As for fish, their inhabitation is severely limited due to deteriorated river water quality and has in fact, been extinguished along the heavily polluted mid and downstream reaches of some major rivers. Still, along the upstreams of most rivers and in the reservoirs which are still unpolluted, some kinds of fish are observed.

2.9.4 Riverine Environment

The upstream reaches of most rivers are of good water quality and rich in ecological resources and species diversity. However, at immediate downstream reaches of the hillside forest area, the water quality has deteriorated due to human-induced pollution. The river banks are generally covered with grown sedge plants, some shrubs and trees.

In the urbanized areas, such as Georgetown and Bayan Lepas, specific riverine landscaping is yet to be introduced and the existing conditions of maintenance is rather poor. However, the water quality of Sg. Air Terjun is kept exceptionally good and transparent, with rich aquatic plants and fish.

The existing riverside landscapes in Georgetown and Penang Island are shown in Figs 2-16 to 2-18.

Tables

TABLE 2-1 MONTHLY METEOROLOGICAL DATA

Item / Month	Temperature					Humidity	Precipitation	
	Highest Recorded (°C)	Average of Daily Highest (°C)	Average (°C)	Average of Daily Lowest (°C)	Lowest Recorded (°C)	Average (%)	Monthly Average (mm)	No.of Rain Days
Jan.	34.7	31.8	27.0	23.1	18.7	74.4	68.2	7
Feb.	35.7	32.3	27.4	23.4	20.4	75.8	93.5	9
Mar.	35.6	32.4	27.7	23.7	20.9	79.1	135.4	12
Apr.	34.6	31.9	27.7	24.9	21.4	83.1	211.3	17
May.	34.4	31.6	27.5	24.1	21.4	84.3	247.9	18
Jun.	33.9	31.3	27.3	23.8	21.0	84.0	180.5	13
July	33.6	31.1	27.0	23.5	20.6	83.4	205.2	15
Aug.	33.4	31.0	26.4	23.4	21.1	84.1	236.5	16
Sep.	33.3	30.6	26.4	23.4	21.3	85.7	345.0	19
Oct.	33.7	30.5	26.5	23.3	21.0	86.2	384.3	23
Nov.	33.4	30.8	26.5	23.3	21.1	94.0	253.4	19
Dec.	33.9	31.1	26.7	23.3	21.0	79.3	112.9	12
Annual	35.7	31.4	27.0	23.5	18.7	81.9	2368	181

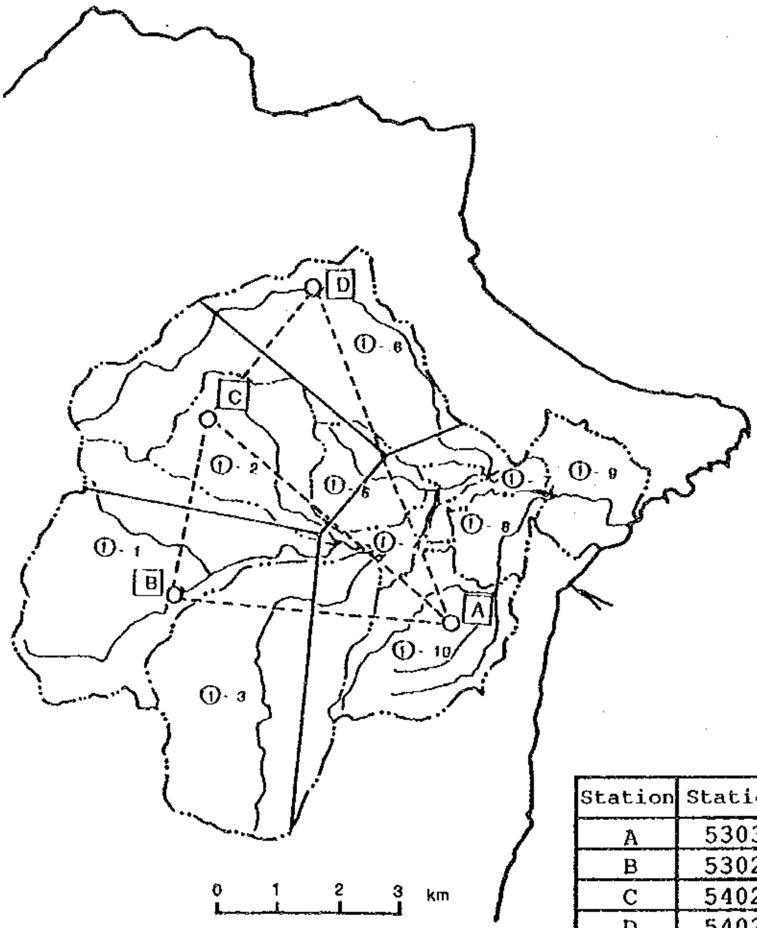
Source : Upgrading of Irrigation and Drainage, PLAU PINANG, 1982, the Government of MALAYSIA

TABLE 2-2 PROBABLE AREAL RAINFALL IN SG. PINANG BASIN

Unit : mm

Station / Return Period	A	B	C	D	*Mean Probable Areal Rainfall in Sg. Pinang Basin
1/2	112	124	142	126	124
1/5	163	179	188	193	178
1/10	197	216	218	237	213
1/20	229	251	247	279	247
1/30	248	271	264	303	266
1/50	271	296	285	334	291
1/70	286	312	298	354	306
1/100	302	330	313	375	323

* Mean probable areal rainfall is calculated by Thiessen Method



THIESSEN POLYGON NETWORK

Station	Station No.	Area(km2)	Portion
A	5303001	16.37	0.32
B	5302003	17.45	0.34
C	5402001	10.85	0.21
D	5402002	6.30	0.13
Total		50.97	1.00

TABLE 2-3 CHARACTERISTICS OF RIVERS AND BASINS

Catchment No.	Name	Cathcment Area (km2)	Flat Land (%)	Mountainous / Hilly (%)	Urbanized Area 2001 year (%)	Erosion / Sedimentation	Future Extension of River Mouth (m)
1	Sg. Pinang	46.07	22	78	45	Serious	710
2	Sg. Teluk Awak	3.95	15	85	66		
3	Sg. Teluk Bahang	12.30	11	89	32		
4	Sg. Batu Ferringghi	11.27	1	99	6		
5	Sg. Satu	2.58	8	92	18		
6	Sg. Mas	2.11	37	63	77		
7	Sg. kechil	2.75	15	85	28	Moderate	
8	Sg. kelian	9.04	15	85	30	Moderate	
9	Sg. Balik Batu	0.80	29	71	91	Serious	
10	Sg. Fettes	1.36	33	67	80	Serious	
11	Sg. BaganJermal	0.83	34	66	78	Moderate	
12	Sg. Babi	0.84	48	52	90		
13	Sg. Gelugor	4.07	32	68	86	Moderate	
14	Sg. Dua Besar	6.19	46	54	93	Moderate	650
15	Sg. Nibong Besar	1.50	81	19	90		600
16	Sg. Nibong Kechil	2.77	84	16	95		490
17	Sg. Keluang	22.17	29	71	44	Serious	900
18	Sg. Nipah	1.69	76	24	84		
19	Sg. Kampumg Masjid	0.84	61	39	84		
20	Sg. Ikan Mati	0.38	47	53	92		
21	Sg. Bayan Lepas	7.04	15	85	28		
22	Sg. Batu	0.90	50	50	43	Moderate	
23	Sg. Mati	0.95	63	37	49		
24	Sg. Teluk Kumbar	7.06	33	67	16		
26	Sg.Gertak Sanggul	1.03	17	83	9		

TABLE 2-4 COMPREHENSIVE EVALUATION OF RIVERS AND BASINS

Catchment No.	Name	Scale of Cathcment	Experienced Floods	Flood Damage	Future Development	Flood Damage In Future	Total	Grade
1	Sg. Pinang	3	3	3	2	3	14	A
2	Sg. Teluk Awak	1	1	1	3	2	8	C
3	Sg. Teluk Bahang	3	1	1	3	2	10	B
4	Sg. Batu Ferringghi	3	1	1	1	1	7	C
5	Sg. Satu	1	1	1	2	1	6	C
6	Sg. Mas	1	1	1	3	2	8	C
7	Sg. kechil	1	1	1	1	1	5	C
8	Sg. kellan	2	1	1	1	1	6	C
9	Sg. Balik Batu	1	1	1	1	1	5	C
10	Sg. Fettes	1	2	1	3	2	9	B
11	Sg. BaganJermal	1	1	1	2	1	6	C
12	Sg. Babi	1	2	1	2	1	7	C
13	Sg. Gelugor	1	2	2	2	2	9	B
14	Sg. Dua Besar	2	2	1	3	3	11	A
15	Sg. Nibong Besar	1	1	1	2	2	7	C
16	Sg. Nibong Kechil	1	1	1	2	2	7	C
17	Sg. Keluang	3	2	2	2	3	12	A
18	Sg. Nipah	1	1	1	3	1	7	C
19	Sg. Kampumg Masjid	1	1	1	3	1	8	C
20	Sg. Ikan Mati	1	1	1	3	1	7	C
21	Sg. Bayan Lepas	2	2	1	2	1	9	B
22	Sg. Batu	1	1	1	2	1	6	C
23	Sg. Mati	1	1	1	2	1	6	C
24	Sg. Teluk Kumbar	2	1	1	1	1	6	C
25	Sg. Gemuroh	1	1	1	1	1	5	C
26	Sg. Gertak Sanggul	1	1	1	1	1	5	C
27	Sg. Pulau Betong	3	2	1	1	1	8	C
28	Sg. Nipah	1	1	1	1	1	5	C
29	Sg. Burong	3	2	1	1	1	8	C
30	Sg. Kongsi	3	2	1	1	1	8	C
31	Sg. Pinang (DBD)	3	1	1	1	1	7	C

The above are evaluated by following criteria:

Scale of Catchment	1	5.0 km^2
	2	5.0 - 10.0 km^2
	3	10.0 - km^2
Experienced Floods	1	Non-existence
	2	Sometimes
	3	Frequently
Flood Damaged	1	No damage
	2	Minor damage
	3	Serious damage
Future Development	1	No development or less than 10%
	2	10%-30% of urban expansion area
	3	30% and more
Flood Damage in Future	1	Not anticipated
	2	Minor damage anticipated
	3	Serious damage anticipated

Method of Grading :
Grade A for aggregate points > 10
Grade B for aggregate points ≥ 9 but ≤ 10
Grade C for aggregate points < 9

TABLE 2-5 RECORD OF HIGHEST FLOOD WATER LEVEL AND RAINFALL IN GEORGETOWN

Year	M.	D.	H.F.W.L.	Observation Site
1976	9	18	R.L. + 10.0 ft	Caunter Hall
1977	11	25	R.L. + 8.5 ft	Caunter Hall
1978	9	6	R.L. + 8.9 ft	Caunter Hall
1979	11	27	R.L. + 9.5 ft	Caunter Hall
1980	9	5	R.L. + 9.5 ft	Caunter Hall
1981	10	18	R.L. + 9.5 ft	Caunter Hall
1982	10	29	R.L. + 8.5 ft	Caunter Hall
1983	10	15	R.L. + 8.5 ft	Caunter Hall
1984	4	16	R.L. + 8.2 ft	Caunter Hall
		18 ~ 19	22;00 ~ 8;00 ~ 17;00 4.6 ft - 10.6 ft - 9.1 ft	Caunter Hall
			20;00 ~ 4;00 ~ 10;00 7mm - 42mm - 5mm (255mm)	5402002 (Kolam Bersih)
		28	6;00 ~ 15;00 ~ 24;00 6.0 ft - 11.0 ft - 5.6 ft	Caunter Hall
			1;00 ~ 9;30 ~ 13;00 0 - 40mm - 1mm (147.5mm)	5303001 (Rumah Kebajikan)
	5	17	5;00 ~ 9;30 ~ 15;30 5.3 ft - 9.3 ft - 6.0 ft	Caunter Hall
			4;00 ~ 4;30 ~ 7;30 4mm - 46mm - 0.5mm (96mm)	5302003 (Kolam Takongan)
	7	14 15	22;00 ~ 2;00 ~ 6;00 4.3 ft - 8.5 ft - 6 ft	Caunter Hall
		15 16	21;00 ~ 3;00 ~ 7;00 5.6 ft - 8.6 ft - 7.3 ft	Caunter Hall
		16 17	23;00 ~ 4;00 ~ 8;15 5.6 ft - 10.5 ft - 8.7 ft	Caunter Hall
1985	8	8	14;00~15;00~17;00 6.0 ft - 7.6 ft - 6.8 ft	Caunter Hall
			13;00 - 15mm	5303001
	10	11 ~ 12	13;55 ~ 20;00 ~ 11;30 7.0 ft - 10.8 ft - 7.2 ft	Caunter Hall
			10/10 2;00 ~ 18;00 16mm 11/10 6;00 ~ 24;00 232mm 12/10 2;00 ~ 6;30 25.5mm	5402002
	12	7 ~ 8	16;00 ~ 20;30 ~ 14;00 4.3 ft - 9 ft - 3.5 ft	Caunter Hall
			7/12 16;30 ~ 17;30 57mm	5303001

Year	M.	D.	H.F.W.L.	Observation Site
1986	9	14 ~ 15	22;00~12;45~11;00 6 ft - 7.5 ft - 3.9 ft	Caunter Hall
			14/9 2;00 ~ 24;00 98mm 15/9 0;00 ~ 5;00 18mm	5303001
		20	5;00 ~ 10;00 ~ 12;00 6.8 ft - 9.6 ft - 9.2 ft	Caunter Hall
			1;00 ~ 8;00 (92mm)	5303001
	10	5 ~ 6	15;00~18;00~10;00 4.6 ft - 7.2 ft - 4.0 ft	Jalan Perak
			5/10 12;00 ~ 23;00 (70mm) 6/10 2;00 ~ 8;30 (40mm)	5302003
	11	13	5;00 ~ 9;00 ~ 15;00 5.5 ft - 7.1 ft - 4.6 ft	Caunter Hall
			1;00 ~ 9;00 (81mm)	5402002
1987	3	19	7;00 ~ 9;30 ~ 12;30 4.2 ft - 7.1 ft - 5 ft	Jalan Perak
			2;00 ~ 10;15 (55mm)	5402002
	6	5	5;00 ~ 9;00 ~ 13;00 4 ft - 7.8 ft - 5 ft	Jalan Perak
			6;30 ~ 9;45 (70mm) 0;15 ~ 9;00 (87mm)	5202003 5402002
	7	22	6;00 ~ 7;30 5.8 ft - 6.9 ft	Jalan Perak
			2;00 ~ 10;00 (55mm)	5402002
	9	14 16	20;00~14;55~14;00 6.5 ft - 6.7 ft - 4.5 ft	Caunter Hall
	10	25 ~ 26	18;00 ~ 21;30 ~ 4;30 5.6 ft - 8.5 ft - 3.6 ft	Jalan Perak
			25/10 6;00 ~ 23;00 (105mm)	5402002
	11	9	2;15 ~ 5;00 ~ 12;00 5 ft - 8.4 ft - 4.8 ft	Caunter Hall
			83mm	5402002
		13	10;30~13;15~14;00 3.6 ft - 9 ft - 8 ft	Caunter Hall
			9;30 ~ 12;00 (80mm)	5402002

TABLE 2-6 EXISTING FLOODED AREA AND ITS CAUSE IN THE BASINS OUTSIDE GEORGETOWN

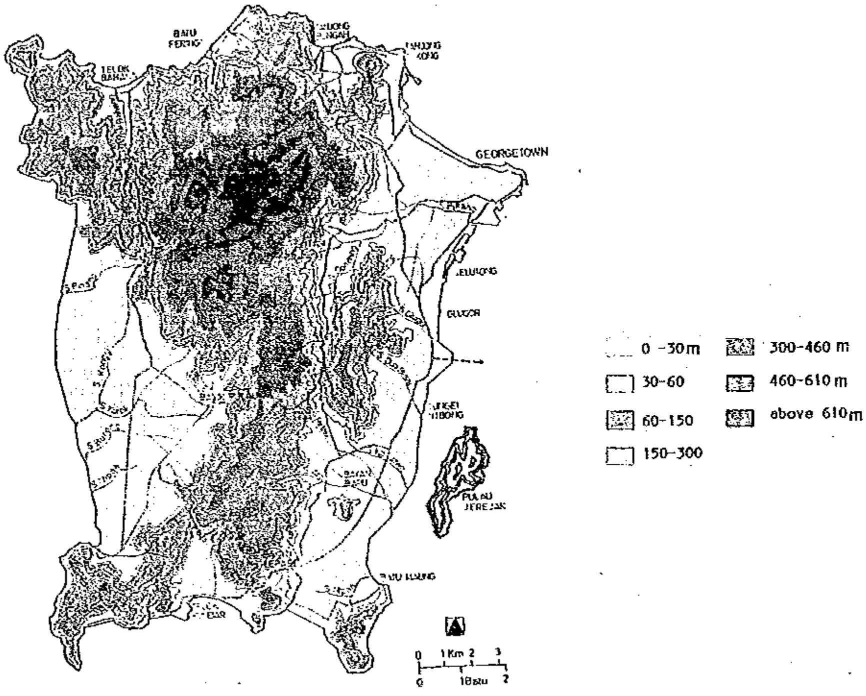
CATCHMENT No. *	INUNDATED AREA	FREQUENCY (times/yr)	DURATION (hr)	CAUSES
13	Sungai Gelugor - Taman Brown Area: 0.12 km2		(2-3)	1. Lowlying area 2. Land erosion due to development
14	Sungai Dua Besar - Tapak Pesta - Pantai Jerjak Area: 0.63 km2		(2-3)	1. Overflow of water from Sg.Dua Besar 2. Shallowness of the river due to land erosion because of development 3. Construction activities of upstream of Sg. Dua Besar 4. Illegal dumping makes the river narrower
17	1. Sungai Relau - PDC Housing Area - Jalan Tengah Area: 1.18 km2		(2-3)	1.1 Lowlying areas 1.2 Due to construction activities - Sg. Relau becomes shallower
21	Permatang Damar Laut		(2-3)	Flash Flood
22	Teluk Kumbar/ Sg. Batu		(2-3)	Flash Flood
27	1. Pulau Betong Area: 0.22km2			1. Lowlying areas
29	1. Kampong Paya Area: 0.17 km2 2. Balik Pulau Area: 0.14 km2 3. Genting			Lowlying areas (swampy area)
30	Kampong Titi Tras Area: 1.08 km2			Lowlying areas

* Refer to Fig. 2-6

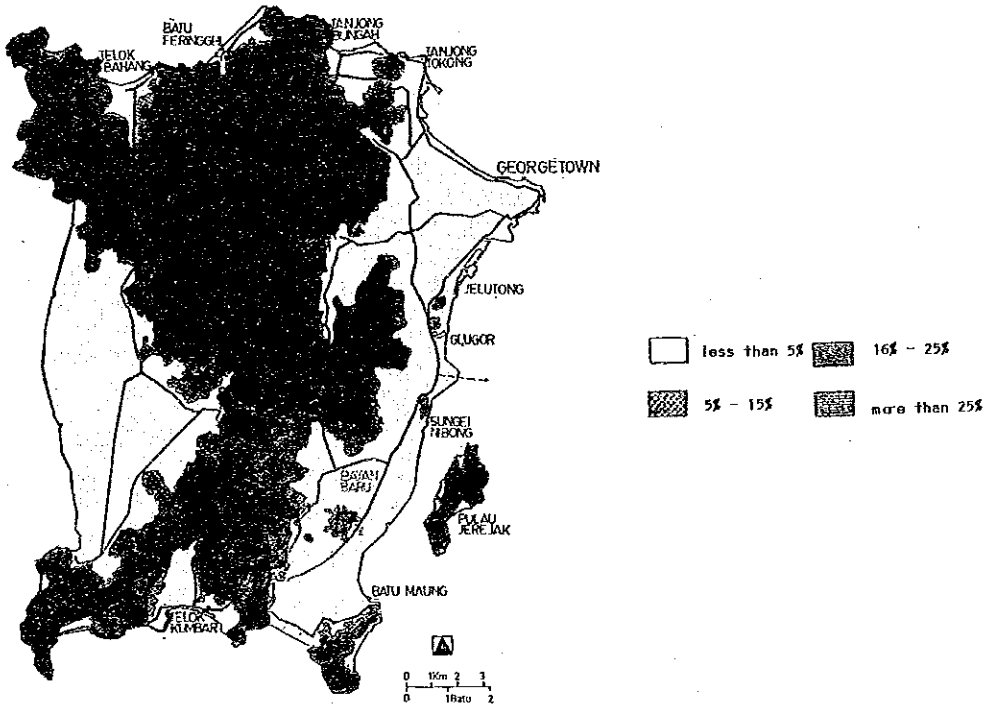
TABLE 2-7 POLLUTION CLASSIFICATION OF RIVERS IN THE STUDY AREA

