as well as in the area of Baling and Kuala Ketil are likely to increase the magnitude of the floods of the lower reach of the Muda River. More specifically, the area around Kuala Ketil is shown in Figure 6.3 as being increasingly developed and this is likely to increase the magnitude of flooding in the south eastern part of the watershed.

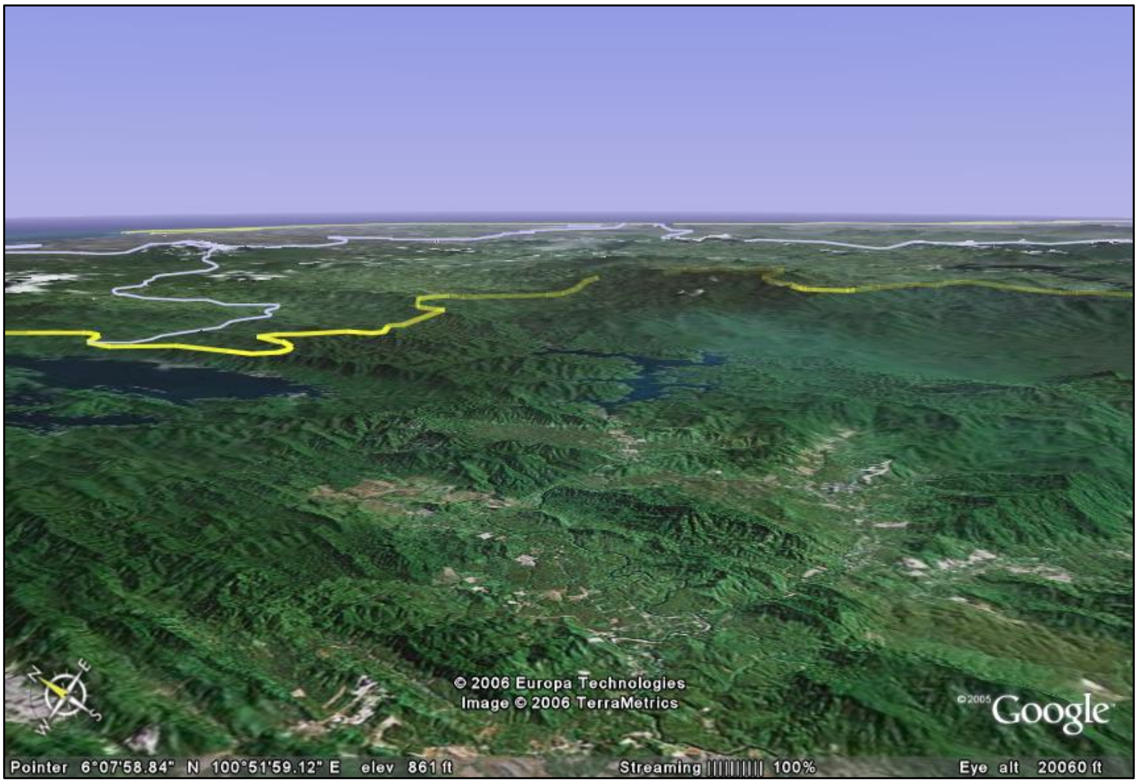


Figure 6.2 Google Earth Map Highlighting The Dense Forested Areas of the Upper Part of the Muda Watershed, Specifically Upstream of Muda Dam

Figure 6.3a Google Earth Map Highlighting the More Developed Part of the Watershed between Kuala Ketil and Baling

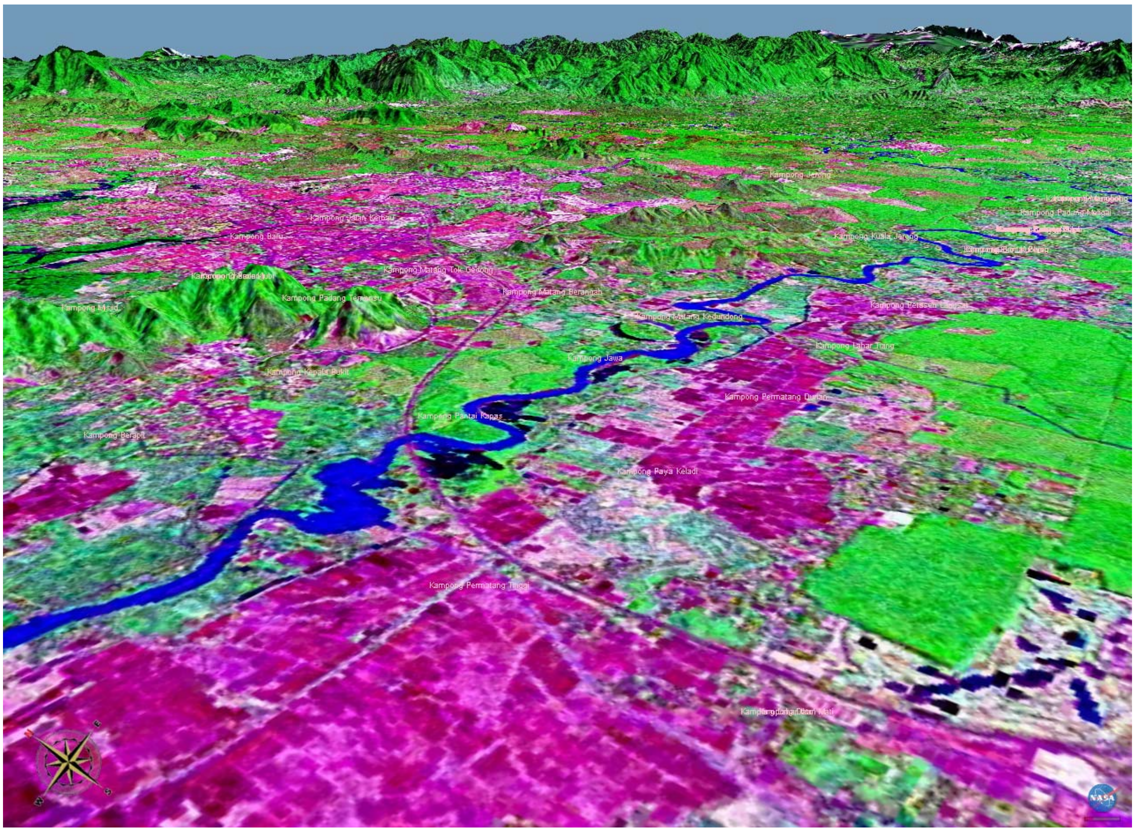


Figure 6.3b More Developed Part of the watershed in the lower reach of the Muda River (green is forested and purple is developed)

The watersheds of the Chepir and the Ketil largely contributed to the 2003 flood. The runoff generated from the steep hillslopes of these tributaries contributes to flash floods of high magnitude. This results in areas prone to flooding in the lower areas of each tributary and also near their confluences with the Sg Muda. For this reason, the idea of possibly using Muda Dam for possible flood control besides water supply has not been explored further. A closer examination of the topographic maps shown in Figure 6.1 also demonstrated that there is no easy location on the Ketil River where a dam could be built. There does not seem to be a readily feasible way to attenuate the flash floods from intense rains on the southern part of the watershed.

The location of flooding from Butterworth to Sungai Petani during the 2003 flood is shown in Figure 6.4. The flooded areas also extended north and south of the Muda watershed boundaries such that plans to possibly divert water in other areas may not be a desirable strategy as long as the population is well distributed in the area. It is particularly interesting to observe that the area of Sg. Korok and also the possible floodway to Sg. Merbok also seem to be flooded. The possibility of diverting additional water in these areas may cause additional problems (see Section 6.2.4 below).

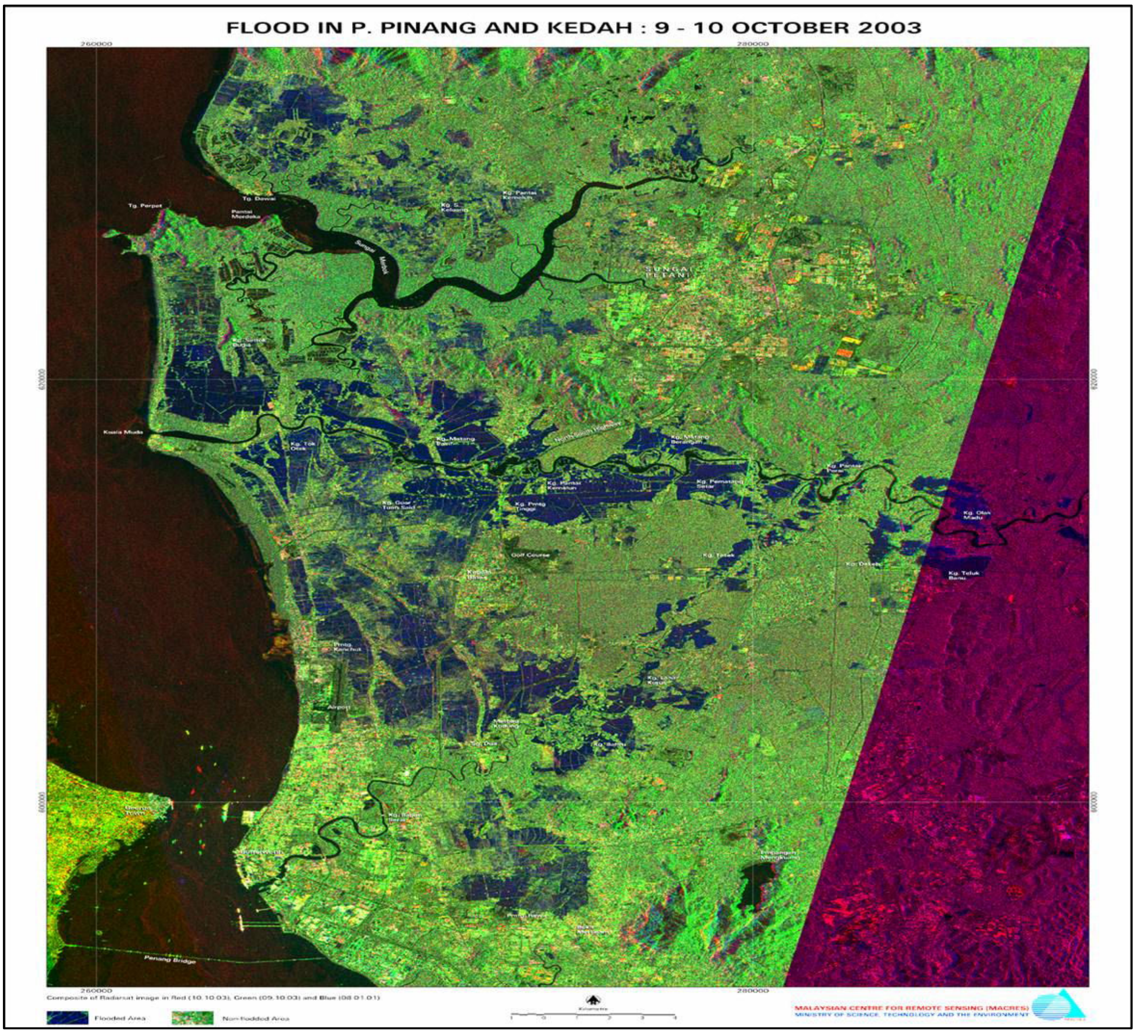


Figure 6.4 Map showing the extent of flooding in the lower Sg Muda watershed on October 9-10, 2003

6.2 Natural River Design

The design mitigation analysis stems directly from the scope of work. The following principal aspects are specifically reviewed: (1) rainfall data; (2) stage and discharge records; (3) alluvial river geometry; and (4) design criteria for the Flood Control Remediation Plan.

6.2.1 Review of the Rainfall Data

The spatial distribution of the rainfall precipitation during the major events has been reviewed. More specifically, it is clear from the analysis of the 2003 rainfall data that most of the rain fell in the southwestern portion of the Muda watershed. As shown in Figure 6.5, the three day precipitation ranged from about 150 mm in the upper part of the watershed to 525 mm near Gunung Jerai. The values around 400 mm covered most of the western part of the Muda watershed. There are few reliable raingage stations in the southern part of the watershed. However, point values of about 225 mm were measured in a period of three days in 2003. Given the very high values near Gunung

Jerai, it is very likely that high precipitation totals fell in the mountains surrounding the Muda watershed. There is however insufficient measurable data to ascertain the case. Lower three-day rainfall totals were obtained in the northern part of the watershed and it should be considered that the average three day precipitation on the watershed in 2003 should be around 225-250 mm. The three-day watershed average precipitation total should be far less than 350 mm for the 2003 flood.

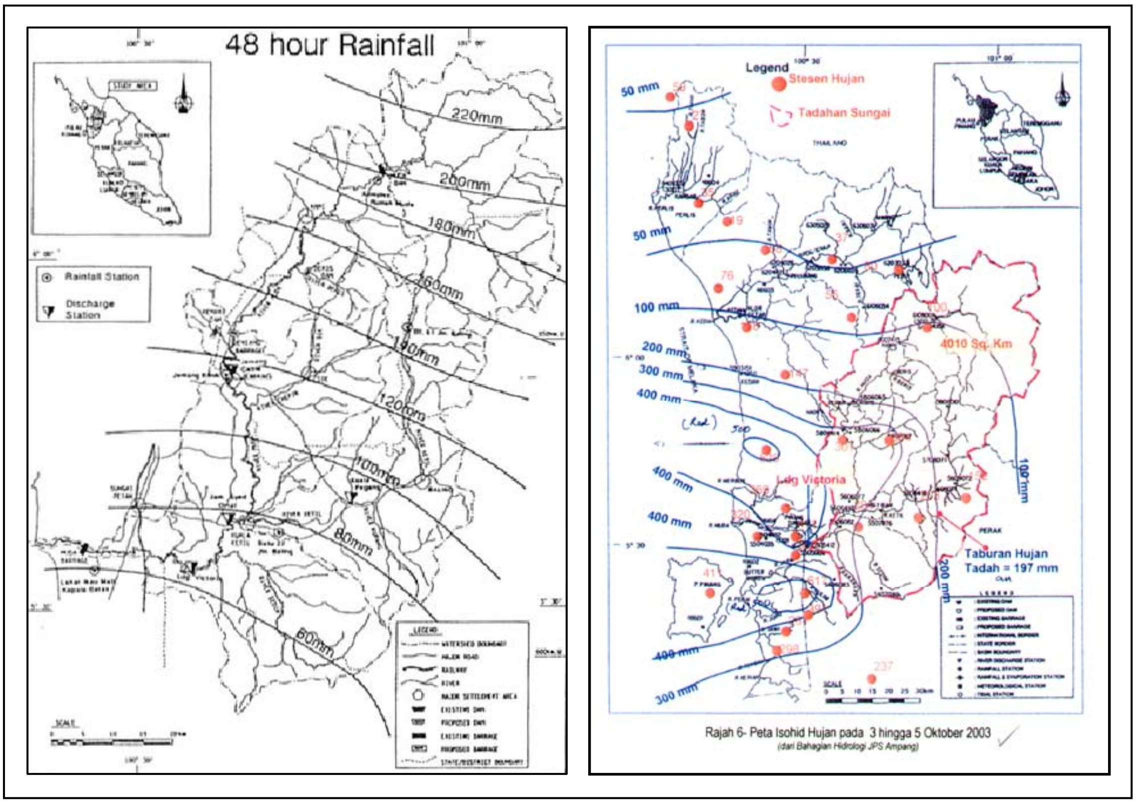


Figure 6.5 Map Showing The Two Day Rainfall Distribution During 1988 (Left) And The Three-Day Rainfall Distribution During October 2003(Right)

6.2.2 Runoff Discharge and Stage Records

The extent of flooding during the 2003 flood is shown in Figure 6.4. Accordingly, the southern part of the watershed experienced most of the flooding. It is clear that the high mountains northwest of Baling provided a major source of runoff draining to the Chepir, Baling and Ketil Rivers. Since these three tributaries eventually join the Sg Muda near Kuala Ketil, their steep slopes and short times of concentration contributed to the large magnitude of the 2003 flood. It is also likely that the Sg. Sedim and Sg. Karangan also increased the flow downstream of Kuala Ketil. In view of the fact that ways to store floodwaters can hardly be found in this relatively flat area of the watershed, there seems to be no other alternative but cope with the high magnitude floods that this region is prone to during the monsoon season.

The stage-discharge relationship was also examined for the entire period of record. As illustrated in Figure 6.6, the shifts in stage-discharge relationships reflect the variability in at-a-station hydraulic geometry of the Sg Muda. It is clear that the bed degradation can be attributed to two main factors: (1) the sand mining activities that have been permitted in the lower portion of the river; and (2) the natural deformation of the river during the large flood events. Overall the major bed degradation trend that has been noticed is a major concern for the stability of the structures such as the bridge piers and intakes to irrigation canals (see further discussion in section 6.2.4). The large variability in the stage-discharge relationships also precluded further analysis of discharge estimates based on stage records.