Classification	Description	Name of River
Extremely Polluted	Considered to be sewerage	Sungai Nibong Kecil Sungai Nipah Sungai Gertak Sanggul
Polluted	Not satisfying Water Quality Standards Class-IV	Sungai Pinang Sungai Fettes Sungai Dua Besar Sungai Nibong Besar Sungai Kampong Masjid Sungai Babi Sungai Bayan Lepas Sungai Batu
Not polluted or tolerable	Satisfying Water Quality Standards Class-IV	Sungai Teluk Awak Sungai Teluk Bahang Sungai Batu Ferringghi Sungai Satu Sungai Mas Sungai Kecil Sungai Kelian Sungai Bagan Jermal Sungai Gelugor Sungai Keluang Sungai Ikan Mati Sungai Teluk Kumbar Sungai Gemuroh

Figures



TOPOGRAPHY



SLOPE ANALYSIS

Source: Structure Plan

FIG. 2-1	TOPOGRAPHY AND SLOPE ANALYSIS OF PENANG ISLAND

THE STUDY ON FLOOD MITIGATION AND DRAINAGE IN PENANG ISLAND

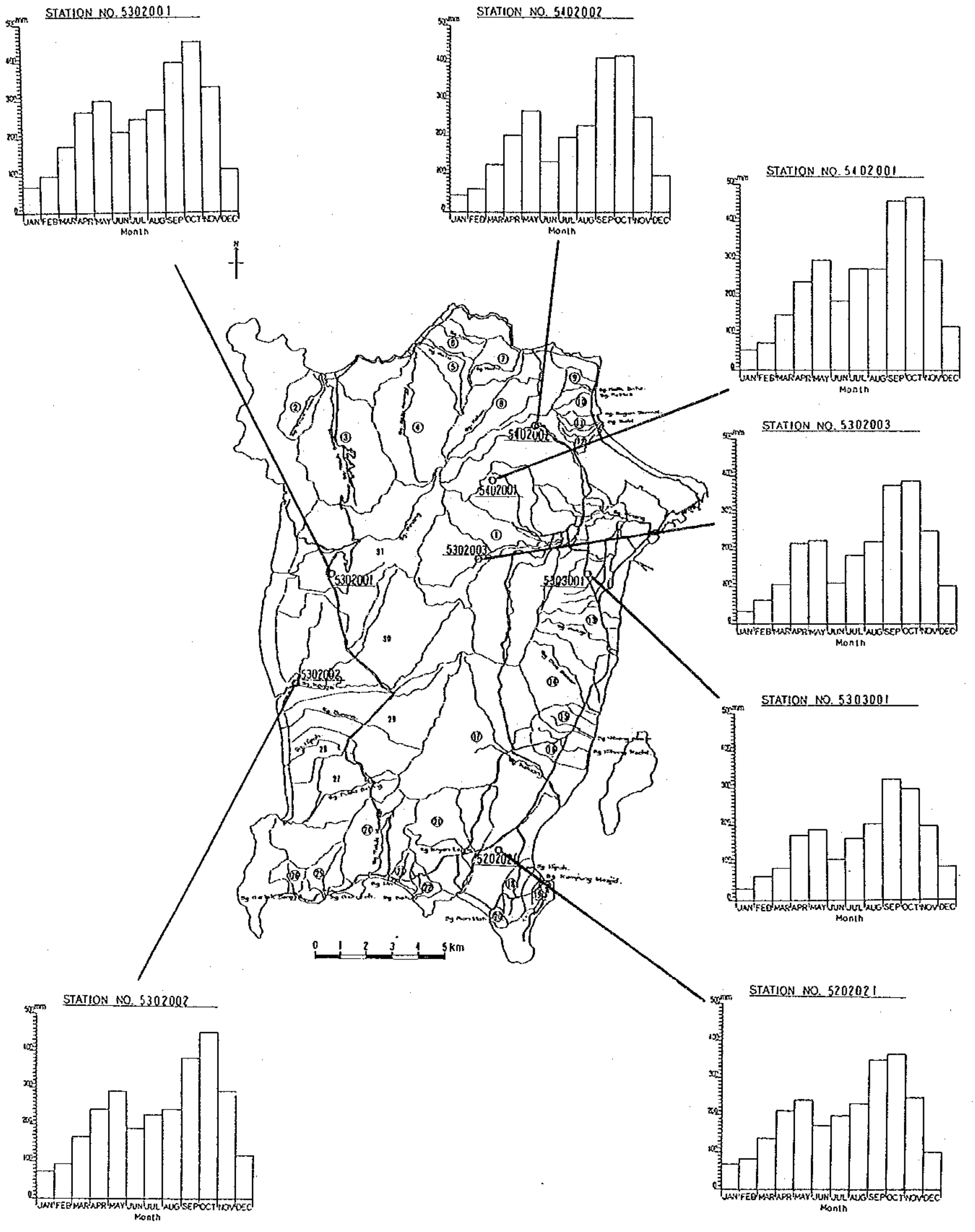
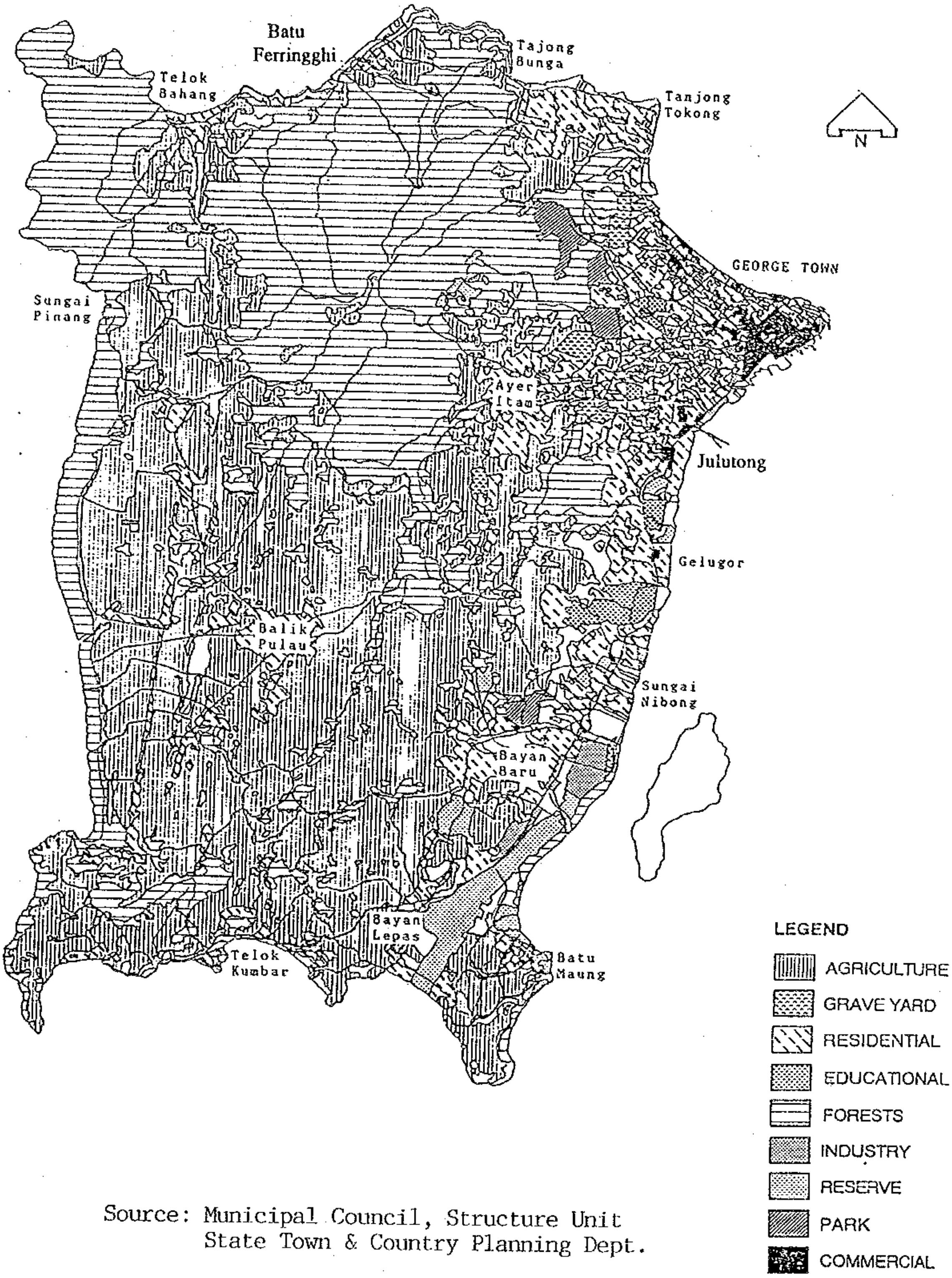


Fig. 2-2 MOTHLY RAINFALL PATTERN AT THE STATIONS IN PENANG ISLAND

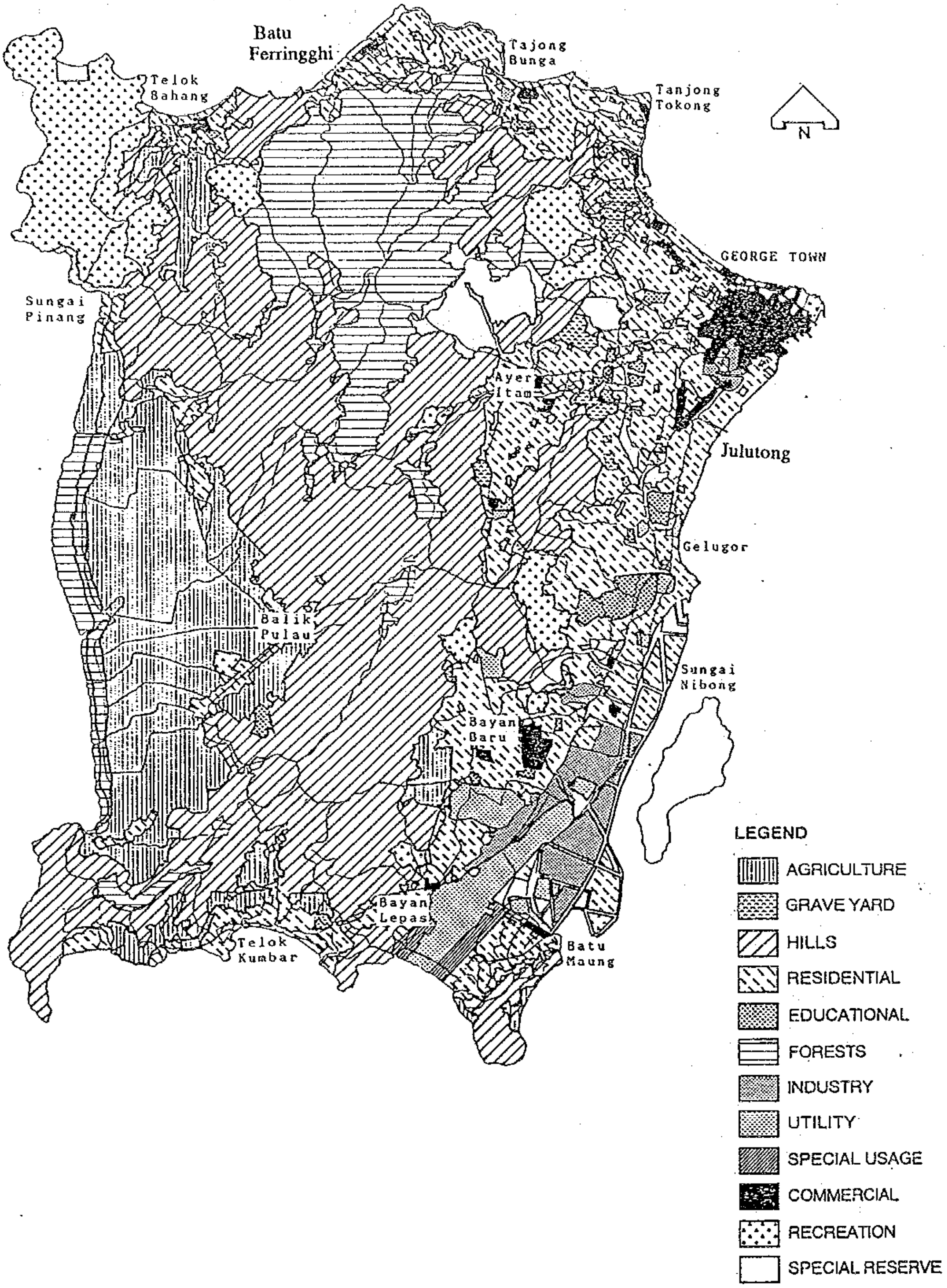
THE STUDY ON FLOOD MITIGATION AND DRAINAGE IN PENANG ISLAND



Source: Municipal Council, Structure Unit
State Town & Country Planning Dept.

FIG. 2-3	PRESENT LAND USE PATTERN IN PENANG ISLAND, 1988

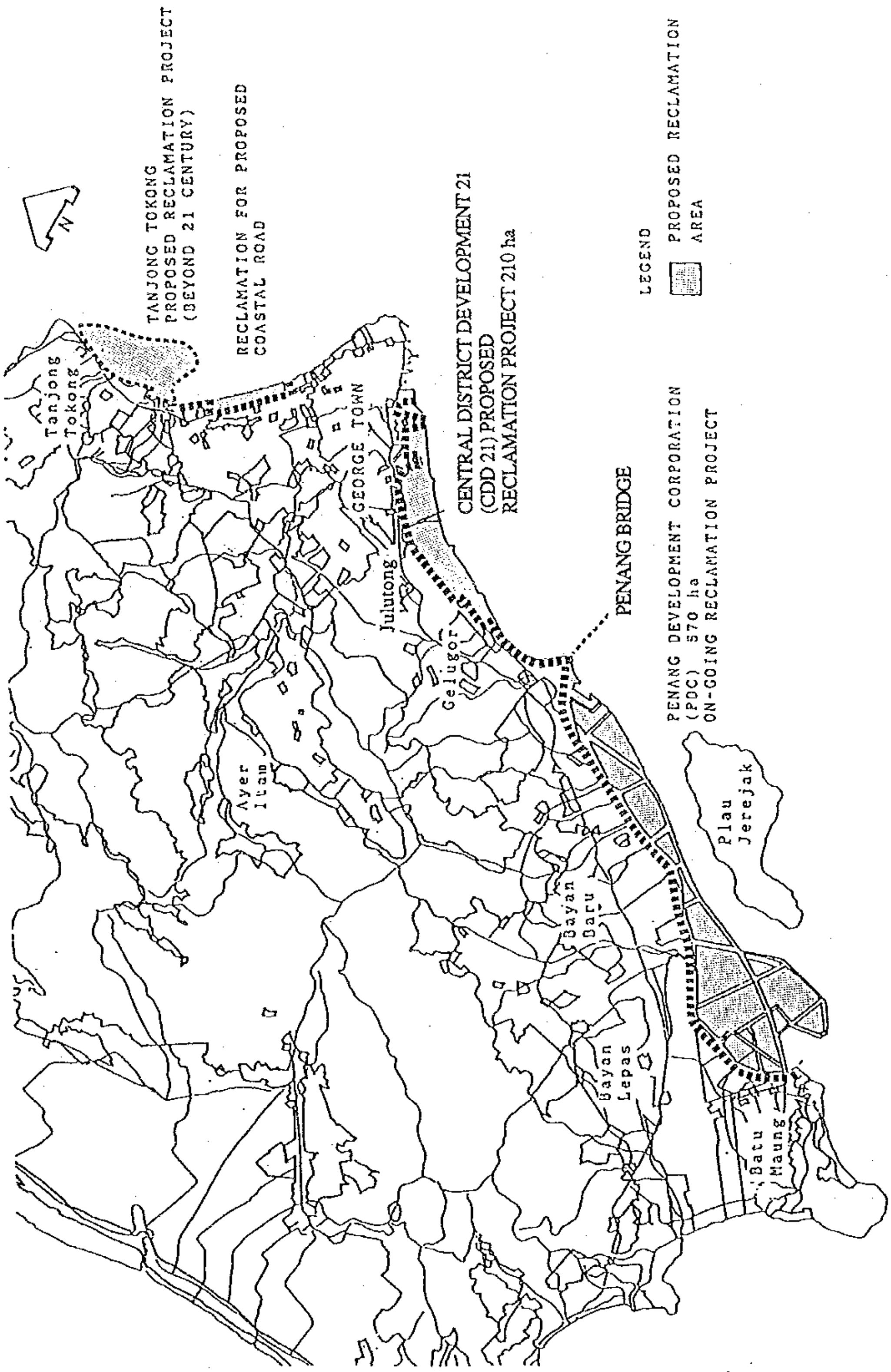
THE STUDY ON FLOOD MITIGATION AND DRAINAGE IN PENANG ISLAND



Source: PDC, State Town & Country Planning Dept.
Municipal Council, Structure Unit

FIG. 2-4	FUTURE LAND USE PATTERN IN PENANG ISLAND, 2010

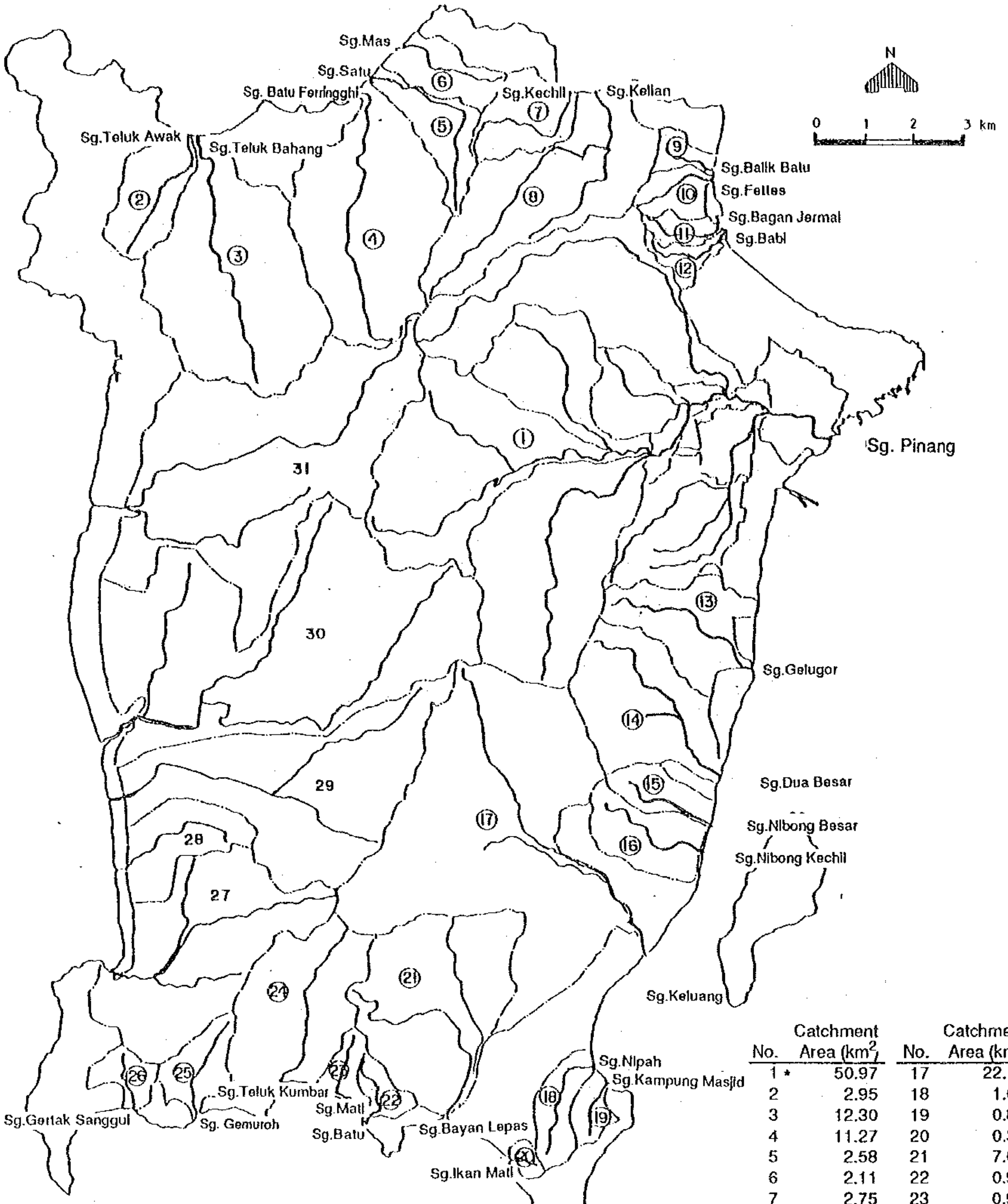
THE STUDY ON FLOOD MITIGATION AND DRAINAGE IN PENANG ISLAND