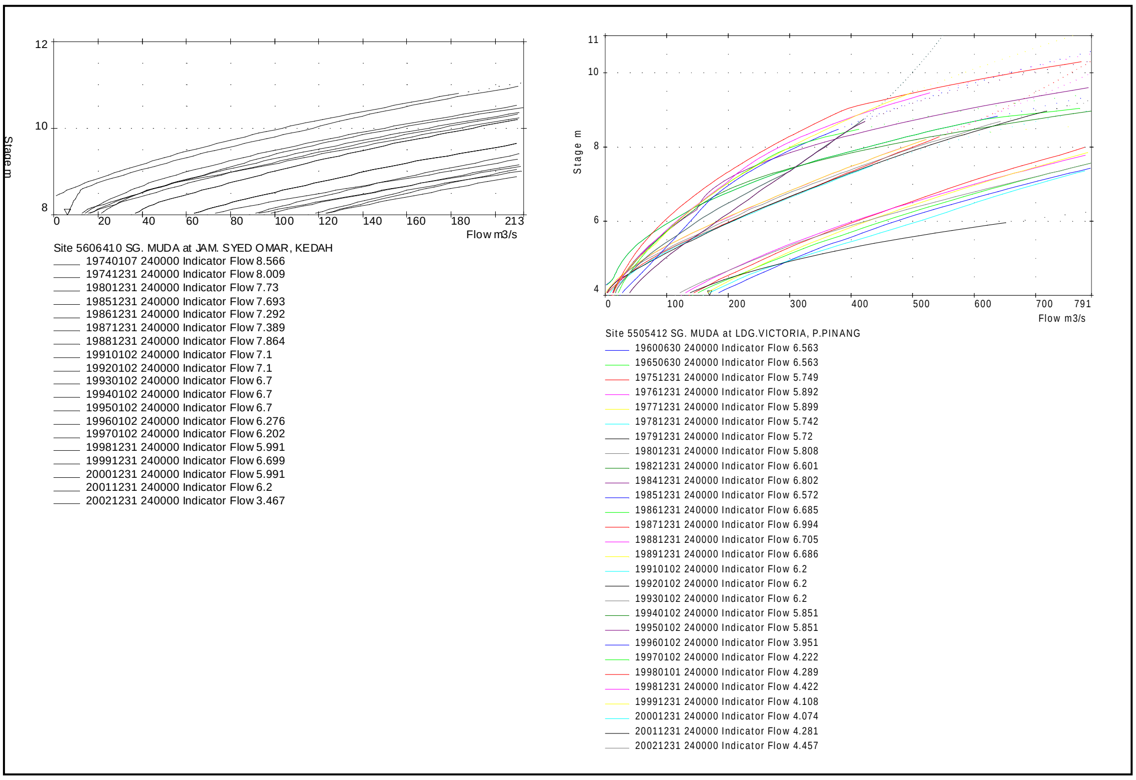


Figure 6.6 Stage-Discharge Relationships at Syed Omar (Left) and Ladang Victoria (Right)

The measured discharges at the various gauging stations of the Sg. Muda were reviewed in order to determine the magnitude of the runoff events leading to major floods (see further discussion in section 2.3). It is important to examine the flood frequency analysis in light of the 2003 flood. The major floods of 2003, 1998 and 1988 have been considered. The review indicates that the 2003 flood at Ladang Victoria was the highest discharge measured in a 44 year period. It is this considered that the discharge of 1,340 cumecs measured in 2003 is the highest during that period of record. This value, which is based on measurable peak discharges, provides a reliable and long period of record Ladang Victoria. This measured value of 1,340 cumecs over a period of 44 years should be very close to the 50-year flood.

A flood frequency analysis by DID and also independently done in this study provides very consistent results with 50-year flood peaks between 1,254 and 1,275 cumecs at Ladang Victoria. It is therefore concluded that this discharge of 1,340 cumecs is slightly larger than the 50-year peak discharge. Consequently, it should seriously be considered as the design peak discharge for the lower Muda River. The period of return of such event is about 50 years and the backwater and sediment transport analyses should be carried with this discharge for the long-term analysis of sediment transport and changes in bed elevation. It is most important to consider that the bund elevation at different locations in the lower 43km of the Muda River should be determined from the flood stage calculations at a discharge of 1,340 cumecs plus freeboard.

6.2.3 Changes in Alluvial River Geometry

This section examines the equilibrium downstream hydraulic geometry of the Sg. Muda. It is used for comparisons with the proposed design river widths, depths, velocities and slopes in the lower reach of the Sg. Muda. The analysis requires the design discharge, riverbed slope and grain diameter of the bed material of the Lower Sg. Muda. It is important to examine if the proposed river width and depth and also the levee/bund width are appropriate for the high discharge that is proposed in this reach.

The field measurements (see section 5.1) show that the bed material load varies from 1-2 mm from Ladang Victoria to Pinang Tunggal. The bed material decreases in size downstream of the Muda Barrage where the median grain diameter ranges around 0.1 mm with well graded mixtures of sand and silt. Recent suspended material samples showed particle size distributions ranging from 2 to 100 microns with a median particle diameter of about 10 microns for the suspended sediment.

Figure 6.7 shows that the sediment rating curves are relatively consistent over time and have not changed nearly as much as the stage-discharge relationships of Figure 6.6.

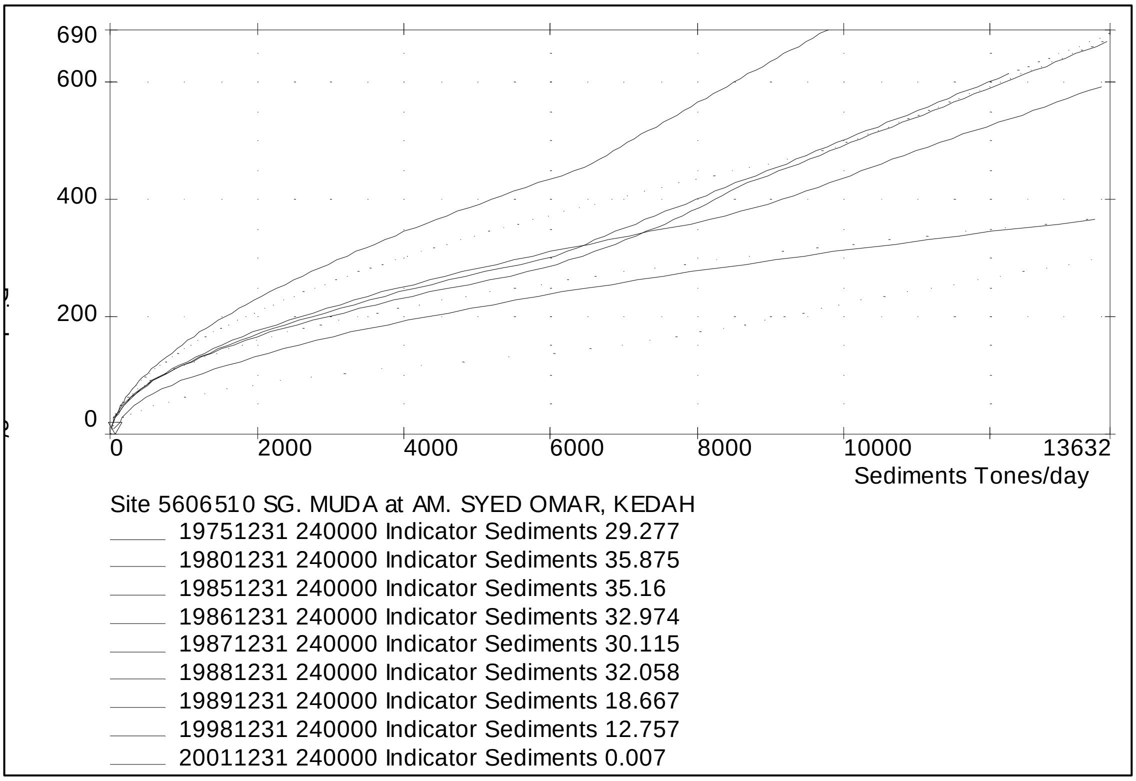


Figure 6.7 Sediment Rating Curve at Syed Omar from 1975-2001

The mean daily sediment load estimate at Syed Omar is about 3,757 tons per day. This corresponds to about 1.35 million tons of sediment per year. If all this sediment deposits over the 43km reach, this would result in a mean accumulation of about 5 cm per year. Moreover, this estimate includes washload and bed material load. Given that the d_{50} for the bed material ranges from about 1-2 mm at Ladang Victoria to about 0.1-0.2 mm at Kuala Muda, it is most likely that the greater majority of the suspended sediment load is going to be wash load. It is important to notice that the bed material load will be less than 100,000 tons per year. This number seems high, e.g. the JICA report stated about 10,000 tons per year of bedload material. It can also be considered that the model Fluvial 12 (see section 5.3.6) provided sediment transport rates of the bed material of the order of 50,000 tons during the three day simulation of the 2003 flood .

Nevertheless, this high estimate of the sediment load would result in a mean annual accumulation of the order of 5 mm per year, which will not exert a significant impact on bed elevation changes for many years to come. The modeling results with Fluvial 12 also substantiate this conclusion that the bed elevation changes are not expected to be significant under the current flow conditions (see section 5.3.6). It is thus concluded that sand/gravel mining activities contribute to most of the bed elevation changes in the lower reach of the Sg Muda. This is also in agreement with the analysis of JICA (1995), where they reported sand mining volumes up to 1.2 million tons per year.

The lower Muda River has become an incised meandering channel. The main reason for this incision is directly attributed to the excessive gravel mining activities that the river has experienced over a number of years. Under the current conditions of a relatively deep channel, further widening of the cross section would result in very low flood stages and may negate the need to raise the bund elevation.

A review of aerial photographs, site visits and field photographs indicates that the river banks are relatively stable although quite steep in many places. The channel incision is primarily due to excessive sand mining. This has resulted in excessive degradation of the main channel. The banks have not changed much except near Merdeka Bridge in an area where the flow depth is controlled by the Muda Barrage. It is recommended to reduce the bank slope in order to stabilize the banks. The plan presented by Wira Kerjaya is relatively sound and some minor modifications in channel realignment will be suggested in the following sections. The concept of widening the river is not viewed as necessary considering that the 50 year flood discharge of 1,340 cumecs is about 25% lower than the peak discharge value of 1,815 cumecs proposed for the design (JPZ, 2000). It is recognized that some of this material can be used to raise the levees/bunds and that the excavation will also result in increasing cross sectional area to reduce the stages for better flood carrying capacity. However, the propose channel widening may result in destabilization of the river channel, particularly in the vicinity of Merdeka Bridge and the Highway. The design of revetments to stabilize the river banks as indicated by Wira Kerjaya appears to be relatively sound. The design including a reduction of bank slope to 1V:3H is very appropriate and the addition of large quantities of riprap at the toe of the bank protection for launching purpose is also well suited to prevent further degradation of the river bed due to excessive gravel mining.

Figure 6.8 illustrates the changes in cross sectional geometry at Syed Omar from 1991-1998. It is clearly shown that the bed has degraded over this period. It corroborates the shifts in the stage-discharge relationships noticed in Section 6.2.2. For the bank stabilization plan to be effective, it will be essential to eliminate all in-stream sand and gravel mining activities on the river bed and within 50 m of the river banks in order to assure the proper use of the river bank stabilization structures. Alternative locations for sand mining are strongly recommended. Specifically, a 50m riparian corridor along the river banks should be left in place and all in-stream mining activities should be prohibited in order to ensure stability of the proposed river bank stabilization features. Off-stream sand and gravel mining activities should be allowed on the flood plain at a minimum distance of 50m from the river banks. Such borrow pits may become effective flood storage areas when the river levels exceed the floodplain elevation. Furthermore, the borrow areas can eventually be filled with low water elevations to provide suitable habitat for aquatic species and waterfowl. This environmental benefit of off-stream sand and gravel mining operations should be considered. The recommendation is thus specifically prohibit all in-stream sand and gravel mining operations between of Sg Muda between Ladang Victoria and the Muda Barrage. Of-stream mining operations could be allowed on the flood plain between the bunds at a minimum distance of 50 m from the riverbanks.

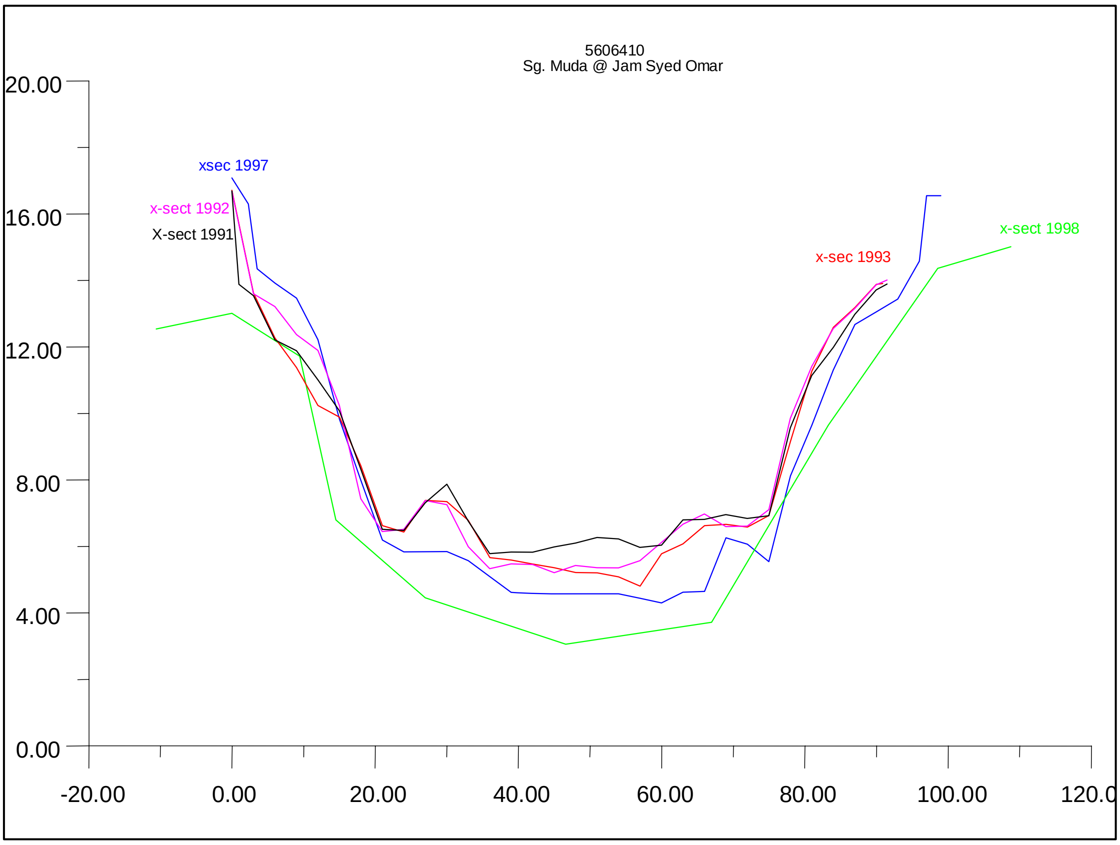


Figure 6.8 Changes in Cross Sectional Geometry at Syed Omar from 1991-1998

The lateral mobility of the lower 43 km of the Sg Muda has been examined and this river is viewed as being relatively stable. Despite incision of the river bed and except for local bank caving, the steep river banks have remained relatively stable despite the conveyance of the large floods in 1988, 1998 and 2003. For this reason, the plan to provide river bank stability in a relatively narrow floodplain seems possible. The need for additional channel widening does not seem necessary. From the aerial photographs examined, there is little evidence of lateral channel migration. Some very sharp bends of this channel seem to have been stable for a long time and this is quite amazing for an alluvial channel. The reason can be attributed to bank vegetation and the presence of large quantities of cohesive material in the banks. Two reaches nevertheless deserve consideration for channel improvement and these two reaches will be specifically discussed in the next section.

6.2.4 Design Criteria for the Flood Control Remediation Plan (FCRP)

Design discharge and bund height

The Flood Control Remediation Plan has been reviewed with the perspective to possibly enhance the proposed design. Some of the issues that were raised during the preliminary review of the FCRP focus on the lower 43 km reach of the Sg. Muda. The sketch of the proposed bunds in the lower reach of the Sg Muda is shown in Figure 6.9.