Source: PDC, State Town & Country Planning Dept.
Municipal Council, Structure Unit

FIG. 2-5	LAND RECLAMATION PLAN

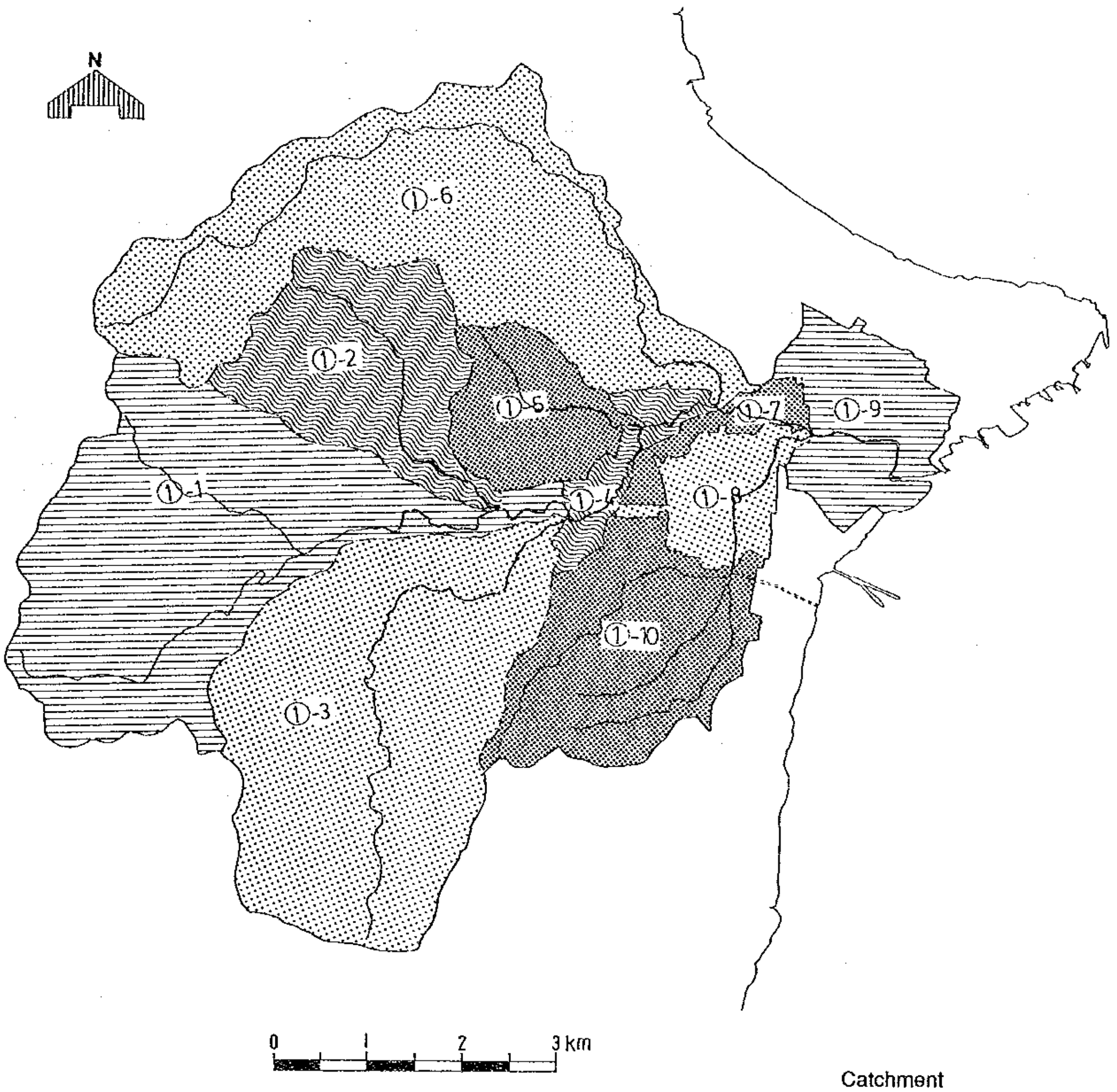
THE STUDY ON FLOOD MITIGATION AND DRAINAGE IN PENANG ISLAND



No.	Catchment Area (km²)	No.	Catchment Area (km²)
1 *	50.97	17	22.17
2	2.95	18	1.69
3	12.30	19	0.84
4	11.27	20	0.38
5	2.58	21	7.04
6	2.11	22	0.90
7	2.75	23	0.95
8	9.04	24	7.06
9	0.80	25	1.91
10	1.36	26	1.03
11	0.83	27	11.04
12	0.84	28	3.24
13	4.07	29	13.79
14	6.19	30	20.63
15	1.50	31	19.99
16	2.77		

* Including Jelutong Diversion Channel Catchment

FIG. 2-6 RIVERS IN THE STUDY AREA



No.	River Name	Catchment Area (sq. km)
1-1	Sg. Air Itam	10.64
1-2	Sg. Air Putih	4.56
1-3	Sg. Dondang	11.33
1-4	Sg. Air Itam	1.05
1-5	Sg. Kecil	2.42
1-6	Sg. Air Terjun	10.76
1-7	Sg. Pinang	0.73
1-8	Sg. Jelutong Downstream	1.69
1-9	Sg. Pinang	2.89
1-10	Sg. Jelutong Upstream (Jelutong Diversion Catchment)	4.90
	Total	50.97

FIG. 2-7-1 SUB-DIVISION OF SG. PINANG CATCHMENT

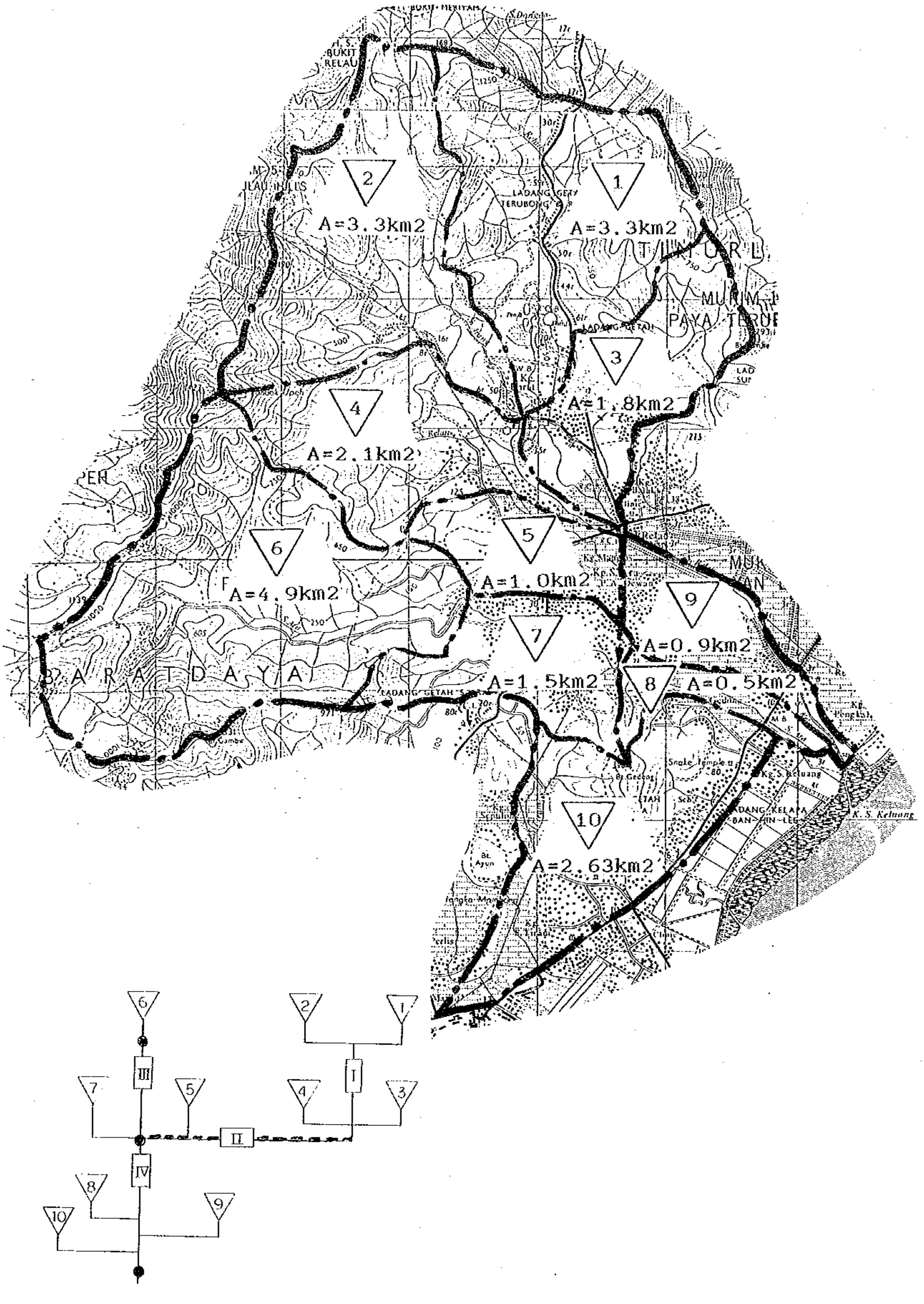


Fig. 2-7-2 SUB-DIVISION OF SG. KELUANG CATCHMENT

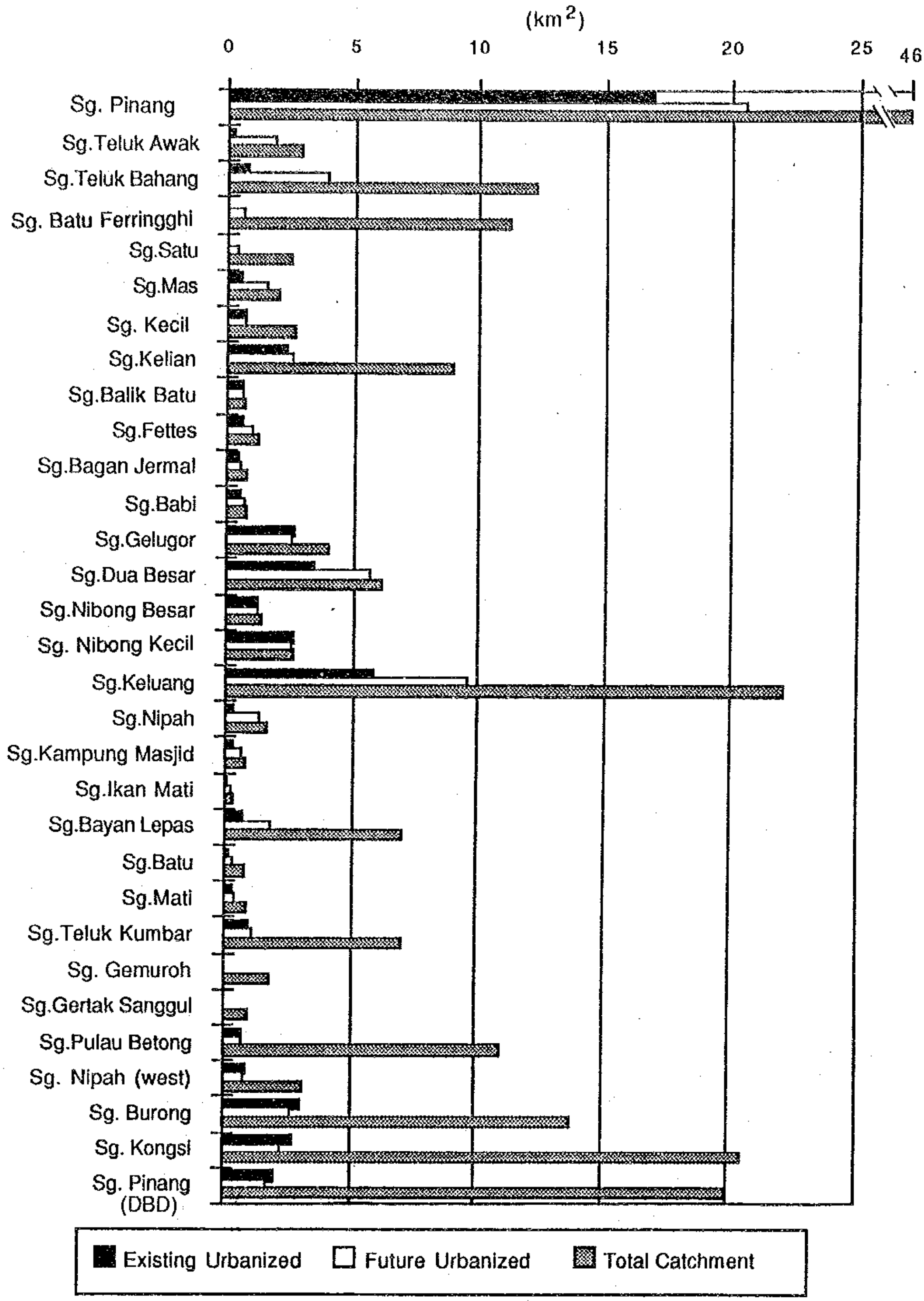
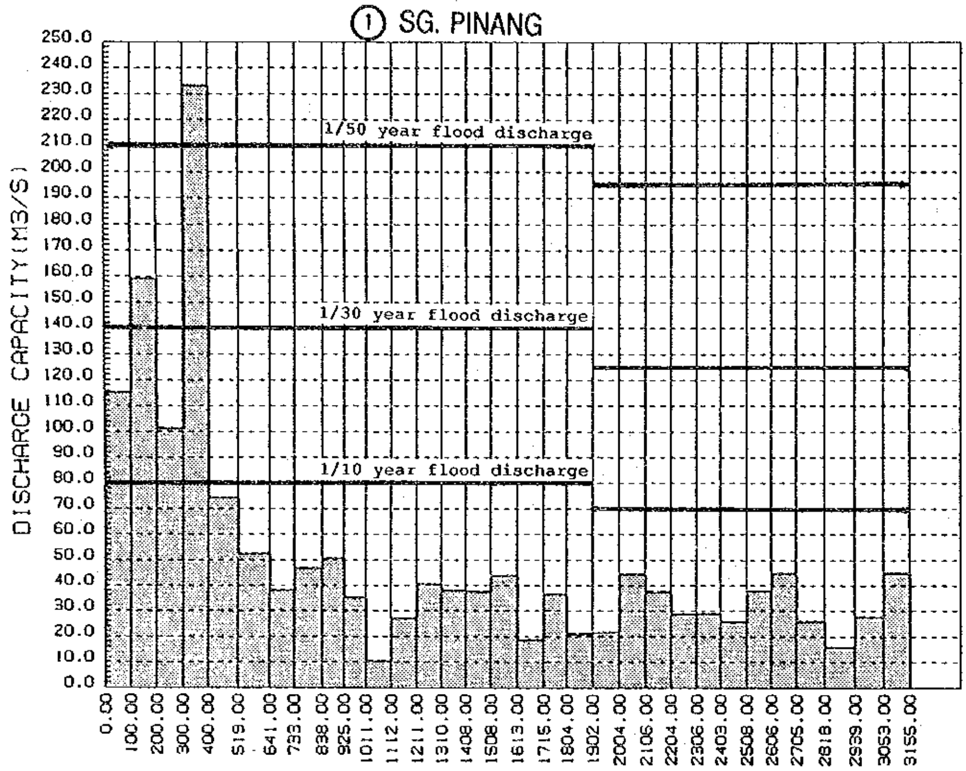


FIG. 2-8	PRESENT AND FUTURE URBANIZATION IN EACH BASIN

THE STUDY ON FLOOD MITIGATION AND DRAINAGE IN PENANG ISLAND

JICA



Note: Probable flood discharges are the values with retention pond and diversion channel.