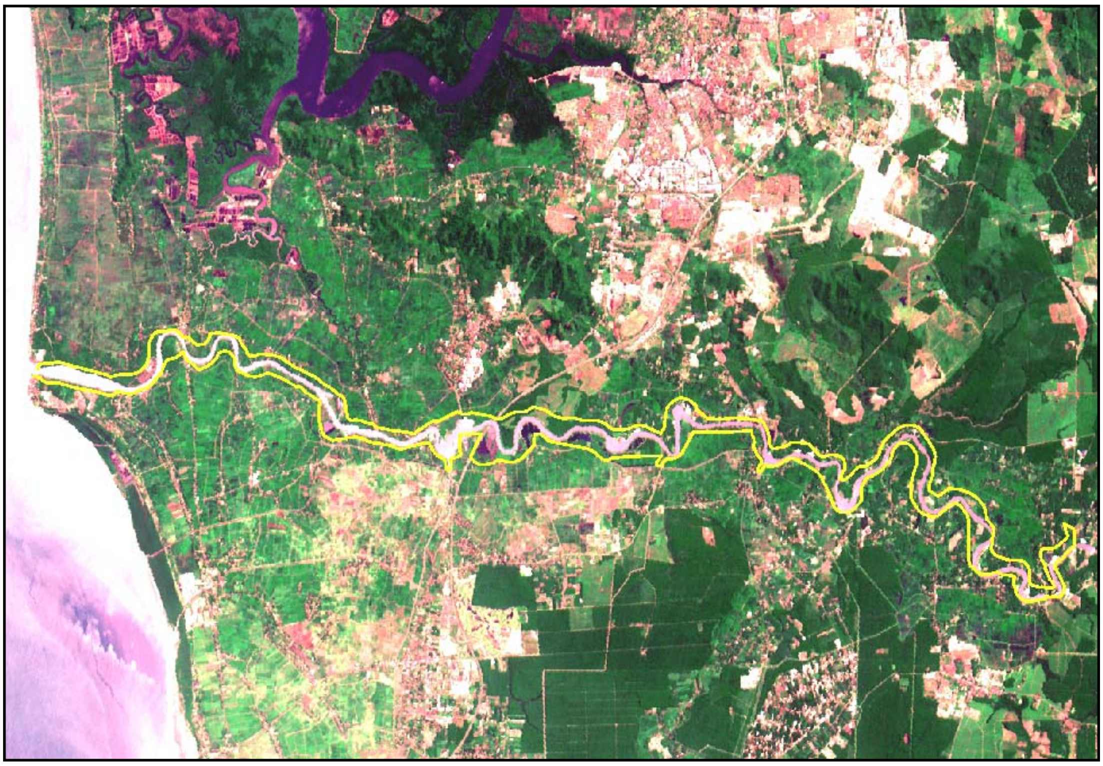


Figure 6.9 Sketch of the bund location in the lower 43 km reach of Sg. Muda

Keeping the bund height at the proposed level is certainly very conservative and should contain flood with frequencies much greater than 100 years. The hydrological analysis yielded discharges greater than the 2003 flood and design discharges as high as 1,815 cumecs have been obtained by mathematical models. However, a larger level of uncertainty was noticeable in the calibration and validation of these results. Indeed, the calibration and validation results are in very good agreement with the 2003 and 1988 observations at Syed Omar, there are several hundred cumecs of difference between the calibration and validation results obtained by the same model when applied at Ladang Victoria (see section 4.2). The reason for these discrepancies is not obvious, but the analysis is based on only four rain gauges and this seems to be a rather limited number to represent the spatial variability of rainfall on this relatively large watershed. Also, two important tributaries in Sg Sedim and Karangan bring surface runoff from relatively steep mountainous region in the southern part of the watershed. The 2003 flood should serve as the design discharge for the bund height plus freeboard.

The recommended height of the bund/levee stems should be determined from the flood stage corresponding to the design peak discharge of 1,340 cumecs plus a 1 meter freeboard. The comparisons between the bund height determined by JPZ and the water level of the 2003 flood without channel widening indicate that the proposed bund height is typically 1-2 meters higher than the highest recorded flood level (see section 4.2). Further widening of the channel cross section would result in further lowering of the bund elevation. If the option to widen the channel is retained for the final design, it is strongly recommended to determine the new elevation of the bund height from the design discharge of 1,340 cumecs plus 1 meter of freeboard. The resulting bund elevation should be much lower than proposed in the design. Such analysis would result in significant cost savings.

Lateral migration and floodplain width

The proposed location of the bund has been considered in terms of flood carrying capacity of a narrow flood plain as well as the consideration for the communities currently living in proximity of the river, see Figure 6.10.

Figure 6.10 People living near the banks of Sg. Muda

The lower reach of the Sg Muda has sustained major floods in recent years without apparent major lateral shifting in its river course. The fact that the banks are resilient to lateral mobility despite major floods and excessive degradation from sand and gravel mining is an indication that a narrow floodplain corridor from Ladang Victoria to Kuala Muda may be viable for this flood control remediation plan.

Proposed channel realignment

Another aspect relates to the sinuosity of the river in the lower end of the Sg. Muda. The analysis of the sinuosity of the river and the possibility of realignment to avoid excessive lateral migration of the channel has been explored. Most of the reach seems relatively stable and should be able to sustain large floods. However, two main areas have been identified where channel relocation should be considered (see section 5.3.6). These two reaches are identified in Figures 6.11a and 6.12. It is proposed to consider straightening these two river reaches in order to improve the conveyance of the river during floods. It is also clear from the river modeling that these two sharp bends are subject to large river bed deformations that could potentially lead to lateral migration and more serious structural instabilities of the river reaches. The proposed realignments are sketched in Figures 6.11b and 6.12 respectively. It is recommended to recalculate the flood stage elevations for the entire reach of Sg Muda. The proposed realignments should result in further lowering of the bund elevation and lead to additional cost savings.

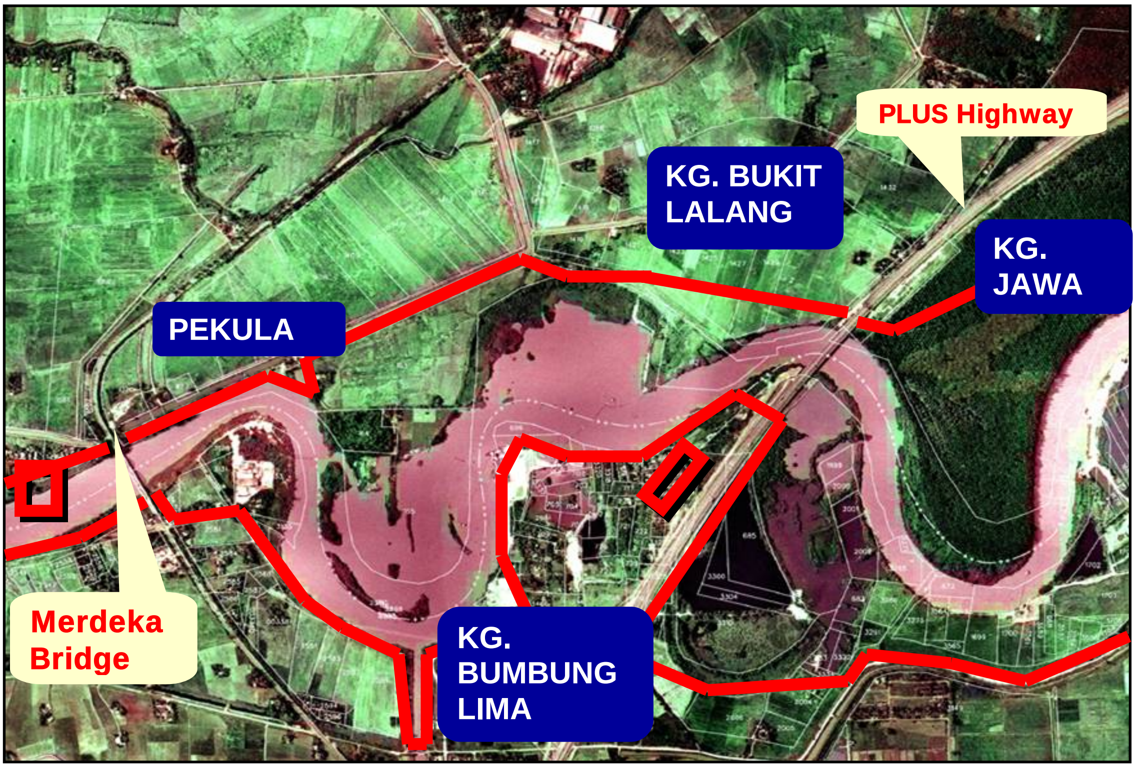


Figure 6.11a Reach from the Plus Highway to Merdeka Bridge

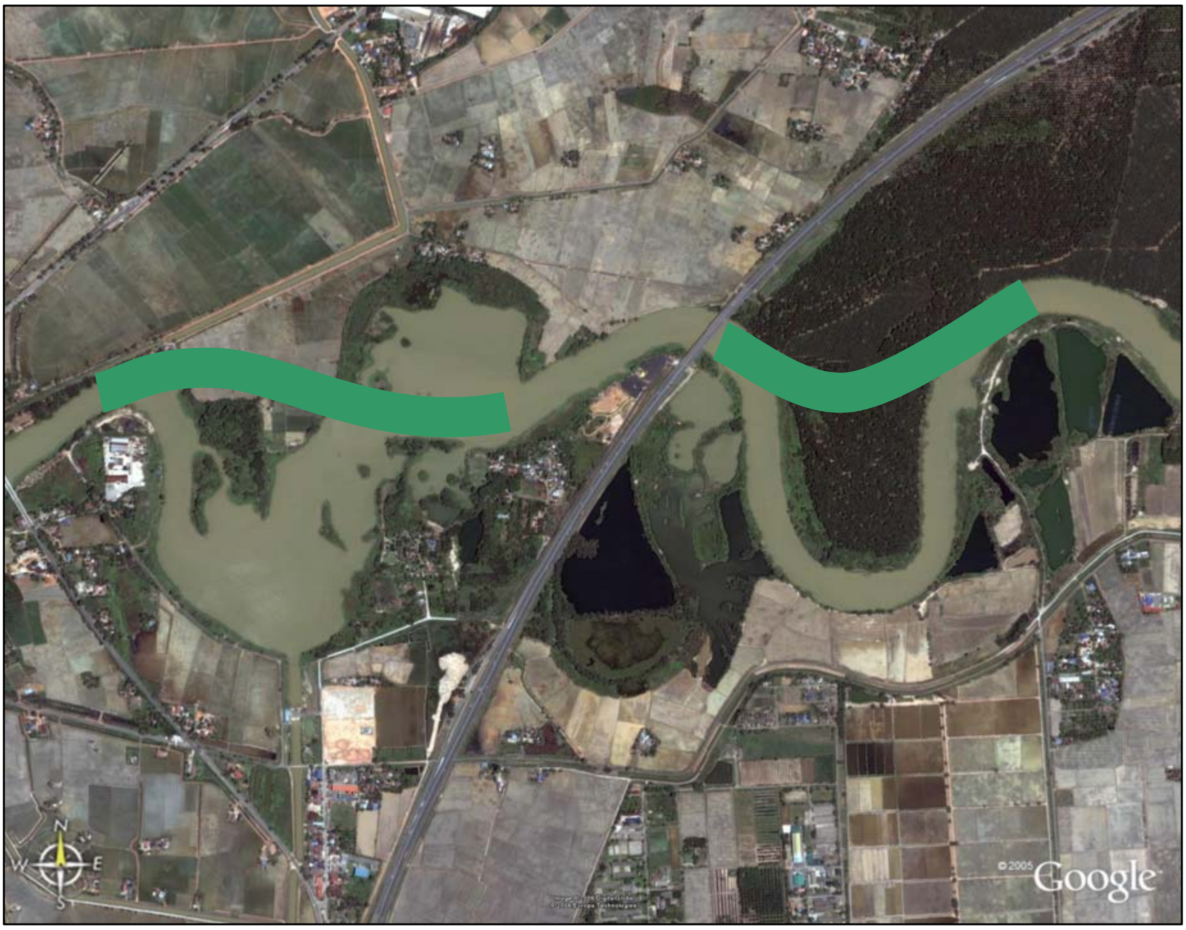


Figure 6.11b Proposed Relocation of the Channel near Merdeka Bridge

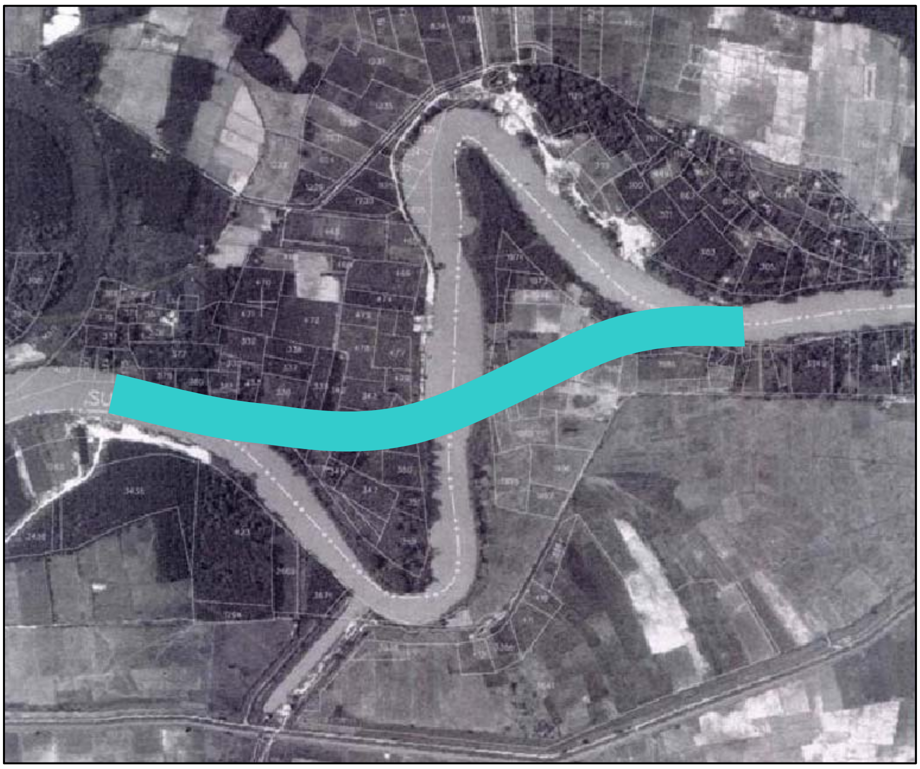


Figure 6.12 Proposed Relocation of the Channel near Lahar Tiang Pumping Station

Flow diversion

The possible diversion of part of the flow to the Merbok floodway has also been considered. It is shown in Figure 6.13 that this proposed floodway would require a long bund. This requirement for additional material required to build the floodway as well as the construction of an additional barrage should far exceed the benefits of the reduced bund height of Sg. Muda between the Merdeka Bridge and the Muda Barrage.

Figure 6.13 View of the Area for the Possible Sg. Muda to Sg. Merbok Diversion

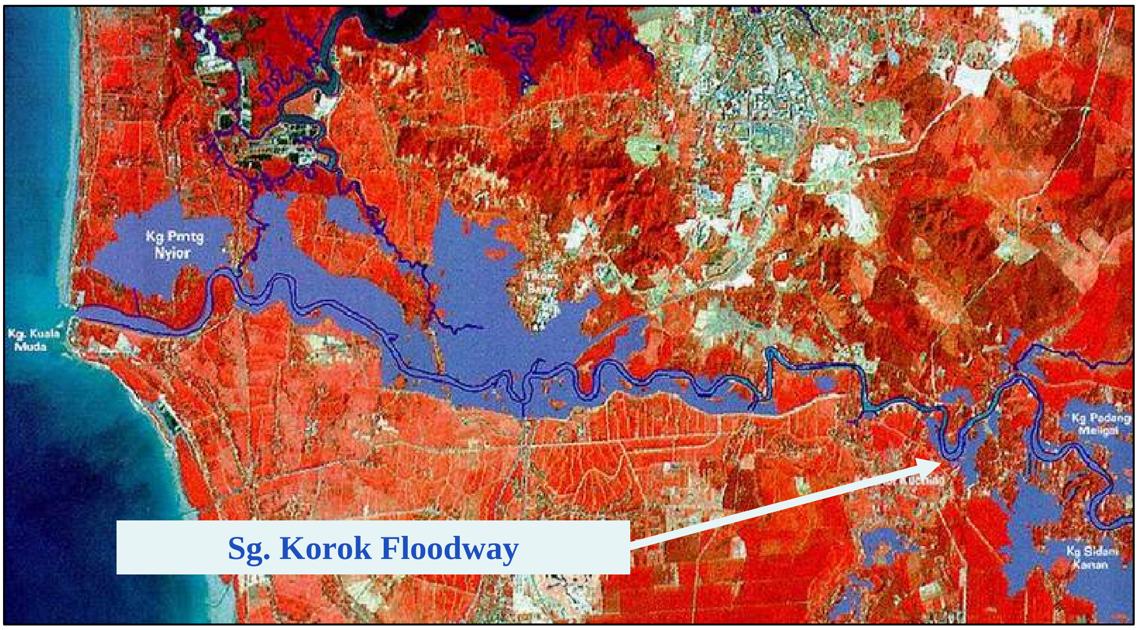


Figure 6.14 Flooded Area of the Lower Sg Muda during the 1998 Flood

Also, it should be further considered that most of the proposed floodway area was naturally flooded during the 2003 and the 1998 floods, as shown in Figures 6.4 and 6.14 respectively. It is also understood that an environmental study has already been done on the possible impact on the Merbok. All things considered, it seems advisable not to proceed with the proposed Merbok diversion. The new Muda Barrage that is readily built would be well designed to handle high floods in the Lower Sg Muda.