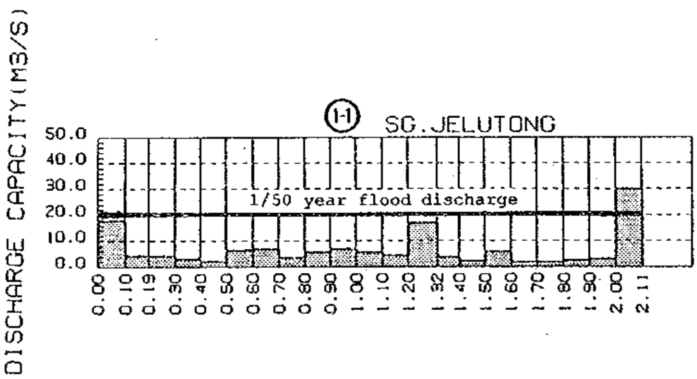


Fig. 2-9-1	EXISTING DISCHARGE CAPACITY OF SG. PINANG SYSTEM

THE STUDY ON FLOOD MITIGATION AND DRAINAGE IN PENANG ISLAND

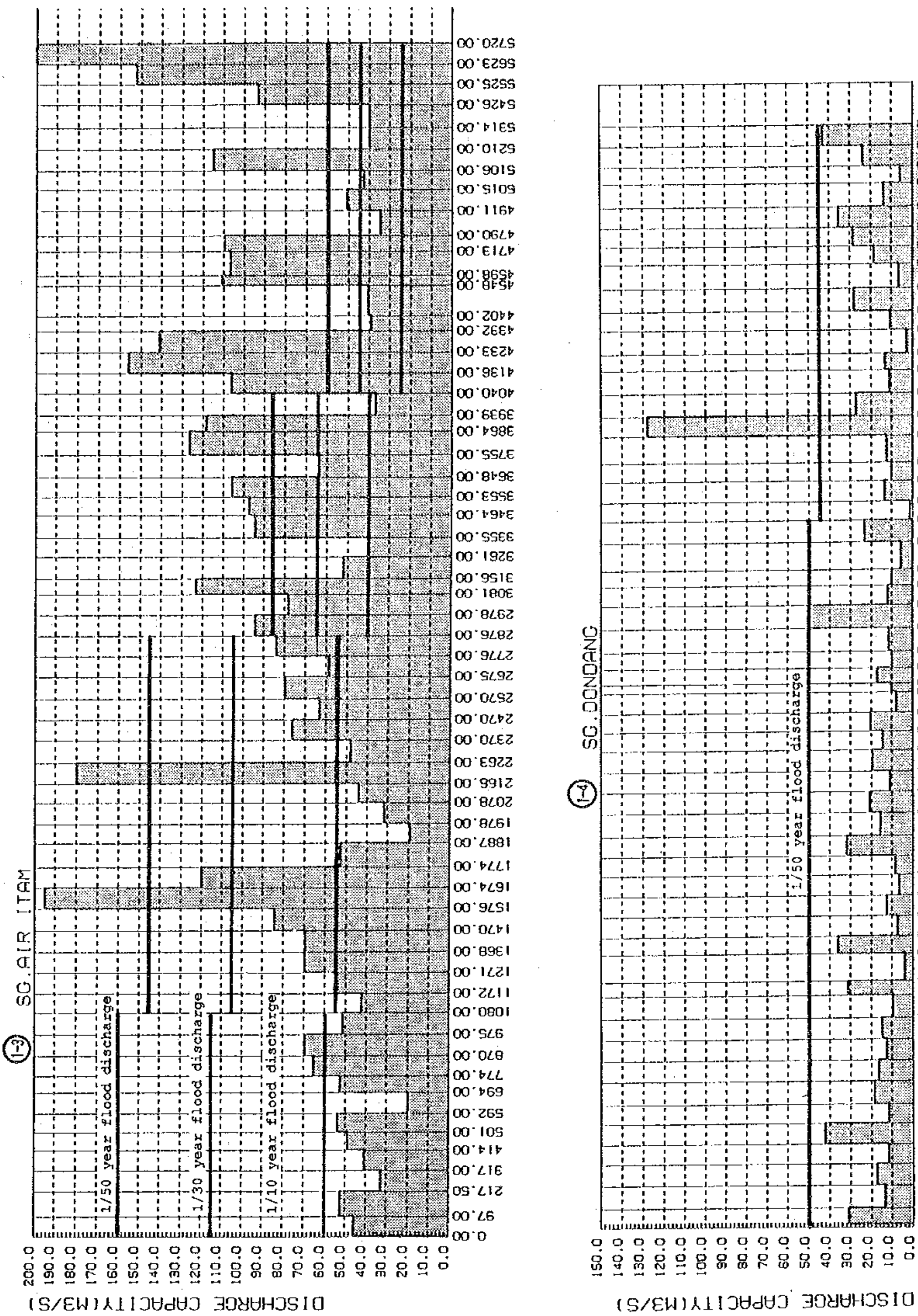


FIG. 2-9-2 EXISTING DISCHARGE CAPACITY OF SG. PINANG SYSTEM

THE STUDY ON FLOOD MITIGATION AND DRAINAGE IN PENANG ISLAND

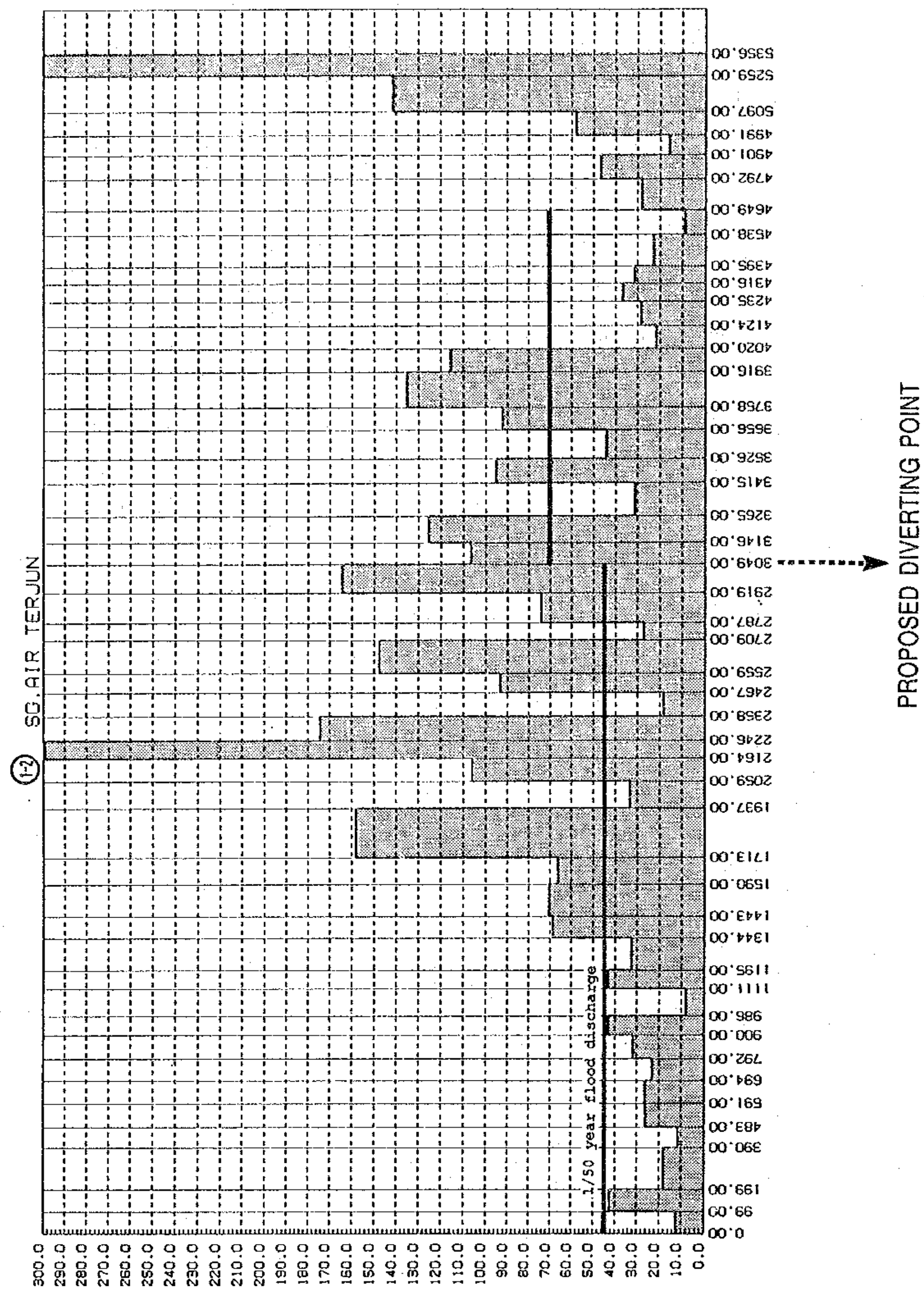


FIG. 2-9-3	EXISTING DISCHARGE CAPACITY OF SG. PINANG SYSTEM

THE STUDY ON FLOOD MITIGATION AND DRAINAGE IN PENANG ISLAND

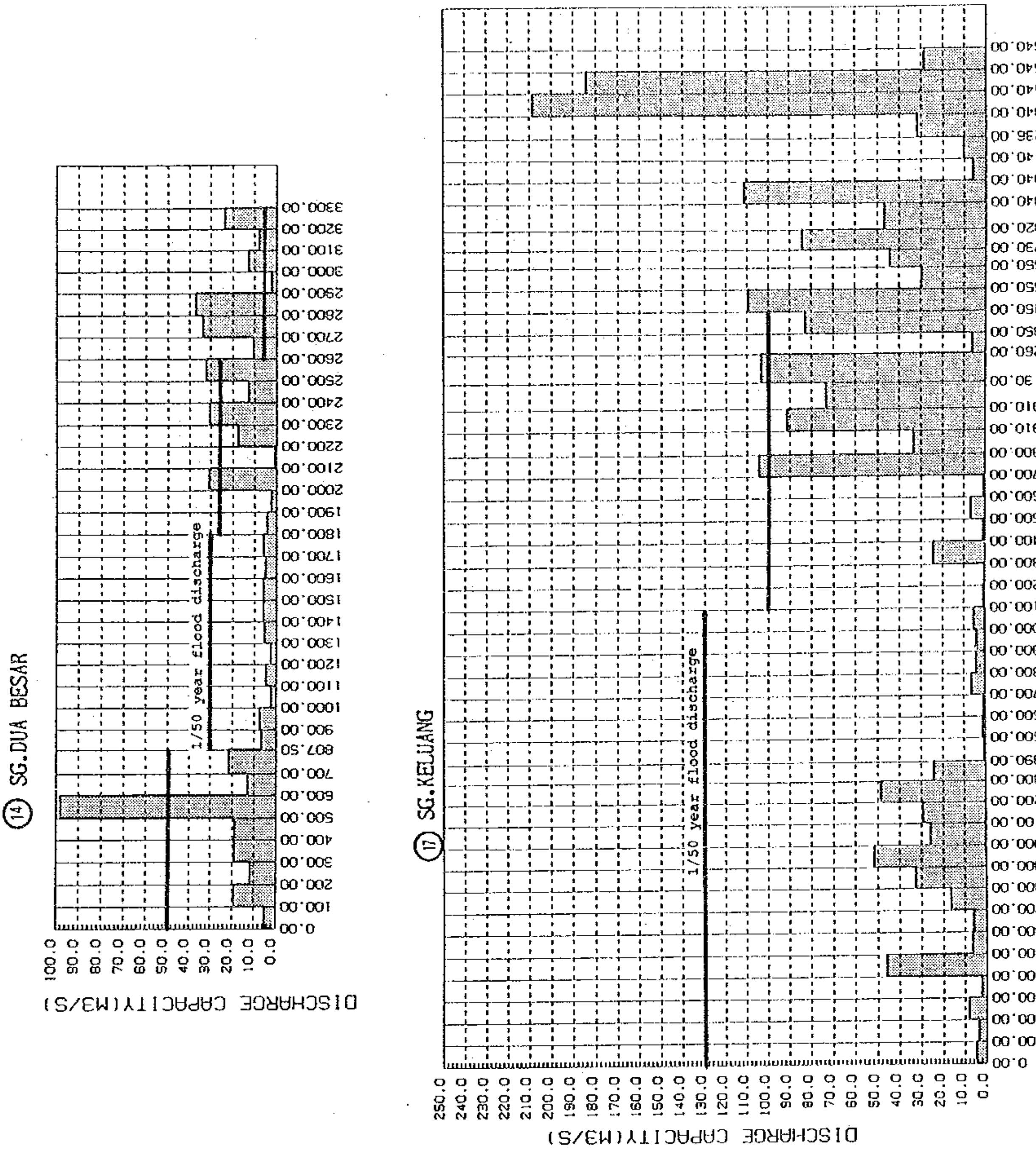


FIG. 2-10	EXISTING DISCHARGE CAPACITY OF SG. DUA BESAR AND SG. KELUANG

THE STUDY ON FLOOD MITIGATION AND DRAINAGE IN PENANG ISLAND

FIG. 2-11	EXPERIENCED FLOOD PRONE AREAS IN GEORGETOWN

THE STUDY ON FLOOD MITIGATION AND DRAINAGE IN PENANG ISLAND

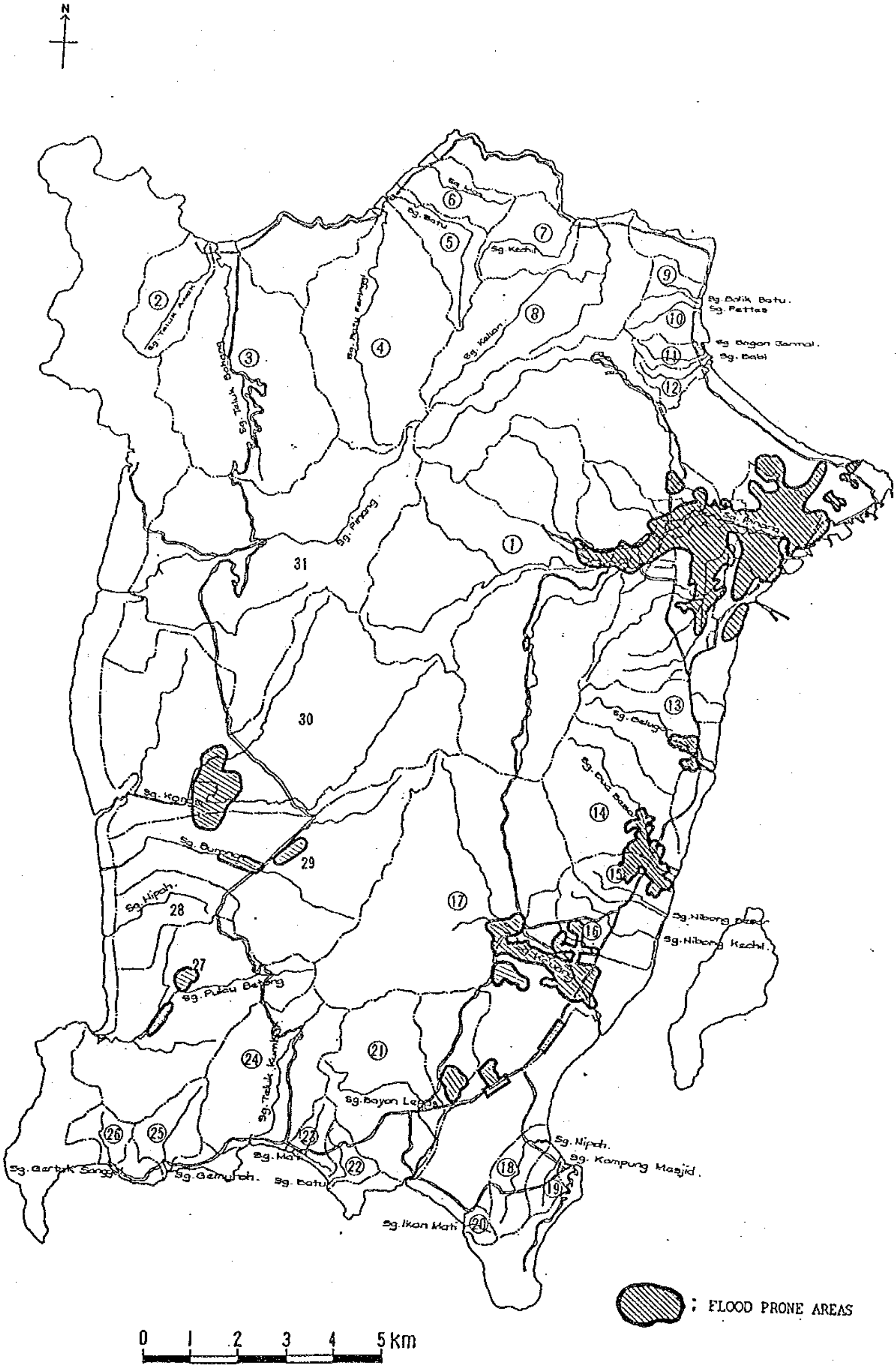


Fig. 2-12	EXPERIENCED FLOOD PRONE AREAS IN WHOLE PENANG ISLAND

THE STUDY ON FLOOD MITIGATION AND DRAINAGE IN PENANG ISLAND

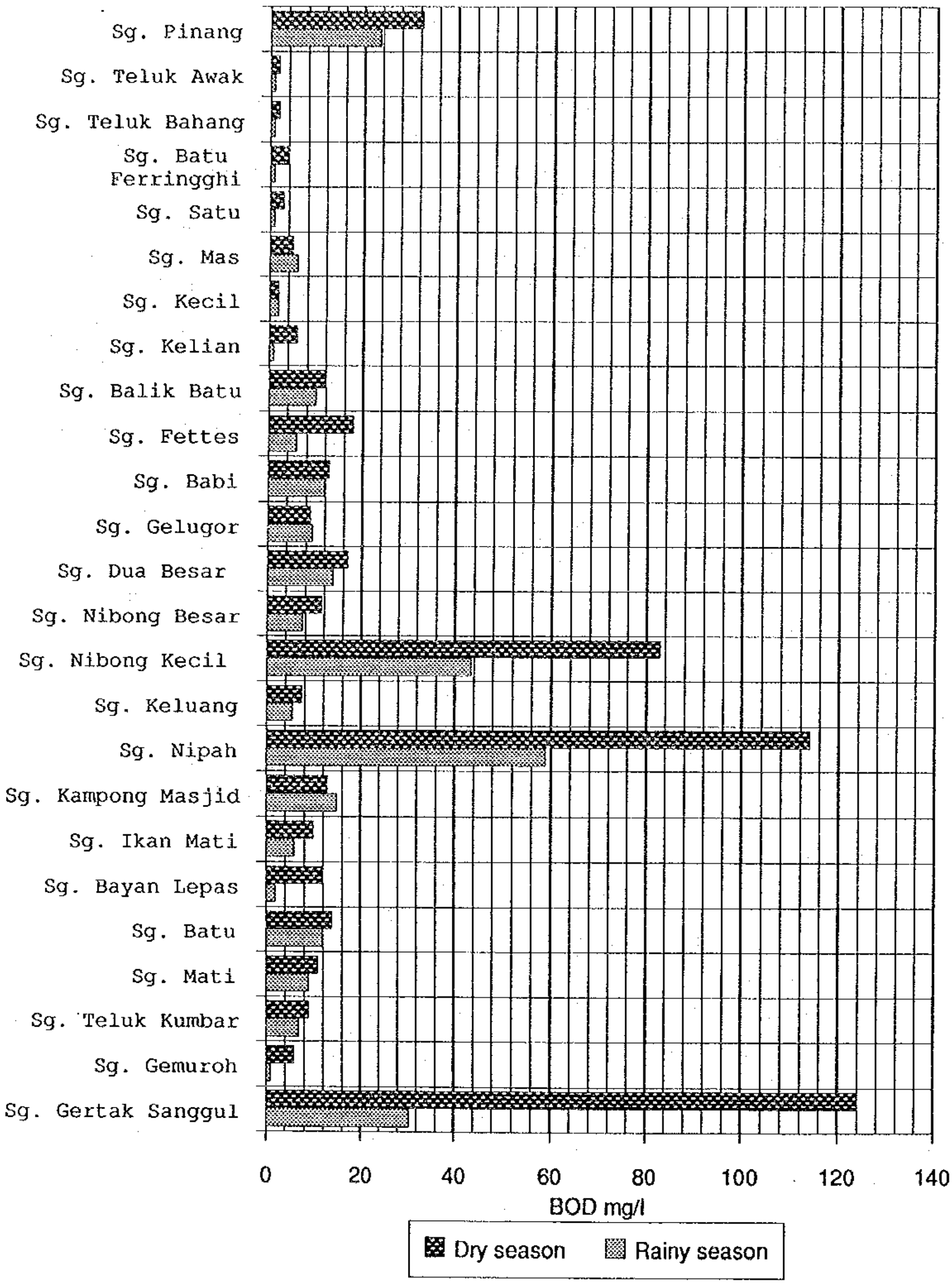


FIG. 2-13	BOD VALUE AT RIVER MOUTH OF EACH RIVER

THE STUDY ON FLOOD MITIGATION AND DRAINAGE IN PENANG ISLAND

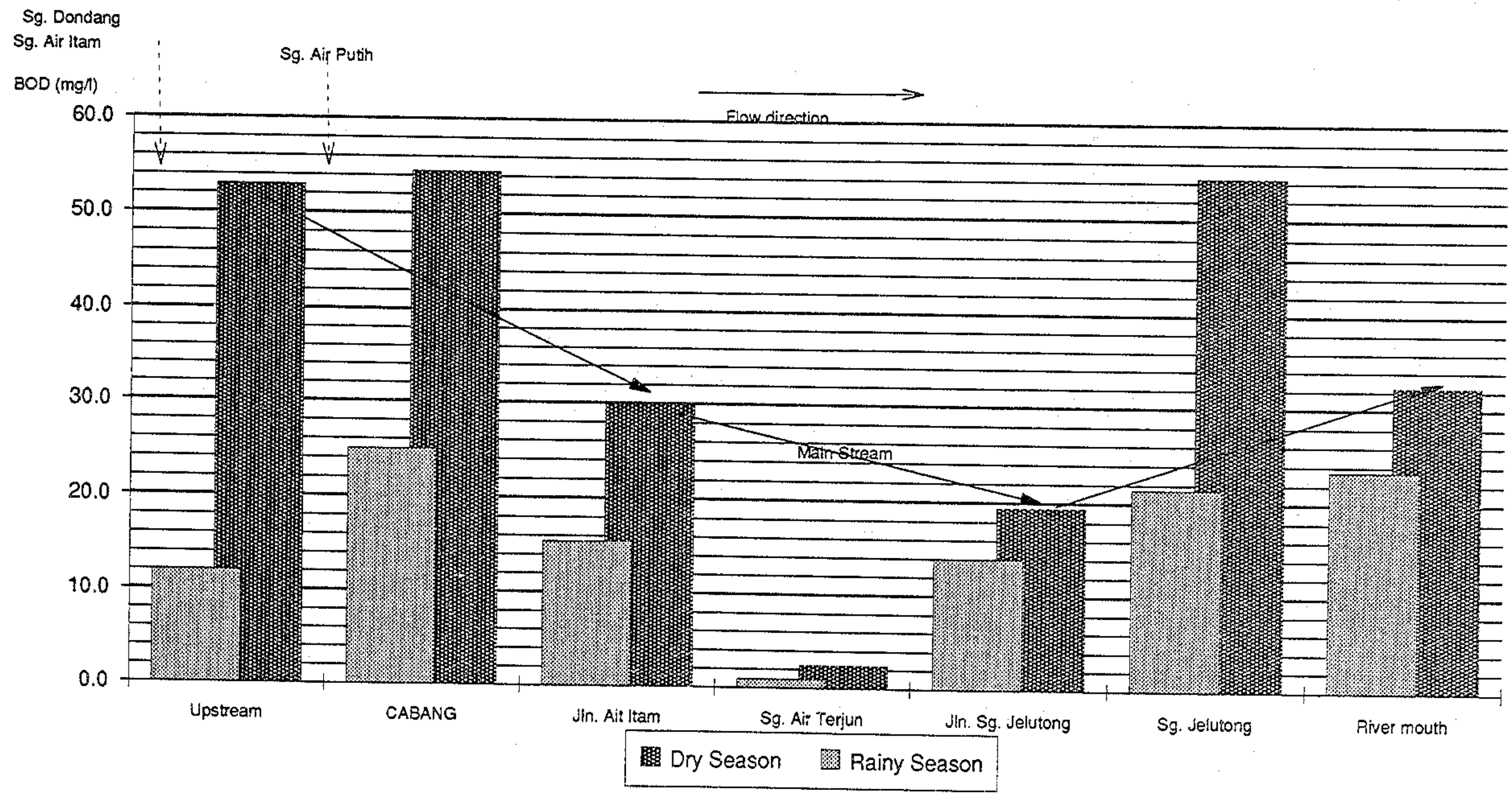
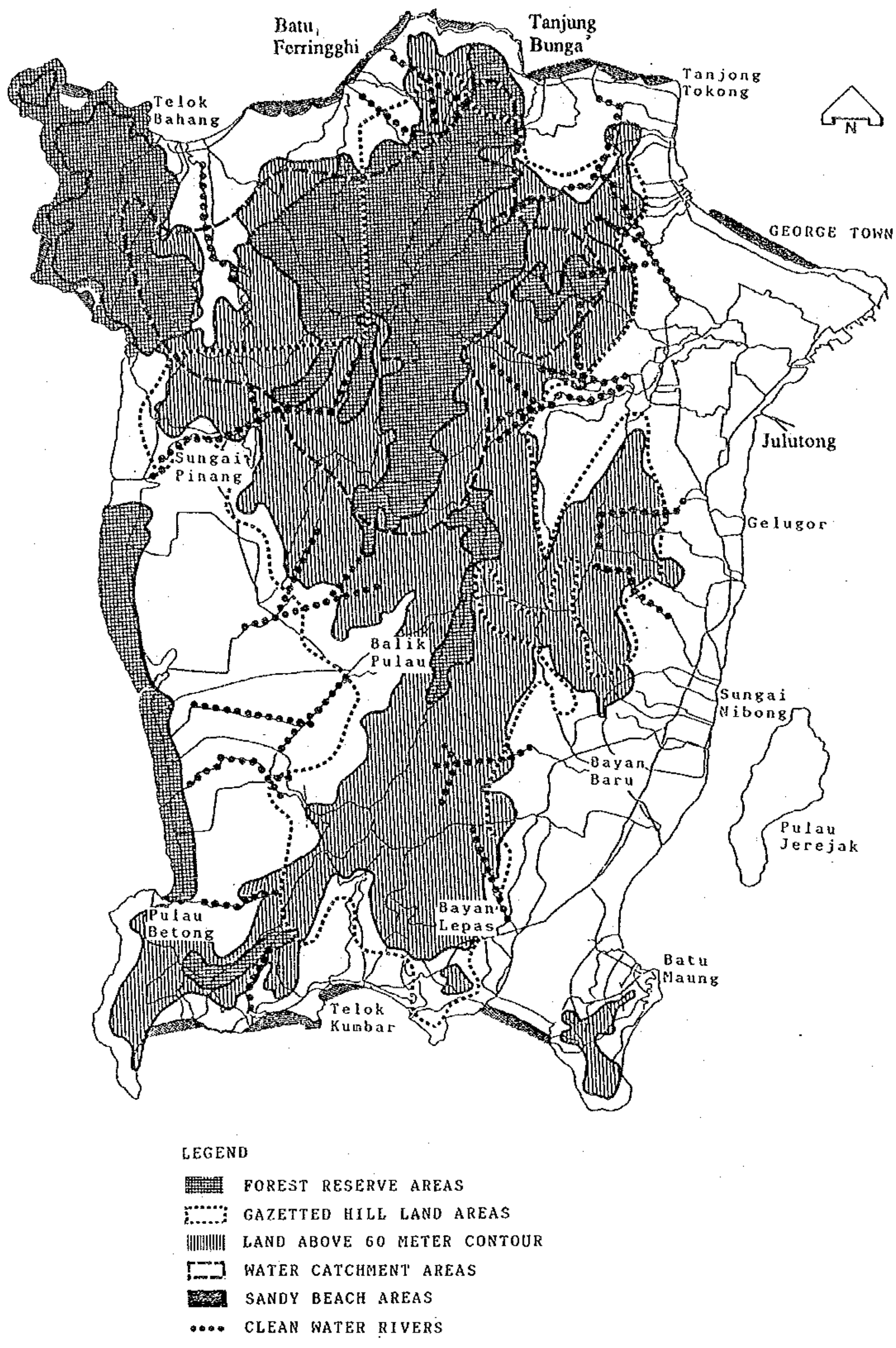


FIG. 2-14	BOD IN SG. PINANG SYSTEM

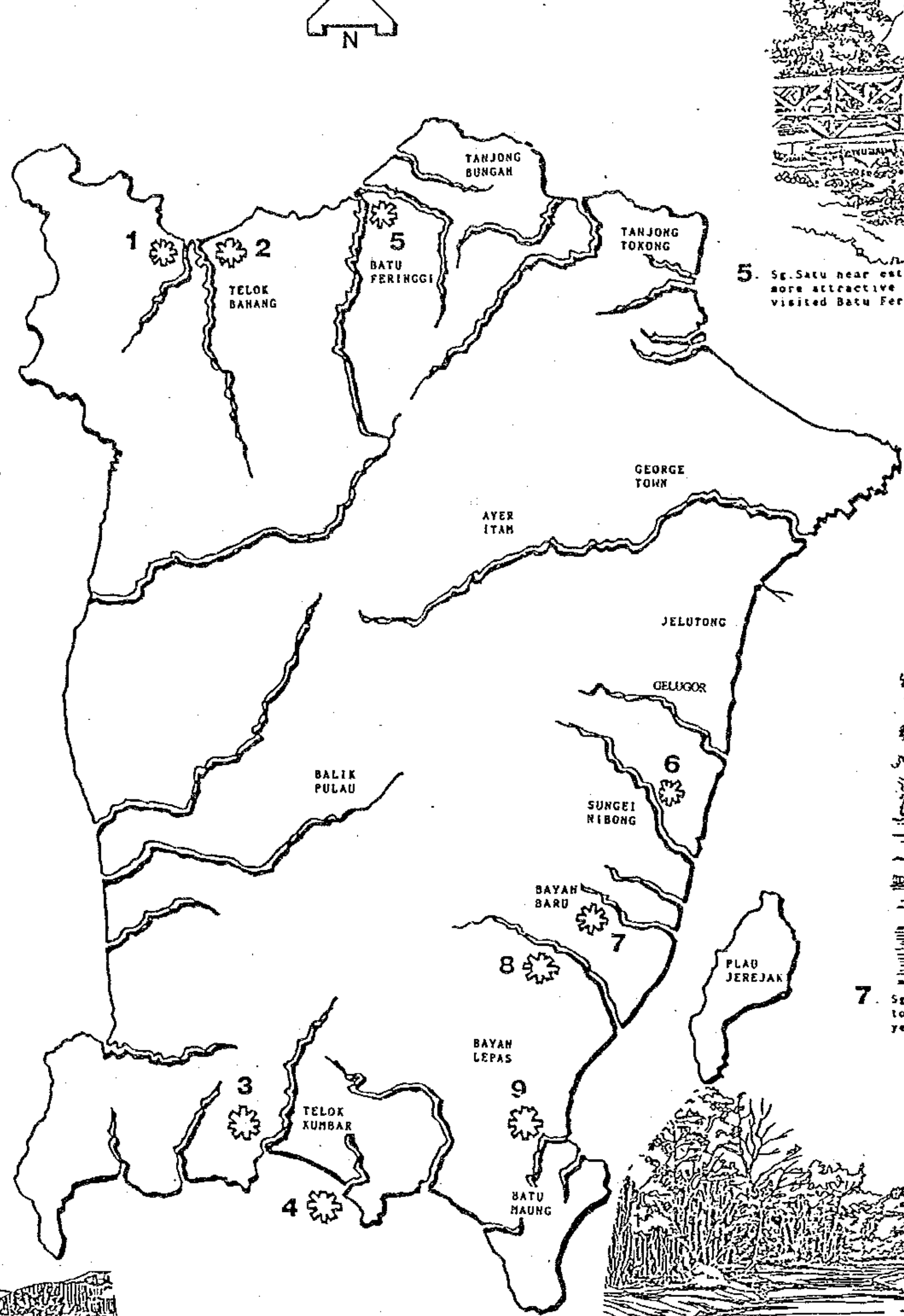