The possibility of an emergency diversion through Sg. Korok on the south side of Sg Muda near Ladang Victoria has also been considered. Unfortunately, without any water diversion, the upper area of Sg. Korok was also flooded in both 2003 and 1998, as shown in Figures 6.4 and 6.16. It is therefore considered that such a diversion could only be viable as an emergency flood way that could potentially cause structural problems to the proposed bunds of Sg Muda.

The possibility of a tsunami at the Sg Muda river mouth near Kuala Muda and its possible impact on the flood control works has been considered. Of course, the analysis needs to keep in mind that the vicinity of Sg. Merbok is without flood protection works like the new Sg. Muda Barrage. From the site visit in May 2006, it appears that the new Muda barrage shown in Fig. 6.15 is the best possible structure to alleviate and possibly eliminate the possible up-river surge caused by a tsunami.

Figure 6.15 New Sg. Muda Barrage

Bridge piers and bridge crossings

Finally, the footing elevation of the bridge piers has been reviewed for the bridge crossing located in the Sg Muda downstream of Ladang Victoria. At several locations, the bridge pier footings have been exposed as a result of the river bed degradation from sand and gravel mining operations on Sg. Muda. Of the locations reviewed, the Merdeka and Plus Highway bridges appear to be fine as a result of the backwater from the Muda barrage. These locations do not require attention. The main concern is at Ladang Victoria where the bridge pier footings are found exposed far above the water surface, as shown in Figure 6.16. It is imperative to retrofit these bridge piers to ensure the structural stability of the bridges. Two types of structures can be considered: (1) a grade control structure that would maintain the river bed elevation at an elevation higher than the footing of the bridge piers; or (2) a strengthening of the bridge piers through caissons, sheet piles with grouting that would consolidate the interaction of the bridge piers and the piles. The new footing depth should be set at an elevation below the current bed elevation. It is also important to make sure that further sand and gravel mining will not be allowed in the future.

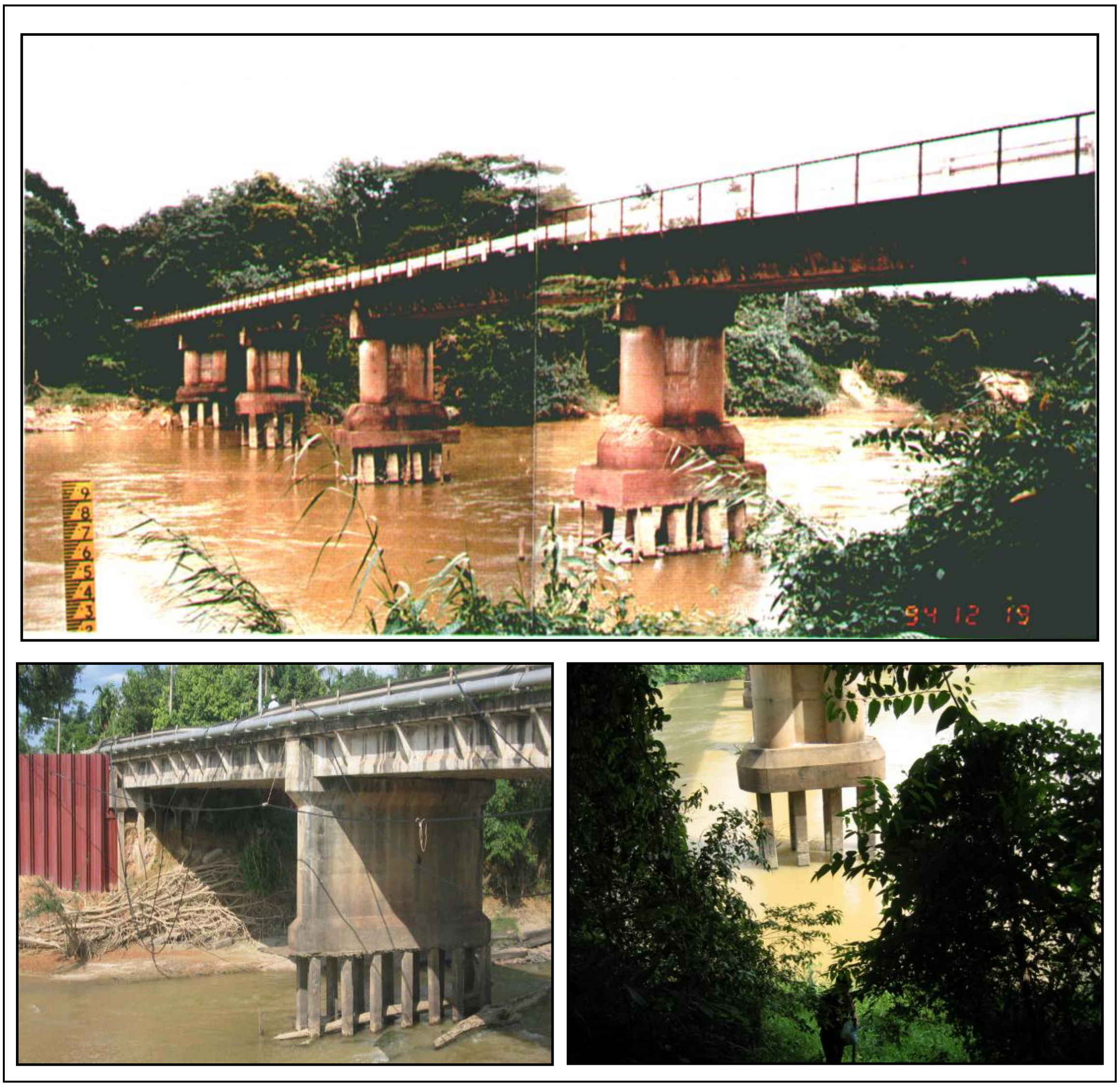


Figure 6.16 Exposed Footings of the Bridge Piers at Ladang Victoria (Above) and Lower Right, and Near Kuala Ketil (Lower Left)

It is also very important that although this analysis focuses on the lower reach of the Sg Muda, headcutting and nick points are expected to develop and migrate upstream. For instance, it has been noticed that the bridge at CH-25 of Sg. Ketil has also experienced similar problems. This systematic degradation caused by sand and gravel mining endangers the stability of the bridges upstream and hence cause a threat to all vehicles crossing bridges on the Sg Muda and its upstream tributaries. Although this conclusion does not directly relate to the Flood Control Remediation Plan, it is certainly one of the most important findings of this study.

6.2.5 Summary of Specific Design of the Proposed Structures

The specific design of several parts of the Flood Control Remediation Plan has been reviewed. More specifically, some of the specific recommendations for design consideration include:

- The size, location and height of the bunds should be based on the flood elevation from the 2003 flood at a discharge of 1,340 cumecs plus a freeboard of one meter. Without any widening of the channel cross sections, the bund elevation proposed by JPZ is already about 1-2 m higher than the 2003 flood elevation (see section 4.2.6). The proposed bund height by JPZ appears to be highly conservative and will pass flows with period of return much in excess of 100 years. The bund elevation should be reconsidered and may result in significant cost savings.
- It is recommended not to widen the channel cross sections. The design flood discharge of 1,340 cumecs should be contained well within the lower bund heights. This results in cost savings for the proposed FCRP. Should some channel widening be retained in the final plan, it is further recommended to recalculate the new flood elevations. Channel widening will result in lower flood stages and lower bund elevations, thus resulting in significant cost savings.

- The specific design of the bank stabilization structures, particularly in sharp bends, is viewed as problematic. Two sites have been identified as shown in Figures 6.11 and 6.12 should be considered for channel straightening. This measure would result in lower resistance to flow, increased conveyance, reduced backwater effects and ultimately lower bund heights.

- Pumping stations for irrigation canals have been required on the Sg Muda as a result of the continuing degradation of the river. The degradation can be clearly attributed to the excessive sand and gravel mining of the Sg Muda. For the bank stabilization structures of the FCRP to be effective, it will be essential not to allow any in-stream sand and gravel mining activities in the future. It is proposed to allow off-stream sand and gravel mining activities at a minimum distance of 50 m from the river banks.

- The floodways to Sg. Merbok is not recommended because it would bring additional water to areas that were readily flooded in 1998 and 2003. The Merbok river diversion would also require long bunds and an additional barrage, which cost will not be economically justified.

- The potential diversion to Sg. Korok can only be justified as an emergency measure to prevent rupture of the proposed bunds designed in this FCRP. This diversions may alleviate the problem of flood mitigation on the Muda, but at the same time may exacerbate the flooding problems elsewhere.

- In view of excessive sand and gravel mining of the Sg Muda, the bridge pier footings at Ladang Victoria need serious and immediate attention. The excessive scour and river bed degradation near Ladang Victoria can cause major structural instabilities and the potential risk of collapse of some of these bridges needs to be prevented. The retrofitting of the footings of the bridge piers is urgent and essential. Similar problems are propagating upstream as a result of headcutting and riverbed degradation from sand and gravel mining. It is recommended to eliminate in-stream sand and gravel mining activities. Off-stream sand mining should be encouraged.

In conclusion, if the design of the bund height can be based on the 2003 flood discharge plus a one meter freeboard, the bund/levee height can be significantly lower than currently specified. The proposed widening of the cross-section also appears not to be necessary. Any channel widening should be carefully examined as it will result in reduced bund heights. These should result in significant savings for the overall cost for the Flood Control Remediation Plan. A plan to address the sand and gravel mining issues on this river is also strongly recommended in order to maintain the stability of the proposed river bank protection structures as well as the bridge piers. In-stream mining should not be allowed between Ladang Victoria and Muda barrage. Off-stream mining should be permitted instead.

Chapter 7

Conclusions and Recommendations

7.1 Conclusions

The Flood Control Remediation Plan (FCRP) has been reviewed with the perspective to possibly enhance the proposed design. The objectives of this review are: (1) ensure that design cross-sections and alignment of the main river channel are economic, effective and environmentally sound; (2) propose alternative designs for identified locations to meet the above requirements; and (3) examine the long term river behaviour through model studies to minimise expensive repair works in future resulting from the new alignment.

The scope of work of this report includes a review of:

(a) rainfall data in space and time leading to chosen flood events.
(b) runoff discharge and stage records of the chosen events;
(c) computer simulation of the flood events;
(d) computer simulation of long term river behaviour to determine stretches prone to meandering, hence needing extra protection;
(e) changes in alluvial river geometry in terms of aggradation and degradation as well as lateral channel migration as a result of the flood events;
(f) design criteria used for the Flood Control Remediation Plan;
(g) specific design of the proposed structures including levee protection, riverbank protection works and protection of bridge crossings and other structures.

In an itemized fashion, the main conclusions of this review are specifically:

(a) There is significant uncertainty in the determination of the three-day rainfall rates in 2003. The watershed average rainfall precipitation is difficult to ascertain from only four raingages. However, the three-day watershed average rainfall precipitation is found to be less than 300mm.

(b) The analysis of a 44 year measured discharge record at Ladang Victoria leads to a well defined 50-year flood peak discharge around 1,270 cumecs. Similar results are obtained from independent flood frequency analyses. This value is the most reliable estimate of the 50 year flood peak discharge. The 2003 flood with a peak discharge of 1,340 cumecs is recommended for the design of the FCRP. Comparatively, river stage records are highly variable as a result of excessive sand and gravel mining operations on Sg. Muda. Stage records should not be used to estimate flood discharges.

(c) Computer simulations of the flood events with the model HEC-HMS showed very good results for the calibration and validation of the discharge hydrographs at Syed Omar in 2003 and 1998 respectively. However, there is a significant variability (error of at least 100 cumecs) in both the calibrated and validated results at Ladang Victoria. This appears to be due to the limited number of raingages in the southern part of the watershed where precipitation showed spatial variability. When using the same high rainfall precipitation as JPZ, the HEC-HMS results are very consistent with their design hydrographs. However, as discussed above in (a), the three-day rainfall precipitation of 350 mm used to determine a 50 year peak discharge of 1,815 cumecs is viewed as excessively large. The results of these rainfall-runoff models are highly variable and less reliable than the measured flood discharges at Ladang Victoria. It is concluded that the 50-year design hydrograph with peak discharge of 1,815 cumecs is excessively large. The value of peak discharge of 1,340 cumecs should be used for the design. The design discharge reduction by 25% should results in significant cost savings for the FCRP of Sg Muda.

(d) The model Fluvial 12 has been used for the lateral and vertical elevation changes during the 2003 flood event. Most cross sections are very stable and the vertical elevation changes are small due to the low sediment transport rates of the bed material. The sand and gravel mining operations are far exceeding the natural sediment transport rates of the river. These operations can cause serious problems to the stability of the proposed structures of the FCRP. It is concluded that in-stream sand and gravel mining operations should not be allowed.

(e) The model Fluvial 12 also highlighted potential lateral migration changes near the sharp bends upstream of Merdeka Bridge and near Lahar Tiang. It is concluded that channel realignment near Merdeka Bridge and Lahar Tiang would minimize potential lateral migration problems of Sg Muda. These realignments should also result in better flood conveyance, reduced roughness and backwater and lower bund elevation.

(f) The proposed bund height under Alternative 2 of JPZ appears to be highly conservative and will pass flows with period of return much in excess of 100 years. The proposed design criterion for the FCRP is to add a one meter freeboard to the flood stage calculated for the current channel cross sections, without widening, using the 2003 flood peak of 1,340 cumecs. The results obtained from the model HEC-RAS result in lowering the proposed bunds by 30cm to 1m over the 43 km reach of Sg. Muda.

(g) It is recommended not to widen the channel cross sections. Channel widening will result in lower flood stages and lower bund elevations, thus resulting in additional cost savings. These cross section were not available to us, but further analysis should be carried out if channel widening is retained as an option. In view of excessive sand and gravel mining of the Sg Muda, the bridge pier footings at Ladang Victoria need serious and immediate attention. Pumping stations for irrigation canals have also been required on the Sg Muda as a result of the continuing degradation of the river. The degradation can be clearly attributed to the excessive sand and gravel mining of the Sg Muda. For the bank stabilization structures of the FCRP to be effective, it will be essential not to allow any in-stream sand and gravel mining activities in the future. It is proposed to allow off-stream sand and gravel mining activities at a minimum distance of 50 m from the river banks. The floodways to Sg. Merbok is not recommended because it would bring additional water to areas that were readily flooded in 1998 and 2003. The Merbok river diversion would also require long bunds and an additional barrage, which cost will not be economically justified. The potential diversion to Sg. Korok can only be justified as an emergency measure to prevent rupture of the proposed bunds designed in this FCRP. This diversions may alleviate the problem of flood mitigation on the Muda, but at the same time may exacerbate the flooding problems in the upper watershed of Sg Perai.

7.2 Recommendations

The Flood Control Remediation Plan (FCRP) has been reviewed with the perspective to possibly enhance the proposed design. The conclusions of this report demonstrate the potential for significant cost saving features as well as structural stability measures. The specific recommendations for the FCRP include the following:

(a) It is proposed to reduce the design discharge from 1,815 cumecs to the proposed discharge of 1,340 cumecs from the 2003 flood. This design discharge reduction of about 25% should yield significant cost reduction of the total cost of the FCRP. It is recommended not to widen the channel. However, any widening of the channel cross sections would result in further lowering the bund elevation thus further reducing the cost of the FCRP. It is recommended to run the HEC-RAS model with the proposed widened cross sections for comparison with the current results (these cross section were not available for this study). More specifically, the effects of the excessive channel widening downstream of the Muda barrage should be considered in terms of bund height and also possible sediment accumulation near the mouth of Sg. Muda.

(b) The suggested channel realignment is expected to result in reduced roughness, reduced backwater effects and thus lower bund elevations. It is recommended to run the HEC-RAS model with consideration of the proposed realignments. The results of these two measures should result in a lower cost of the FCRP.

(c) It is strongly recommended to prohibit all in-stream sand and gravel mining activities between Ladang Victoria and the Muda Barrage. Off-stream mining activities should instead be allowed at a minimum distance of 50 m from the channel. We recommend a more detailed analysis of the locations and volumes of sand and gravel that can be extracted under this proposal.

(d) It is recommended to recalculate the bund height and provide a more detailed estimate of the cost saving features discussed in (a), (b), and (c).

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