THE STUDY ON FLOOD MITIGATION AND DRAINAGE IN PENANG ISLAND

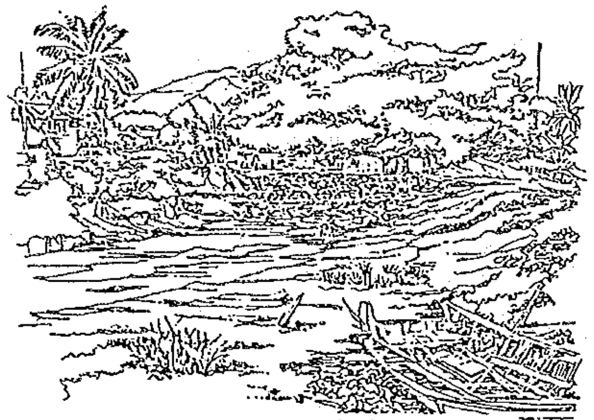


Source : Draft Structure Plan of Penang Island

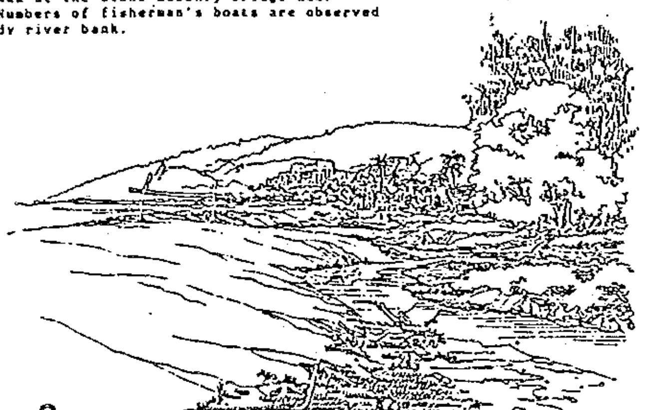
FIG. 2-15 ENVIRONMENTAL SENSITIVE AREAS IN PENANG ISLAND

THE STUDY ON FLOOD MITIGATION AND DRAINAGE IN PENANG ISLAND





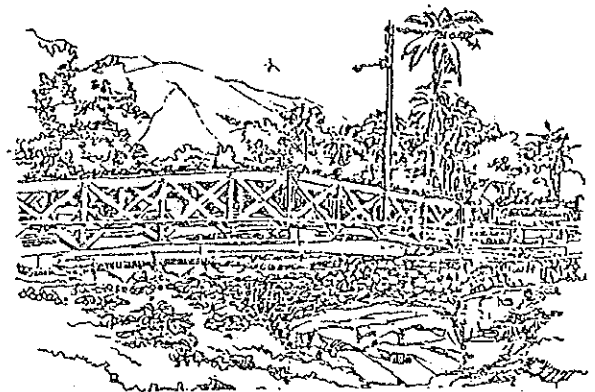
1. Sg.Telok Awak at the stone masonry bridge near estuary. Numbers of fisherman's boats are observed at the sandy river bank.



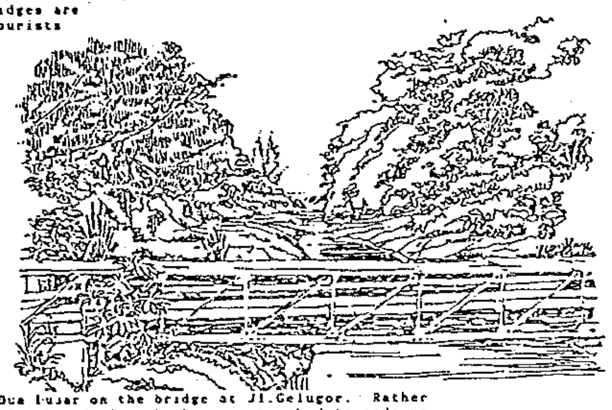
2. Sg.Telok Bahang at the confluence with Sg.Telok Awak. Rivercourse are winding near the estuary beach.

3. Sg.Telok Kombar at the estuary. Many fishing boats are lying on the muddy bank slope and mangroves are dencely inhabited near here.

4. Sg.Batu at estuary. Stony bank landscape is much characteristic here and water flow is much faster to be seen.

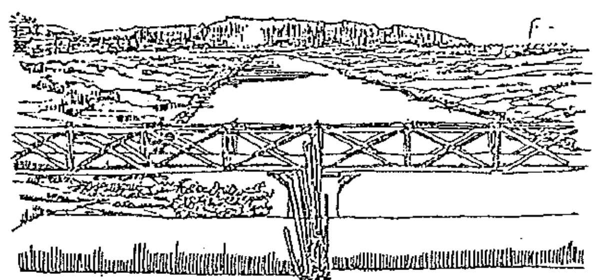


5. Sg.Satu near estuary. Newly built wooden bridges are more attractive and safe strolling for the tourists visited Batu Feringgi resort area.



6. Sg.Dua Lujar on the bridge at Jl.Gelugor. Rather gentle shaped river banks are streched towards upstream.

7. Sg.Nibong Kechil. Exstra dark turbid flow with intollerable smells are alllways in such a condition. yet some mangroves are still survived.



8. Sg.Ara with wide opened river reserve. New industrial facilities can be observed along the river surroundings.

9. Sg.Nipa at Batu Maung. Heavy polluted water with intorellable smell is dominated along mangrove forest.

Fig. 2-16	RIVERSIDE LANDSCAPE : PENANG ISLAND
THE STUDY ON FLOOD MITIGATION AND DRAINAGE IN PENANG ISLAND	

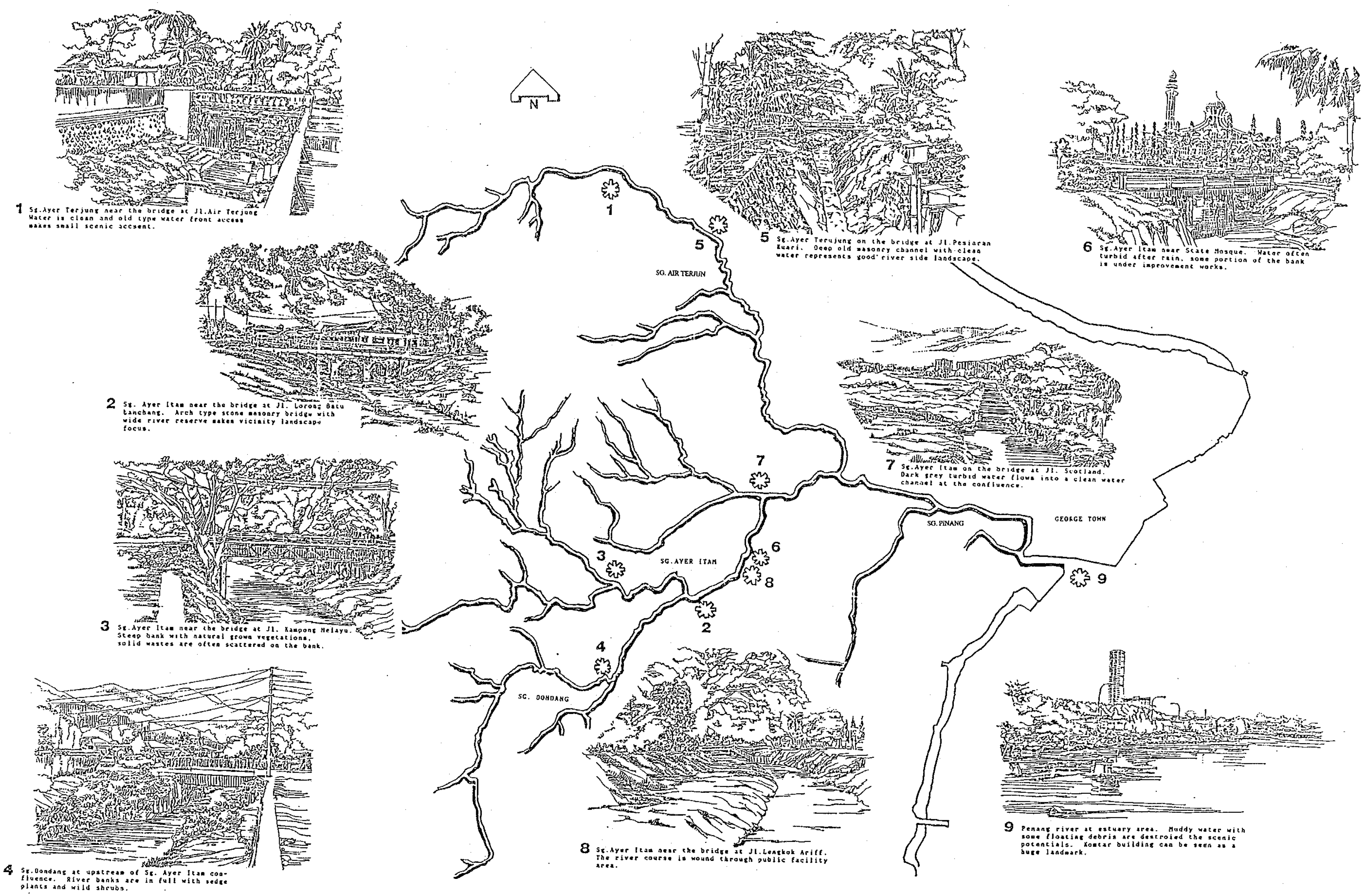


Fig. 2-17	RIVERSIDE LANDSCAPE : GEORGETOWN

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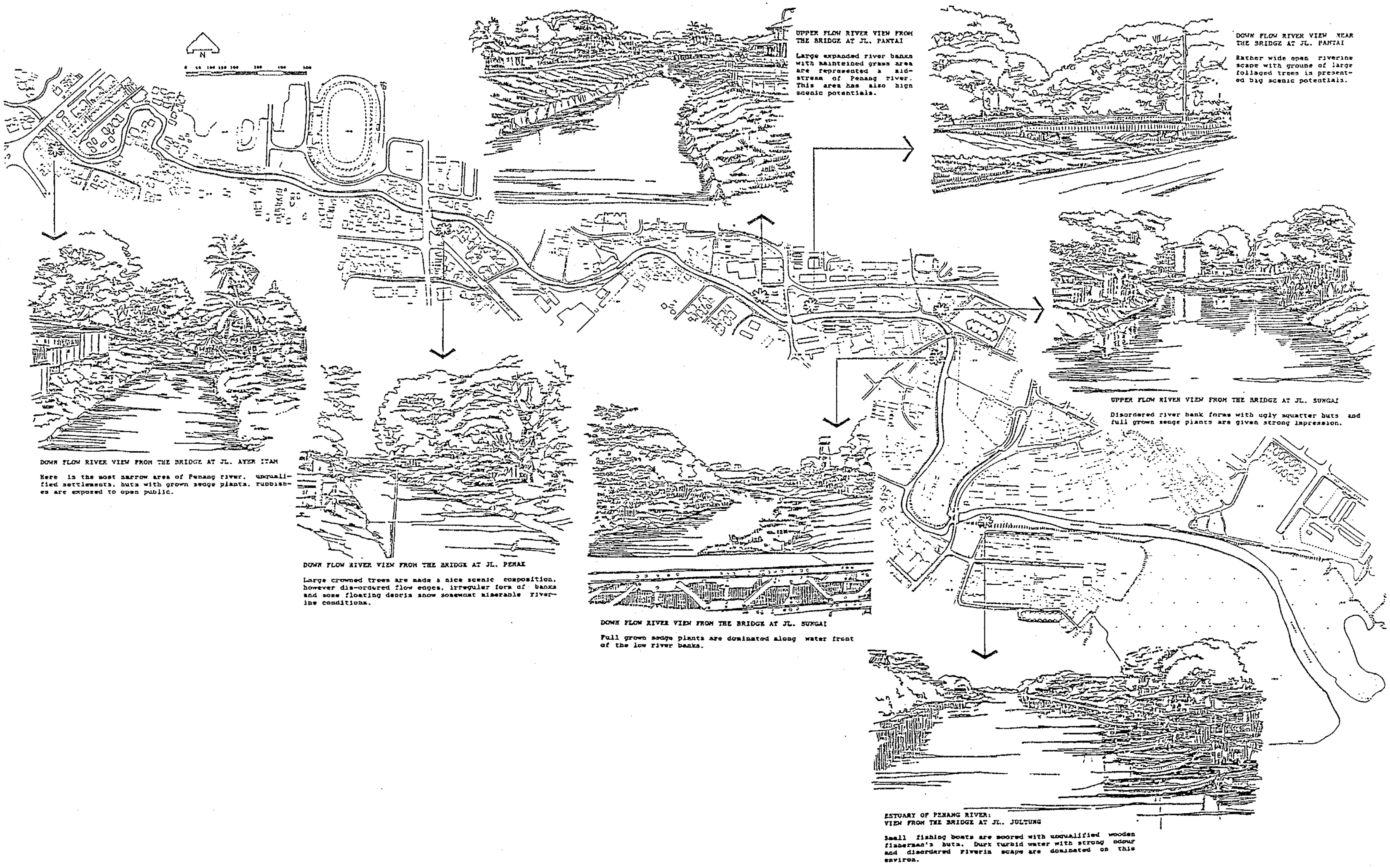

FIG. 2-18	RIVERSIDE LANDSCAPE : SG. PINANG

THE STUDY ON FLOOD MITIGATION AND DRAINAGE IN PENANG ISLAND

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Chapter 3 EXISTING FLOOD MITIGATION PROJECTS

CHAPTER 3 EXISTING FLOOD MITIGATION PROJECTS

For the rivers in the island, neither a comprehensive flood mitigation study nor a master plan of flood mitigation has ever been carried out in the past. The river improvement works have been executed locally only along some very important river stretches by SDID or MPPP. These improved river stretches exist mainly in the newly urbanized area, such as river reaches along developed areas or land reclamation areas.

These localized river improvement works have been executed, in general, by housing developers based on the design conditions approved by SDID.

3.1 COMPLETED FLOOD MITIGATION PROJECTS

The major flood mitigation projects already executed by SDID or MPPP are as follows:

3.1.1 Jelutong Diversion Channel

The Jelutong Diversion Channel was completed in 1976, diverting 80% of run-off discharge from the Sg. Jelutong catchment (6.59 km^2) to South Channel.

The diversion channel is about 1 km long and has a carrying capacity of about 60 m^3/s.

3.1.2 Sg. Tiram Diversion, Stage I

Sg. Tiram is a small river located in the vicinity north of the Bayan Lepas International Airport.

During the construction of the airport runway extension, the natural drainage outlet of the Sg. Tiram was blocked off and it was decided to divert the run-off from the Sg. Tiram catchment partly northeasterly to the Sg. Ara and partly southwesterly to the Sg. Bayan Lepas.

The diversion works to the Sg. Ara, named as the Sg. Tiram Diversion Channel-Stage I, was completed in 1970. It involved the construction of about 2.2 km of unlined trapezoidal channel, with a design capacity of 34 m^3/s, which runs parallel to the airport runway.

The Sg. Bayan Lepas diversion channel project is termed as the Sg. Tiram Diversion Channel-Stage II.

3.2 ONGOING FLOOD MITIGATION PROJECTS

The ongoing major flood mitigation projects are described below:

3.2.1 Sg. Pinang Improvement Works

This river improvement works are planned to be carried out by SDID for 3.2 km stretches between the river mouth and Datuk Keramat Bridge. The improvement works comprised the widening and deepening of the existing river channel section.

The First Phase of the improvement works commenced in 1989 was expected to be completed by 1990.

The construction cost is estimated to be about M$4.5 million.

3.2.2 Sg. Tiram Diversion Channel, Stage II

Stage II consists of diverting a portion of the Sg. Tiram to the Sg. Bayan Lepas with a diversion channel. The implementation work was planned to commence in 1989 by SDID. The total length of the diversion channel is 2.8 km.

The discharge capacity for the 0.68 km upstream portion of the diversion channel is 52.4 m^3/sec, whereas in the downstream portion of 2.12 km it is 76.4 m^3/sec.

Chapter 4 EXISTING URBAN DRAINAGE SYSTEM

CHAPTER 4 EXISTING URBAN DRAINAGE SYSTEM

4.1 EXISTING URBAN DRAINAGE SYSTEM

The existing drainage system in Greater Georgetown consists of a network of drains which discharge, via 45 man-made outfalls, to the North and South Channels or directly to rivers and streams. Outside Georgetown, all drainage outlets are natural rivers. Fig. 4-1 shows the existing outfalls and their respective catchment areas in Georgetown.

Among these drains, N-20, N-21 and S-23 are, in fact, natural rivers (Sg. Babi, Sg. Bagan Jermal and Jelutong Diversion) and these were dealt with separately under the Flood Mitigation Study.

The existing man-made drainage outlets in most areas are inadequate for handling for the drainage. The situation is aggravated by drains blocked by garbage, siltation and high tides.

In the drainage areas S-10 and S-18, exist lowlying areas. They are lower than the exceptional high tide level (+1.60 m). These areas become inundated even by spring tides.

The major man-made outfall to the South Channel is the Prangin Canal which has tide gates and 2 large capacity pumps with a total pumping capacity of 7.6 m^3/s.

The existing flow capacity of the main drains in the North and South Channels is shown in Tables 4-1.

4.2 EXISTING DRAINAGE IMPROVEMENT PLANS

The survey and study for the Penang Island Structure Plan were carried out by MPPP in 1985. As one of the public utilities studies, the drainage improvement study was executed and the following plans were proposed:

(a) As almost all of the drainage outlets are subjected to tidal inundation, the provision of a drainage system with tide controlled flap gate outlets is warranted. If necessary, pumping facilities should be installed at the outlets. Construction of a pumping station and the installation of pumps and a new tide gate were proposed at the existing Brick Kiln Road outfall (S-18). Also, the installation of new pumps to replace the existing ones were proposed at Prangin Canal outlet (S-10).

(b) To improve the drainage system of the City of Georgetown and to alleviate flooding, a reorganization of the existing outfalls and catchment areas along the north and south channels is necessary.

(c) Adequate drainage access reserve must be provided to all drainage outlets to facilitate their regular maintenance.

Tables

TABLE 4-1 EXISTING DISCHCARGE CAPACITY OF MAIN DRAIN AND OUTFALL IN NORTH AND SOUTH CHANNEL

No.of Existing Outfall	Discharge Capacity (m3/s)		Remark
	Main Drain	Outfall	
N1	-	5.2	a
N2	-	0.7	a
N3	0.1	0.2	d
N4	0.4	0.4	b
N5	0.4	0.4	d
N6	1.8	2.6	d
N7	0.4	0.4	d
N8	2.0	2.0	b
N9	3.7	1.9	d
N10	-	-	-
N11	1.1	-	-
N12	6.2	6.7	d
N13	3.1	3.1	a
N14	1.1	3.0	d
N15	1.8	1.8	a
N16	12.8	8.4	d
N17	1.2	1.2	a
N18	2.9	7.6	a
N19	6.8	4.1	a

No.of Existing Outfall	Discharge Capacity (m3/s)		Remark
	Main Drain	Outfall	
S1	-	-	-
S2	0.2	1.4	d
S3	2.2	2.7	a
S4	1.6	1.6	a
S5	0.7	3.7	d
S6	0.3	4.3	d
S7	1.2	0.5	d
S8	1.2	1.7	d
S9	1.8	1.8	d
S10	15.4	15.4	b
S11	-	-	-
S12	0.5	0.5	a
S13	-	-	-
S14	-	-	-
S15	0.4	0.4	d
S16	5.7	12.3	a
S17	3.7	3.7	a
S18	2.8	2.8	d
S19	0.7	0.7	a
S20	2.4	2.4	a
S21	0.6	0.6	a
S22	3.4	2.3	d
S23	80.7	80.7	a
S24	0.6	0.6	d

Remark
The existing flow capacity was categorized by return periods as follow ;
a > 10 year return period, 10 > b > 5, 5 > c > 2, 2 > d

Figures

Source: Report of Survey, Penang Island Structure Plan

FIG. 4-1	EXISTING URBAN DRAINAGE SYSTEM IN GEORGETOWN

THE STUDY ON FLOOD MITIGATION AND DRAINAGE IN PENANG ISLAND

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Chapter 5 HYDROLOGICAL ANALYSIS

CHAPTER 5 HYDROLOGICAL ANALYSIS

5.1 RAINFALL ANALYSIS

The daily rainfall data observed at 7 stations in Penang Island for 35 years (4 stations in the Sg. Pinang basin for 13 years) have been obtained, and were statistically analyzed by means of the Gumbel, Hazen and five other methods. As a result, the rainfall estimated by the Gumbel method was adopted, because the value was comparatively higher than the others and the Gumbel method was widely used in Malaysia.

There are 4 stations in the Sg. Pinang basin, and the average probable daily rainfall was adopted for the run-off analysis as a design rainfall. The average probable rainfall in Sg. Pinang basin is as follows:

Return periods (year)	2	5	10	20	30	50	100
Average Probable Daily Rainfall of the Basin (mm/day)	124	178	213	247	266	291	423

Two curves of rainfall intensity-duration-frequency prepared by the previous studies are shown in Fig. 5-1. One is by DID and the other by MPPP. The latter was developed by revising the former. Both curves have been adopted for flood control and drainage plans separately. The rainfall intensity of DID's curve is greater than that of MPPP's in the lower range of return periods, but the relation between these two curves reverses in the upper range over 50 years.

However, it is not necessary to unify these two curves, because MPPP usually uses 10 years and under as a design return period but DID uses 50 years.

As for the design rainfall, the daily rainfall was used for the Sg. Pinang and the Sg. Keluang which have comparatively large catchment areas. The rainfall intensity-duration curve by DID was used for other rivers having small catchments. The rainfall intensity-duration curve by MPPP was used for the drainage plan.

The rainfall pattern data recorded in the Sg. Pinang and other basins from 1975 until 1987 have been obtained. The rainfall pattern which caused the highest peak discharge was adopted as a design rainfall model by taking into account of the conditions given below:

(a) Enlargement ratio for design probable rainfall (291 mm in average) must be under 2.0 (approximate).

(b) The enlarged values of 1-hour, 3-hour and 6-hour rainfall must not significantly exceed the rainfall intensity-duration curve by DID.

Thus, the rainfall pattern observed on September 17, 1976 at Air Itam station was adopted as the design rainfall model. The 24-hour rainfall is 231.8 mm and the enlargement ratio is 1.25. Three typical rainfall patterns are shown in Fig. 5-2.

5.2 RUN-OFF ANALYSIS

5.2.1 Simulation of Actual Flood Discharge

Run-off simulation of actual flood discharge was carried out in order to establish a simulation model for the run-off analysis of the Sg. Pinang and the Sg. Keluang. Flood discharges were observed twice during the Study period. The flood that occured on August 25 was adopted as the actual flood discharge because the discharge was comparatively high. The storage function method was applied for the conversion of the areal rainfall to the flood hydrograph. The check points were Brook Road and Jln. Scotland. The flood hydrograph describing both the actual and computed discharge are shown in Fig. 5-3.

5.2.2 Determination of Probable and Design Flood Discharges

Probable flood discharge and design flood discharge were calculated by using the established simulation model. Some alternative flood mitigation plans were examined. The conditions assumed in the calculation are as follows:

(a) Land use in 2010 was considered as the future land use of the basin.

(b) The existing Air Itam Dam can not have effective flood control potential even if improved. Thus, the control effect of this dam was not taken into account.

(c) As discharge from the upper reaches directly flows into the sea, the discharge of the Sg. Jelutong was only due to run-off from the catchment that corresponds to the river reaches downstream of the Jelutong Diversion Channel.

(d) All other rivers, except Sg. Keluang, have comparatively small catchment areas and short time of concentration. The Rational Formula was adopted determining the discharges of these rivers.

The 50 year return period flood discharge of the Sg. Pinang at the river mouth is 270 m^3/s without any protective measures.

The determined probable flood discharge distribution of the Sg. Pinang is shown in Fig. 5-4, while those of all the other 25 rivers are given in Table 5-1.

5.3 FLOODING ANALYSIS

The flooding analysis was carried out for Sg. Pinang and the other rivers to identify flooding areas and inundation depths (or flood water levels) under existing river conditions for the estimation of the annual flood damage potential.

The flooding analysis was carried out for five flood frequencies ranging from 5 year to 100 year (5, 10, 30, 50 and 100 year return periods floods) under the land use conditions of the year 2010.

The results of the analysis for the Sg. Pinang basin are shown in Fig. 5-5.

The estimated total inundation area in the Sg. Pinang basin for various return periods are as follows:

Return Period (Year)	5	10	30	50	100
Inundation Area (km^2)	1.6	7.1	12.6	14.8	15.9

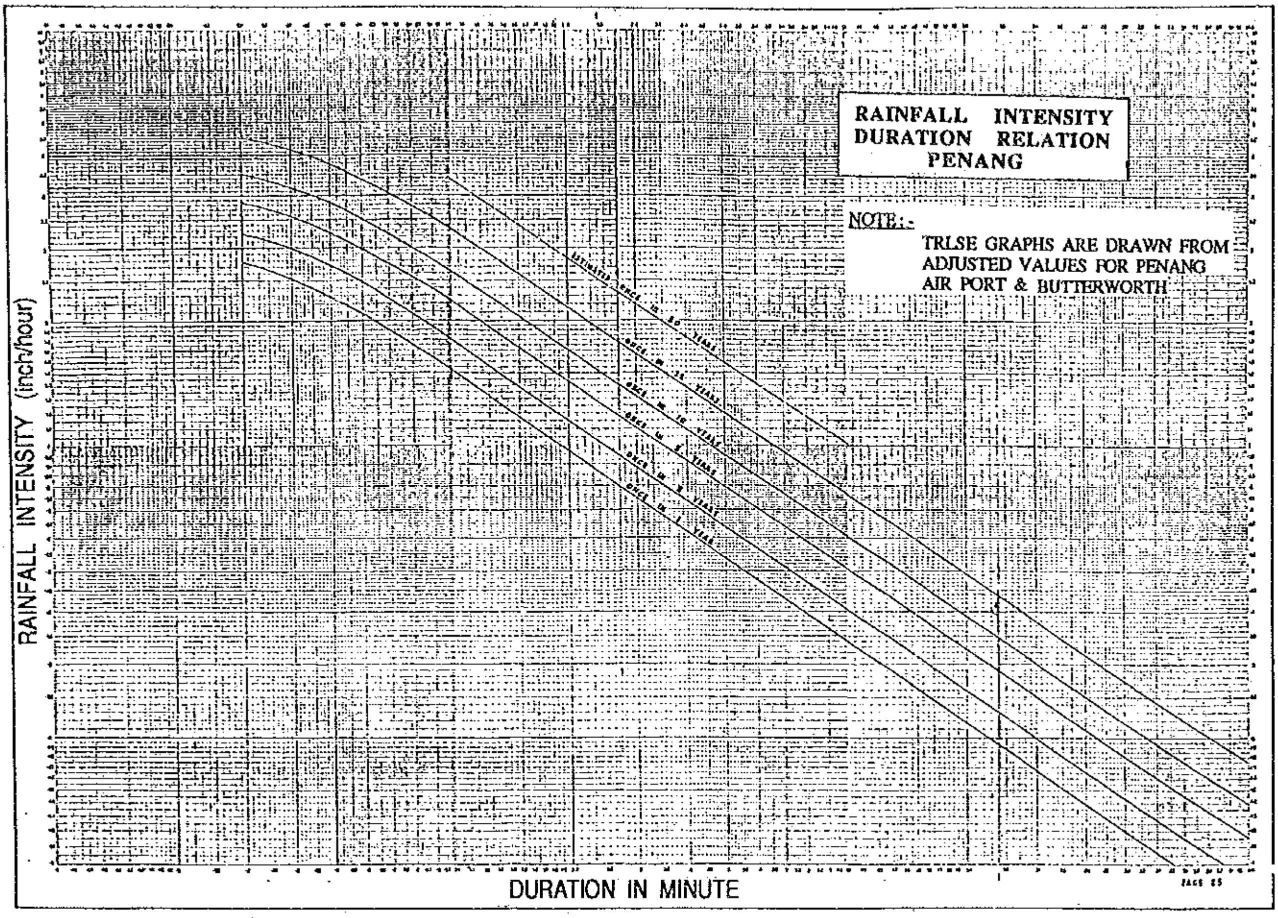
Tables

TABLE 5-1 PROBABLE FLOOD DISCHARGE OF 25 RIVERS IN THE STUDY AREA

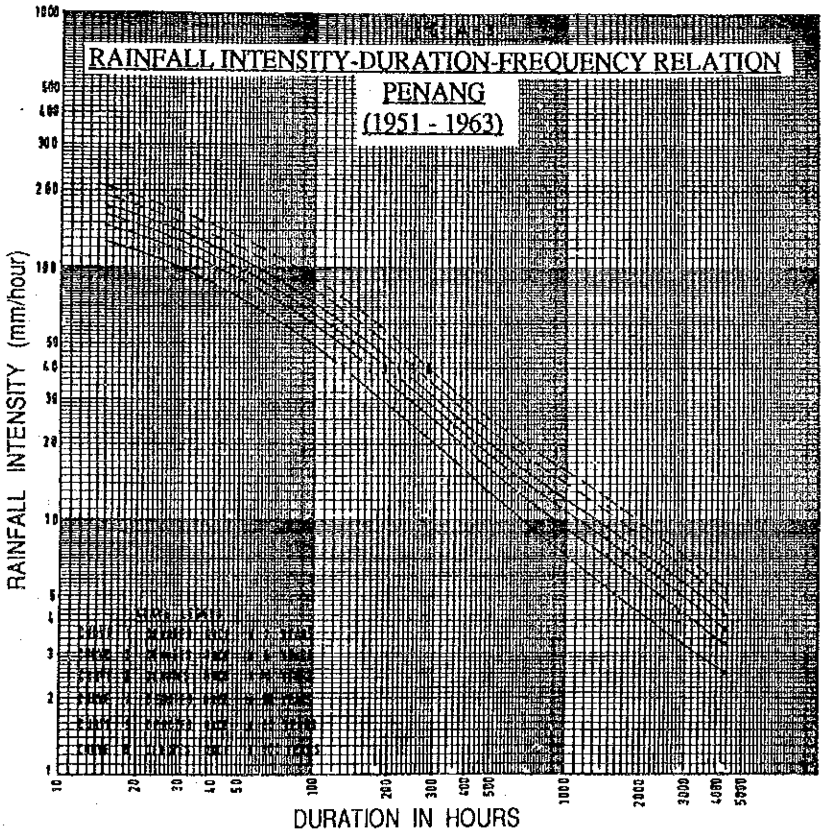
Land Use Condition in 2010

NO.	River Name	Catchment Area (km^2)	Run-off Coefficient	Time of Con-centration (minute)	Probable Flood Discharge (m^3/s)				
					5 year	10 year	20 year	50 year	100 year
2	Sg.Teluk Awak	2.95	0.22	37	16	17	19	21	22
3	Sg.Teluk Bahang	12.30	0.22	56	39	44	48	52	56
4	Sg. Batu Ferringghi	11.27	0.21	49	40	45	49	53	57
5	Sg.Satu	2.58	0.23	35	15	17	19	20	22
6	Sg.Mas	2.11	0.33	32	20	22	25	27	29
7	Sg.Kechil	2.75	0.25	33	19	21	23	26	27
8	Sg.Kelian	9.04	0.25	56	33	37	40	44	47
9	Sg.Balik Batu	0.80	0.37	23	14	15	17	18	20
10	Sg.Fettes	1.36	0.34	24	20	22	24	27	29
11	Sg.Bagan Jermal	0.83	0.26	24	9	10	11	13	14
12	Sg.Babi	0.84	0.29	28	8	9	10	11	12
13	Sg.Gelugor	4.07	0.31	39	28	32	35	38	40
14	Sg.Dua Besar	6.19	0.29	42	37	41	45	49	52
15	Sg.Nibong Besar	1.50	0.36	29	18	20	22	24	26
16	Sg.Nibong Kechil	2.77	0.41	33	32	35	38	42	45
17	Sg.Keluang	22.17	0.28	63	36	61	81	130	157
18	Sg.Nipah	1.69	0.35	25	24	27	29	32	35
19	Sg.Kampung Masjid	0.84	0.35	23	14	15	16	18	20
20	Sg.Ikan Mati	0.38	0.37	19	9	10	11	12	13
21	Sg.Bayan Lepas	7.04	0.24	47	30	34	37	40	43
	Sg.Tiram Diversion	2.59	0.30	35	20	22	24	26	29
22	Sg.Batu	0.90	0.26	26	9	10	11	12	13
23	Sg.Mati	0.95	0.29	25	11	12	14	15	16
24	Sg.Teluk Kumbar	7.06	0.23	40	35	39	43	46	50
25	Sg. Gemuroh	1.91	0.20	25	16	17	19	21	22
26	Sg.Gertak Sanggui	1.03	0.22	22	11	12	14	15	16

Figures



by MPPP



by DID

FIG. 5-1	RAINFALL INTENSITY CURVE

THE STUDY ON FLOOD MITIGATION AND DRAINAGE IN PENANG ISLAND

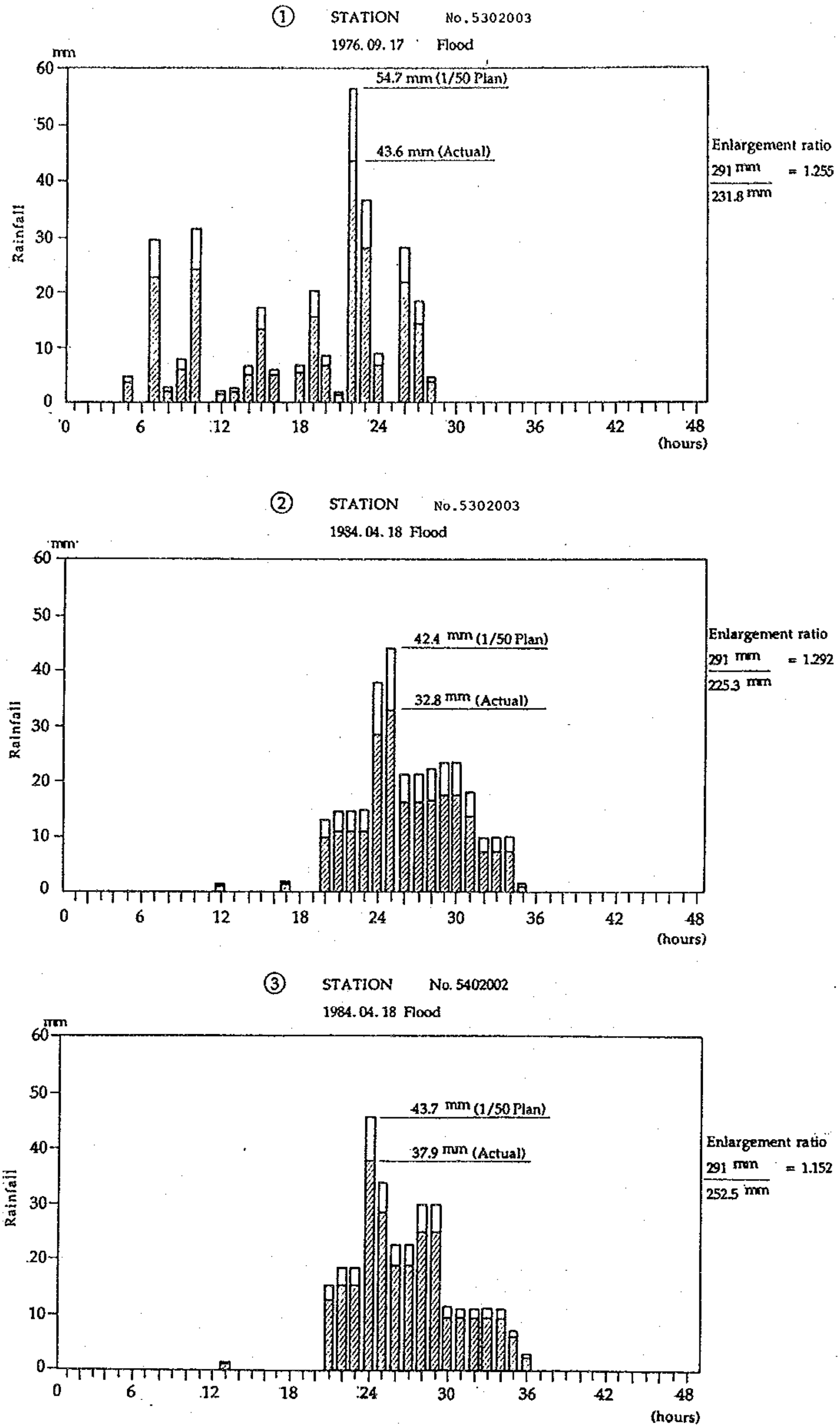
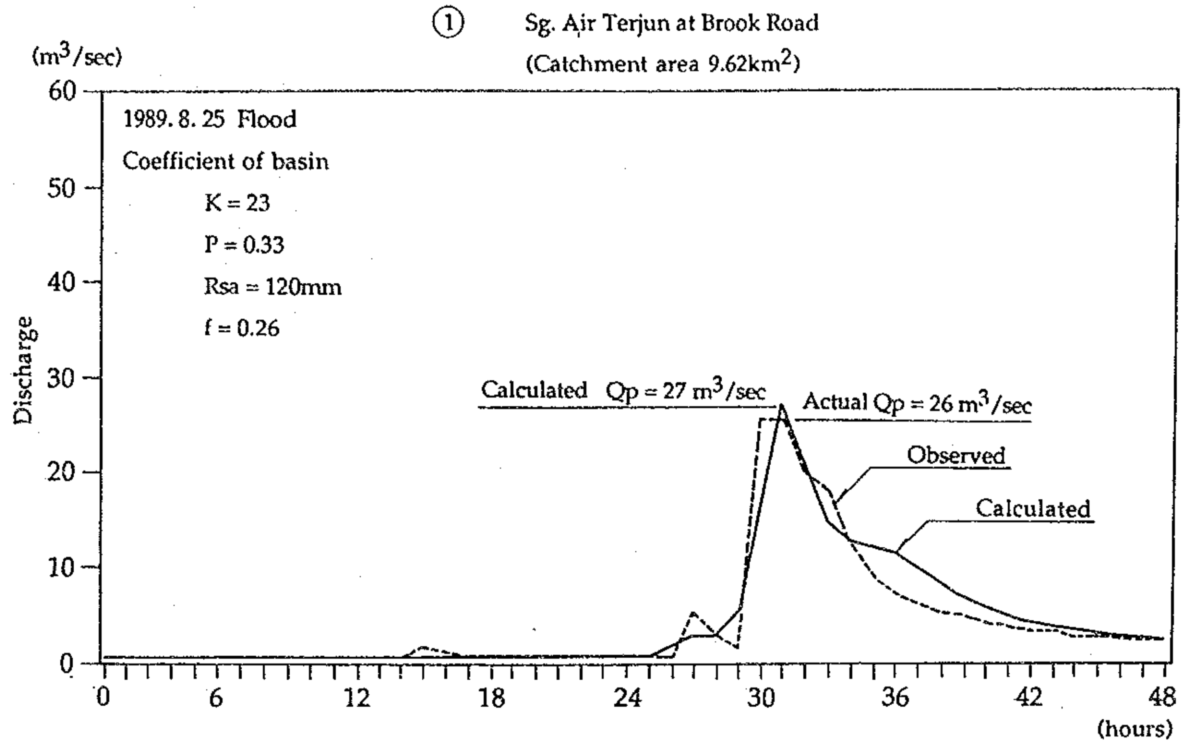


FIG. 5-2	ACTUAL HYETOGRAPH IN 1976 AND 1984 FLOODS

THE STUDY ON FLOOD MITIGATION AND DRAINAGE IN PENANG ISLAND



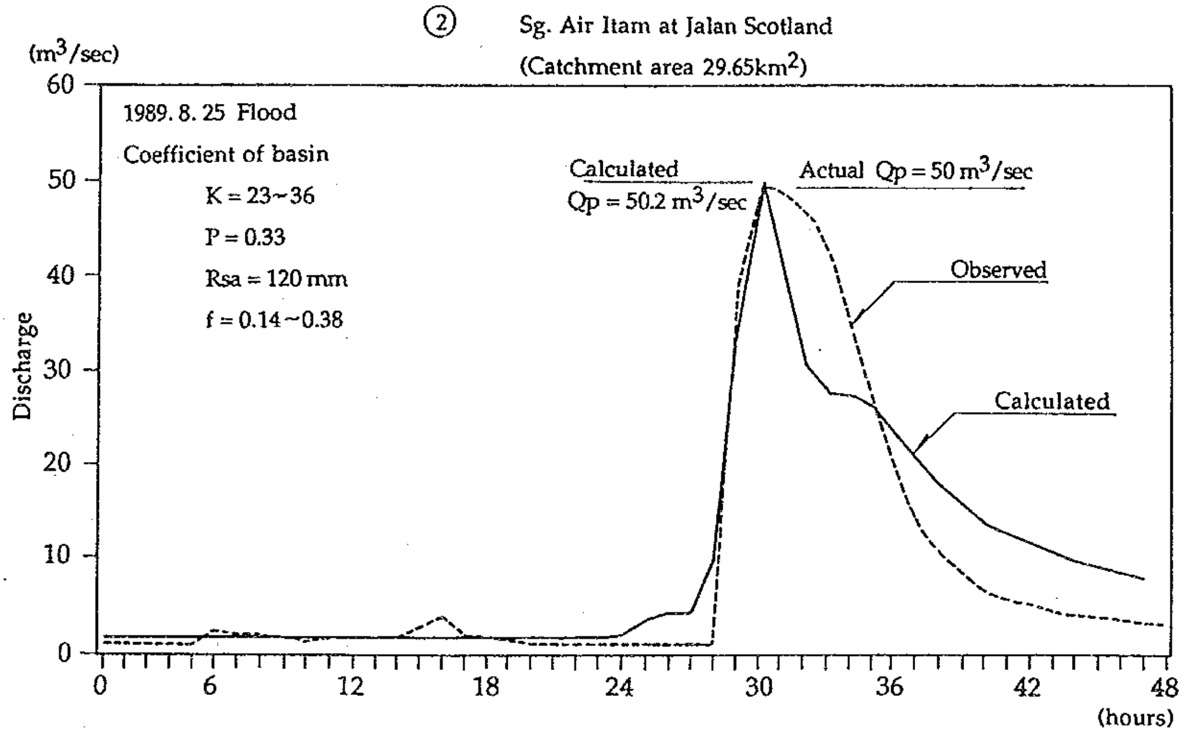


FIG. 5-3	OBSERVED AND SIMULATED FLOOD HYDROGRAPH

THE STUDY ON FLOOD MITIGATION AND DRAINAGE IN PENANG ISLAND

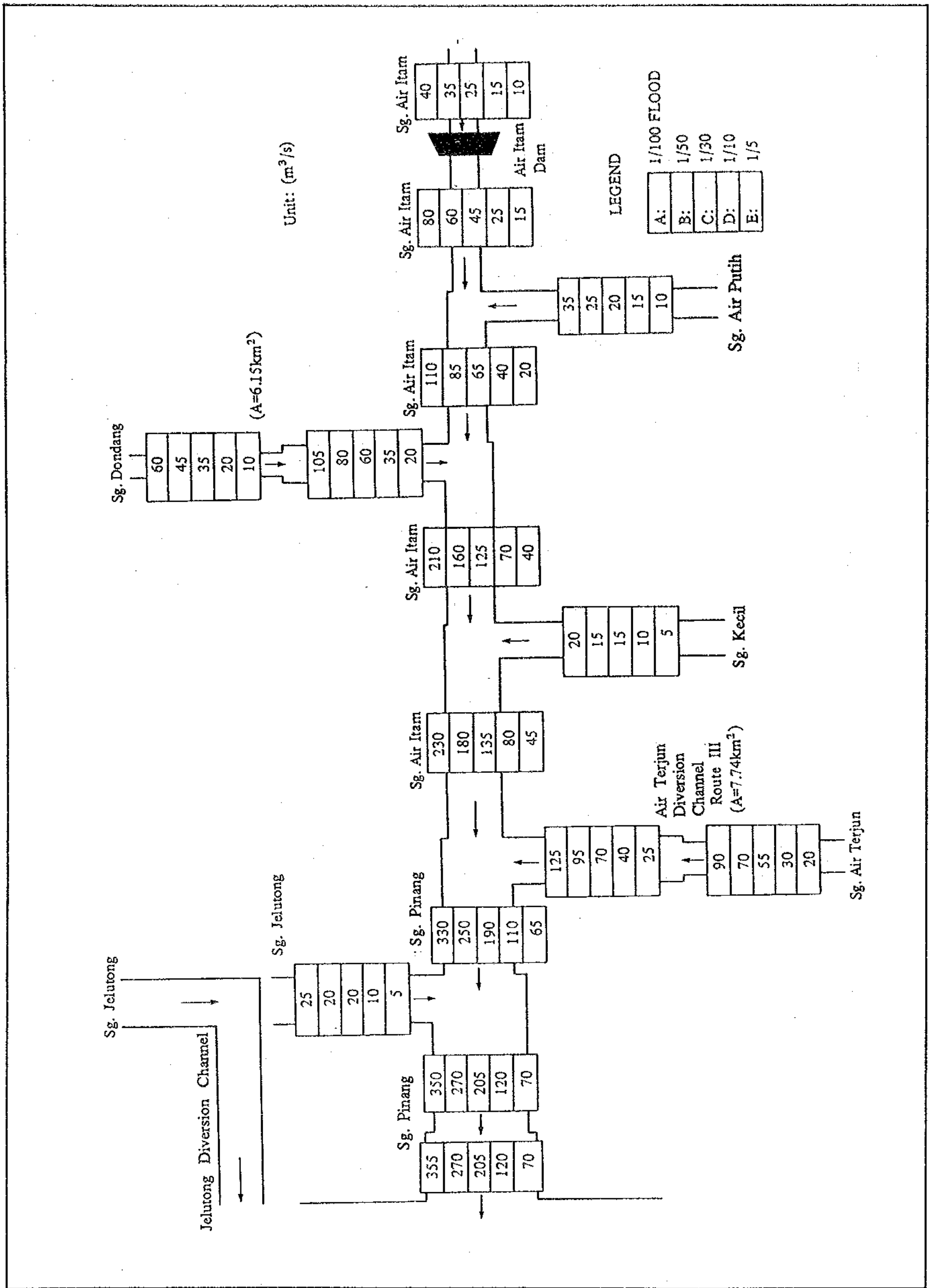


FIG. 5-4 **PROBABLE FLOOD DISCHARGE DISTRIBUTION**

THE STUDY ON FLOOD MITIGATION AND DRAINAGE IN PENANG ISLAND

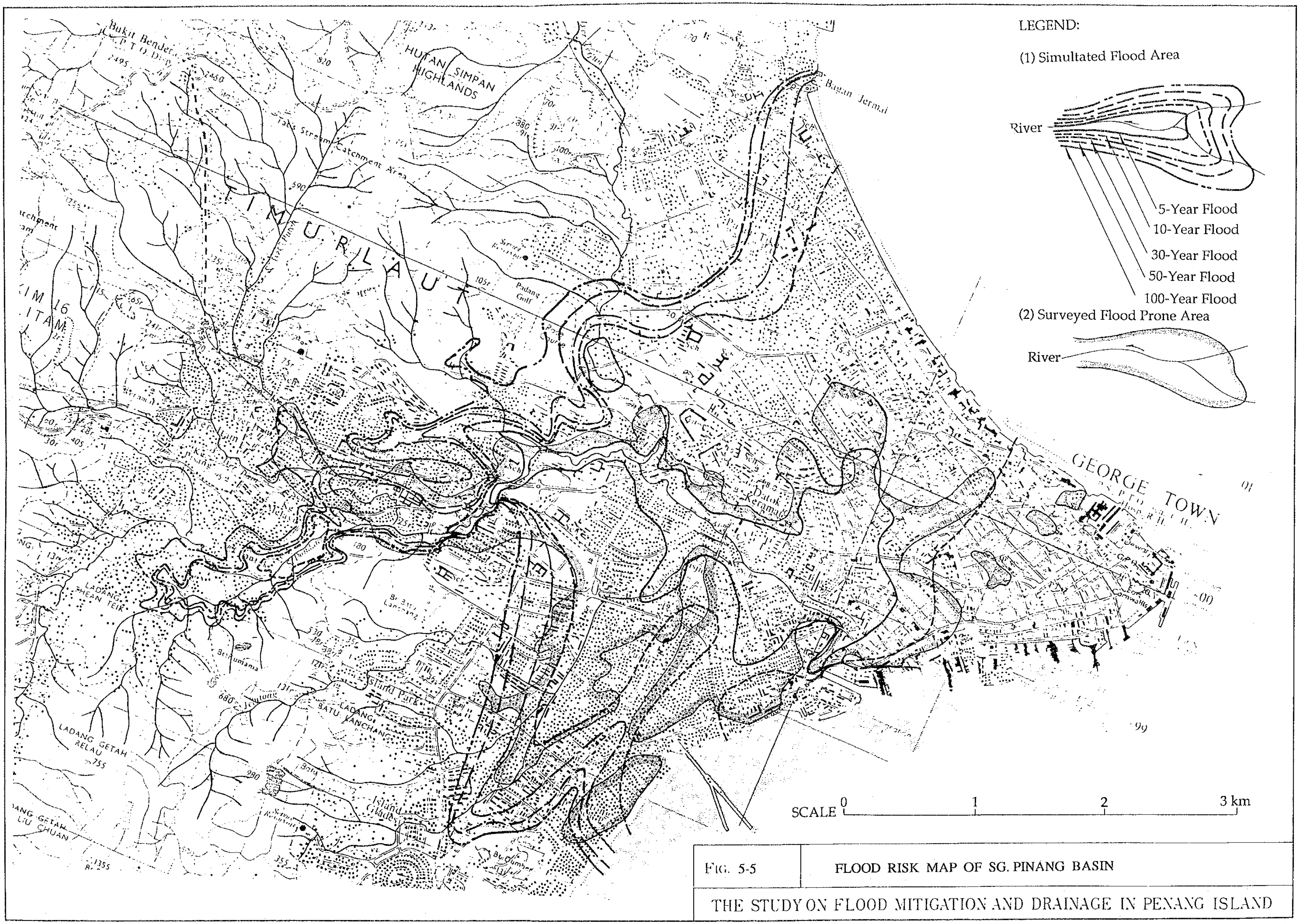


FIG. 5-5 FLOOD RISK MAP OF SG. PINANG BASIN

THE STUDY ON FLOOD MITIGATION AND DRAINAGE IN PENANG ISLAND

Chapter 6 FORMULATION OF MASTER PLAN OF FLOOD MITIGATION

CHAPTER 6 FORMULATION OF MASTER PLAN OF FLOOD MITIGATION

6.1 INTRODUCTION

Flooding in the Sg. Pinang basin has so far occurred mainly in the centre of old Georgetown along the Sg. Pinang and its tributaries, Sg. Dondang, Sg. Air Terjun, Sg. Air Itam and Sg. Jelutong.

In other basins, flooding has occurred mainly in the lower basins. However, due to recent intensive land development in the upper basin, especially in the hilly side, flooding now occurs even in the upper or middle basin, such as in the Sg. Dondang, Sg. Gelugor or Sg. Relau.

In addition, the roles and responsibilities of the various departments and agencies in the planning, development and maintenance of flood mitigation and urban drainage works both within and outside the City of Georgetown are not clearly defined. To make matters worse, there is no effective coordination between DID or MPPP and the agencies having jurisdiction over land development or human activities, such as cultivation, housing development, land reclamation, deforestation, and mining. This has resulted in erosion and siltation , frequent flooding and drainage problems.

In order to overcome these intricate problems, an overall flood mitigation and drainage plan for the entire basin of the island was considered.

6.2 PLANNING CRITERIA FOR FLOOD MITIGATION

6.2.1 Establishment of Flood Protection Level

The degree of protection with respect to flood mitigation is determined by the adoption of a suitable design storm return period.

In principle, the required design storm period should be decided upon based on the comparative study between the cost of investment and the resultant benefit. However, owing to the difficulty in determining the basic data for analysis, and in order to eliminate regional discrepancies, usually the central government decides the standard degree of protection although these are subject to change along with the economic growth of the country.

For Malaysia, according to the "National Water Resources Study, Malaysia" carried out by JICA in 1982, a design storm return period of 50 years is recommended when the flood damage exceeds M$ 20,000 per km of river reach and the population is more than 500 persons/km^2. However, if loss of life is recorded, then a 100 year return period is to be adopted.

Incidentally, the conceivable structural measures for the Sg.Pinang system are very limited because of its topographic and land use conditions. River improvement works are essentially required as the major flood mitigatory measure, even with utmost use of the other measures of diversion channel and retention pond. Hence, the scale of river improvements that would be possible will eventually dictate the degree of an attainable flood protection level for the Sg.Pinang.

The relevant important rationale that necessitates river improvements as the major work component for attaining any considerable flood protection level for the Sg.Pinang are as follows:

- The existing discharge capacities of both the Sg.Pinang reaches upstream of Jln. Jelutong Bridge and the Sg. Air Itam are so low and correspond to even less than a 1.1 year return period, which in itself points out the requirement for river improvement works that are to attain any considerable flood protection level.

- The Sg.Pinang reaches downstream of Jln. Jelutong Bridge has a maximum width of 46 m and will have a comparatively high discharge capacity of about 200 m^3/sec, after deepening the river channel, which corresponds to a 30-year return period.

Finally, a flood protection level corresponding to 50-year return period was selected with due consideration of the following:

It is possible to widen the following stretches of the Sg.Pinang, with due consideration to existing riverine land use, so that all their carrying capacities would correspond to a 50 year return period.

They are as follows:

- The stretches between Jln. Jelutong Bridge and the Sg. Jelutong could be widened to 40 m to enhance its carrying capacity to about 210 m^3/sec.

- The immediate upstream stretches between the Sg. Jelutong and the Sg. Air Terjun could be widened to 35 m to have a carrying capacity of 190 m^3/sec.

- The further upstream stretches between the Sg. Air Terjun and the Sg. Kecil could be widened to 30 m to have a carrying capacity of 160 m^3/sec.

Nevertheless, reconstruction of all the major bridges along these reaches of the Sg.Pinang is necessary, as the average width of a typical existing bridge is only 20 m, and the maximum average discharge capacity across the bridge is only about 85 m^3/sec, which corresponds to a 10-year return period.

For all rivers other than the Sg. Pinang, land acquisition for river improvement works will be comparatively simple. The catchment areas of these rivers are quite small having fewer developed areas in comparison to Sg.Pinang basin. Nevertheless, with due consideration to the future developments, and to be compatible with the overall flood mitigation plan, a 50-year return period was selected, universally.

The design storm return period adopted in Japan for rivers with similar catchments is shown in Table 6-8.

6.2.2 Planning Criteria for Flood Mitigation Facilities

The following design criteria were adopted for planning the flood mitigation facilities with due consideration given to the topographic, geological and land use conditions, and the effectiveness and safety of the structures.

1) River Improvement

- The river channel will be basically of single or double trapezoidal section type.
- The double section will be adopted for the undeveloped reaches of large rivers having comparatively large catchment areas.
- The planned river channel will be, as far as possible, excavated waterways. Levees will be avoided in order to minimize the requirements of inner water drainage
- The design high water level at the Sg. Pinang mouth will be the mean high water springs which is +1.08 m. This value will be assumed for all rivers neglecting any slight variations that may occur according to location changes.
- A minimum freeboard of 0.6 m will be allowed at all river banks.

- All levee crest elevations shall be higher than the higher water level estimated by assuming a water stage of 1.60 m at the river mouth.

2) **Diversion Channel**

- The design discharge through a tunnel section will be 130% of the design flood discharge.

- The tunnel section will have a minimum clearance area of 15% of the area of flow corresponding to the design discharge.

3) **Retention Pond**

- The retention pond will be planned for multi-purpose use considering its effective use under normal conditions of no flooding.

6.3 CONCEIVABLE STRUCTURAL MEASURES

To establish the appropriate protective measures against flooding in Penang Island, the existing and future conditions of the rivers and basins shall be given careful consideration, as described in the following section.

- Topographic condition
- Problems of land acquisition
- Existing river and related structures
- Present and future land use pattern
- Land reclamation plan in the coastal area

In the Sg. Pinang basin, including its tributaries, almost all flat land has already been urbanized and in these areas land acquisition for widening the river channel is rather difficult. Hence, as conceivable alternative protective measures, river improvement by deepening, diversion channel, retention pond and flood control dam were considered.

In the northern coast of the island, the rivers with rather large catchments, such as Sg. Teluk Bahang, Sg. Batu Ferringghi and Sg. Kelian, have 85% to 99% of their catchments in mountainous areas. Also, the river stretches to be improved are short. Hence, river improvement will be the major protective measure.

In the east coast, the Sg. Keluang has quite a large catchment and long river stretches but there is no sufficient space for a retention pond. For this basin, river improvement and diversion channel seem to be the appropriate protective measures.

Almost all rivers in the east coast which discharge into the South Channel should be extended at their river mouths due to land reclamation activities. This would result in the rising of the river stage making drainage of lowlying areas, including those reclaimed, rather difficult and vulnerable to flooding.

In the south coast, the Sg. Bayan Lepas and Sg. Teluk Kumbar are the main rivers. Large portions of their catchment areas are mountainous having no significant development potential. Hence, river improvements seem to be the most suitable alternative.

The existing conditions, the potential future developments and the conceivable structural measures for each river are outlined below.

6.3.1 Sg. Pinang

The Sg. Pinang system is composed of the 3.15 km long Pinang main stream and its main tributaries, the Sg. Air Itam, Sg. Air Terjun, Sg. Dondang and Sg. Jelutong.

In this basin, flooding problems have occurred mainly in the old Georgetown area along the Sg.Pinang and in the areas along the tributaries the Sg. Air Itam and the Sg. Jelutong.

Since the completion of Jelutong Diversion Channel, flooding problems of the area along the Sg. Jelutong have been mitigated. While in the Sg. Dondang basin where intensive development is in progress, some lowlying areas have recently become frequent flooding areas.

In the Sg.Pinang basin, two major flooding patterns are recognized. The first is flooding due to over topping of river banks of the main river or tributary. The second is flooding due to inner water, especially in the lowlying area.

The inner water problems will be dealt with separately in Chapter 7, with due consideration to the tidal effects in the lowlying coastal area.

To mitigate flooding due to bank over-topping, the following measures will be considered for the main river and tributaries.

(1) River Improvement

For the Sg.Pinang, river improvement by widening and deepening to maximum permissible extent will be considered. The tributaries will also be improved.

(2) Diversion Channel

For the tributaries near the coast, e.g., Sg. Air Terjun, diversion channel to directly divert the discharge into the North Channel will be considered. The five alternative routes were considered. In addition to these alternatives, a diversion channel from Sg. Air Itam to one of above routes was considered as an additional alternative. These routes are shown in Fig. 6-1.

Each alternative consists of the following facilities:

Route No.1	Botanical Garden - Sg. Bagan Jermal Diversion Tunnel + Improvement of Sg.Bagan Jermal.
Route No.2	Botanical Garden - Sg. Babi. Diversion Tunnel + Improvement of Sg. Babi.
Route No.3	Diversion Channel under the Jalan Gottlieb and Jalan Bagan Jermal Improvement of Sg. Babi.
Route No.4	Diversion Channel under the Jalan Cantonment.
Route No.5	Diversion Channel under the Jalan Residensi, Lebuh Raya Peel and Jalan Pangkor.
Route No.6	Diversion Channel from Sg. Air Itam to Route No.5 Channel.

The merits and demerits of the alternative routes were evaluated in Table 6-1. The final selection of the most suitable alternative among these alternative diversion channels was made considering the combination of construction cost of river improvement works because the scale of river improvement varies according to the point of diversion and discharge. As the representative diversion routes of small scale (50 m^3/s) and large scale (80 m^3/s), Route No. 3 and Route No.5 were selected for detailed alternative study.

(3) Flood Control Dam

For the Sg. Air Itam, the possibility of raising Air Itam Dam was investigated to obtain some flood control storage. It is expected to raise this dam by about 3 meter in height in consideration of its topographical and geological conditions. The consequent maximum flood control capacity that could be attained is about 600,000 m^3, thereby reducing the run-off discharge at Jln. Jelutong Bridge by about 20 m^3/s. The spillway is a bellmouth type massive concrete structure which could be raised. Even then, the flood control mechanism will only be natural without any gate, which is not an effective means of flood control. Furthermore, the catchment of this dam is only 5 km^2. Hence, this dam alternative is not very useful.

As per the other tributaries of the Sg.Pinang system, the Sg. Air Putih and Sg. Air Terjun, the rivers' catchment areas are very small. The catchment area of the dam could only be about 2 km^2. This dam's catchment area is too small to obtain any useful flood control storage; hence, this alternative was rejected.

(4) Retention Pond

Dondang area of the Sg.Pinang basin is undergoing rapid development and is frequently affected by flash floods.

Park lands proposed by the Land Use Plan of MPPP were studied for their suitability as retention ponds to mitigate flooding in the Dondang area as well as in the downstream reaches of Sg. Air Itam and Sg.Pinang.

The existing race course in the vicinity of the left bank of Sg. Air Itam was also considered for the retention pond. However, due to topographic conditions, the pond must be an underground type.

Considering the removal of sediments and grits, the construction cost would be very high and these would be cumbersome maintenance requirements. Hence, this underground pond alternative was rejected.

6.3.2 Sg. Dua Besar

The urbanized area of the catchment is expected to increase to 65% with the development of hilly areas. The downstream stretch of Sg. Nibong Road, which is a meandering unlined channel, is planned to be straightened with concrete channel.

In the midstream stretches there are many concrete canalization plans prepared by housing developers. River improvements would be the basic flood mitigatory measures to be considered.

6.3.3 Sg. Keluang

The Sg. Keluang river system consists of 500 m long Sg. Keluang main river and its tributaries, Sg. Relau and Sg. Ara. The total catchment area of the entire river system is 22 km^2, of which about 77% is comprised of mountainous and hilly areas.

Future land development is expected to reach up to the hilly areas with urbanized areas comprising 40% of land use.

Of the east coast river basins, this catchment area is developing most rapidly. A very high increase in run-off is expected.

A diversion channel, connecting the Sg. Relau to the Sg. Ara, to protect the downstream reaches, is planned by a housing developer.

The Sg. Keluang has already been improved to an unlined channel and has sufficient river reserve.

However, to cope up with the development of the upper reaches, river improvements was considered.

In addition, mining and quarrying sites exist and there are ongoing land development activities, especially in the hilly areas of these upstream reaches. This has led to severe soil erosion and sediment run-off resulting in siltation and rise in the downstream river bed, a phenomenon already in progress. It is absolutely necessary to institute suitable measures to control sediment run-off due to these activities.

The river channel of Sg. Keluang at the river mouth will have to be extended 350 m in consideration of the ongoing land reclamation activities.

6.3.4 Sg.Gelugor

The lowlying area of the catchment remains inundated due to rapid and ongoing land development activities in the upstream hilly areas. In the downstream reaches, the concrete floodway to South Channel has already been completed. Both the existing and once improved channel portion at the middle stream stretches will be further improved for flood mitigation. The uppermost hilly areas undergoing rapid land development require urgent erosion control measures against sediment run-off.

6.4 ALTERNATIVE PROTECTIVE MEASURES

6.4.1 Alternative Measures

Six possible alternative protective measures of flood mitigation for the Sg.Pinang were considered for the selection of a most suitable alternative.

For all the other rivers in Penang Island, excluding the Sg.Pinang system, river improvement works, including diversion channels, are the only conceivable structural mitigatory measures.

These alternatives are shown in Fig.6-2-1 and 6-2-2. Except for Alternative I, all other alternatives consist of combinations of several structural measures, and are capable of regulating the discharge in the main stream of the Sg.Pinang at Jln. Jelutong Bridge not to exceed the permissible maximum discharge of 210 m^3/s.

The Alternative I consists only of river improvement by means of widening or deepening; hence, it will not have any effects on river discharge.

Alternative V consists of the same protective measures as Alternative II and Diversion Channel No.5. In this case, the discharge at Jln. Jelutong Bridge is 175 m^3/s.

The distribution of design flood discharge for each alternative is shown in Fig.6-3-1 and 6-3-2.

(1) Alternative I

The Alternative I consists of only river improvement of Sg.Pinang (3.15 km) and its tributaries, Sg. Air Itam (3.00 km), Sg. Jelutong (2.50 km), Sg Air Terjun (2.20 km) and Sg. Dondang (5.3 km). The total length of the river improvement will be about 15.8 km.

(2) Alternative II

The Alternative II consists of river improvement of Sg.Pinang and its tributaries, the Air Terjun No.3 Diversion Channel (Q=50 m3/s) and Dondang Retention Ponds (V=300,000 m^3).

(3) Alternative III

No.5 Diversion Channel was considered in Sg. Air Terjun as the alternative instead of the No.3 Diversion Channel. The discharge capacity of No.5 Diversion Channel is 80 m^3/s; hence, Dondang Retention Ponds are not necessary.

The river improvement works are necessary for the Sg. Pinang and its tributaries.

(4) Alternative IV

Enlargement of the body and raising the top level of the existing Air Itam Dam by three (3) meters were considered as an alternative instead of Dondang Retention Ponds.

River improvements and No.3 Diversion Channel are also necessary.

(5) Alternative V

This alternative consists of river improvement of Sg.Pinang and its tributaries, No.3 Diversion Channel and No.5 Diversion Channel at Sg. Air Terjun with a capacity of 45 m^3/s.

(6) Alternative VI

This alternative consists of the same protective measures as Alternative V. However, No.5 Diversion Channel will cater to divert the discharge of about 45 m^3/s of the Sg. Air Terjun and about 35 m^3/s of the Sg. Air Itam. An additional diversion channel of 500 m in length between the Sg. Air Itam and the Sg. Air Terjun will be necessary.

These alternatives are summarized as follows:

Alternative	Sg.Pinang	Sg. Air Itam	Sg. Air Terjun	Sg.Dondang
I	R.Improvement	R.Improvement	R.Improvement	R.Improvement
II	ditto	ditto	No.3 Diversion R.Improvement	Retention Pond R.Improvement
III	ditto	ditto	No.5 Diversion R.Improvement	R.Improvement
IV	ditto	Air Itam Dam R.Improvement	No.3 Diversion R.Improvement	ditto
V	ditto	R.Improvement	No.3 & No.5 Diversion R.Improvement	Retention Pond R.Improvement
VI	ditto	ditto	No.3,No.5,No.6 Diversion R.Improvement	ditto

6.4.2 Comparison of Alternatives

The costs of civil works, land acquisition, and compensation required were estimated for each alternative. The cost of civil works is calculated by multiplying the quantity of work by the unit cost.

A tentative estimation of construction cost for all six alternatives is summarized below:

(unit:10^3M$)

Alternative	Civil Works	Land Acquisition House Evacuation	Total
Al-I	29,764	40,619	70,383
Al-II	34,376	32,276	66,652
Al-III	35,120	35,593	70,713
Al-IV	36,537	34,087	70,624
Al-V	40,890	30,032	70,922
Al-VI	45,432	27,915	73,347

It should be noted that all these alternative schemes have the same flood protection level of 50 year return period.

Based on cost comparison it is evident that Alternative II (Al-II) is the most economical.

In fact, as well as being economical, it is selected as the Master Plan alternative because it is evaluated to be the optimum alternative with respect to the technical and social aspects of the project implementation.

A brief description of the merits and demerits of all alternatives are summarized below:

- Alternative I (Al-I) is the second most economical scheme as evident from the above cost comparison table. However, the scheme is expected to encounter many difficulties with respect to land acquisition, housing relocation and compensation as it involves long river improvement reaches.

- Alternative II (Al-II), as described above is selected as the Master Plan alternative. It is the most economical scheme, and its work components, the river improvements, Dondang retention ponds and No.3 route diversion channel are not expected to involve any significant social problems during implementation.

  The No.3 Diversion Channel will be constructed mostly under the existing roads, and is of a small scale as it is located in the upper reaches of the tributary Sg. Air Terjun. Also, it eliminates the requirement of river improvement works at downstream. The scheme involves virtually no land acquisition requirements other than in the area near Sg. Babi river mouth.

- Alternative III (Al-III) differs from Alternative II mainly with respect to the diversion channel scheme. However, it is only the fourth most economical scheme.

  The No. 5 Diversion Channel is located at downstream of Sg. Air Terjun. Not only does it have a larger capacity than No. 3 Diversion channel but it requires larger scale river improvement works for the stretches of the Sg. Air Terjun.

  Also the construction of this diversion channel would encounter technical, social and environmental concerns and difficulties.

  They are:

  - The culvert is 12 m wide and its construction would result in the destruction of many trees. During construction, the entire road would become inaccessible and local communities would