8. Reference Figures

8.1 General

1) Fig. E.2 shows the outline of bi-dimensional Model.

2) Fig. E.3 - E.5 show the schematic discription for drainage facilities in the bi-dimensional model.

3) Fig. E.6 shows the flow chart for main program of bi-dimensional model.

4) Fig. E.7 shows the flow chart for polder drainage study

8.2 Result of Actual Application of Two Basin Model

1) Fig. E.8 to Fig. E.13 show the simulated inundated conditions which expressed the inundation area under calculation condition of with/without Green Belt Project, stormwater retention area and improvement of capacity of drainage facilities. These results are used the observed rainfall data in the year of 1980.

2) Fig. E 14 to Fig. 16 show the flood water levels with refer to Fig. E.8 to Fig. E. 13.

3) Fig. E.17 to Fig. E.21 show the simulated inundated conditions which expressed the inundation area under the same calculation condition using the observed rainfall data in the year of 1983.

4) Fig. E.22 to Fig. E.24 show the flood water levels with refer to Fig. E.17 to Fig. E.21.

8.3 Result of Actual Application of Bi-Dimensional Model

1) Fig. E.25 shows the mesh arrangement for calibration of 1983 Flood.

2) Fig. E.26 shows the mesh arrangement for calculation of alternative III.

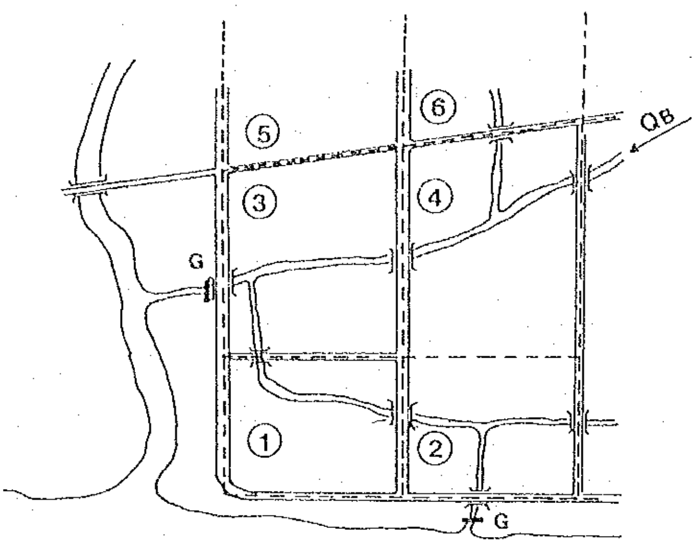
3) Fig. E.27 show the simulated water level and inundation depth for alternative III in the main report.

4) Fig. E.28 shows the comparison of simulated storage volumes in 1983 Flood using two basin model and bi-dimensional Model.

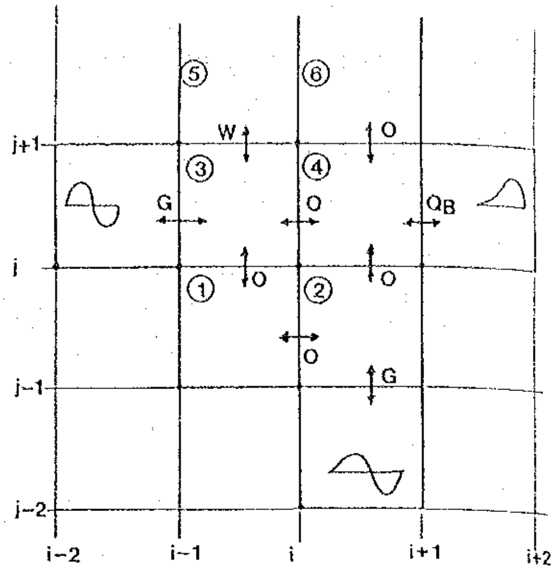
8.4 Others

1) Fig. E.29 show the existing topographical condition in Ramkamhaeng site.

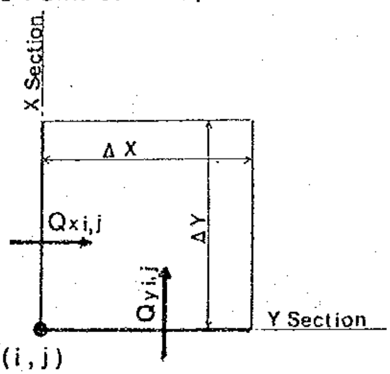
1. Overall Picture of Two Dimensional Model



2. Mesh Arrangement



3. Definite Point of Mesh/Section



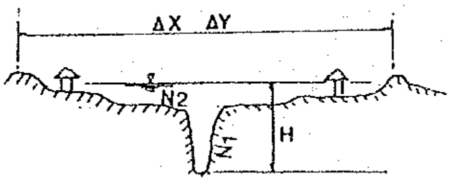
W Weir
O Open
G Gate
② Mesh
Inflow Boundary
Water-Level Boundary
i, j Mesh Node

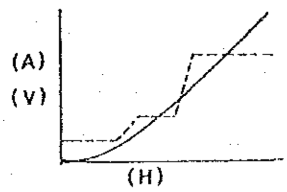
MESH DATA

ΔX, ΔY : Size of Mesh
R : Rainfall
E : Evapotranspiration
Z : Water Level
H : Water Depth
ZB : Lowest Bottom Elevation
H–V : Water Depth — Mesh Volume
H–A : Water Depth — Water Surface Area

SECTION DATA

Qx i,j : Discharge of X section
H–A·N : Sectional Water Depth — Flow Area, Coef. of Roughness
ZBS : Lowest Bottom Elevation
Type : Open Canal, Gate, Weir, Pump





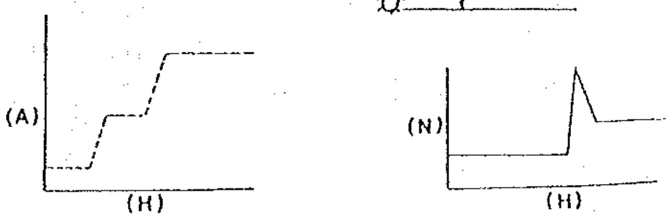


FIG. E.2

Outline of Bi-Dimensional Model

FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK

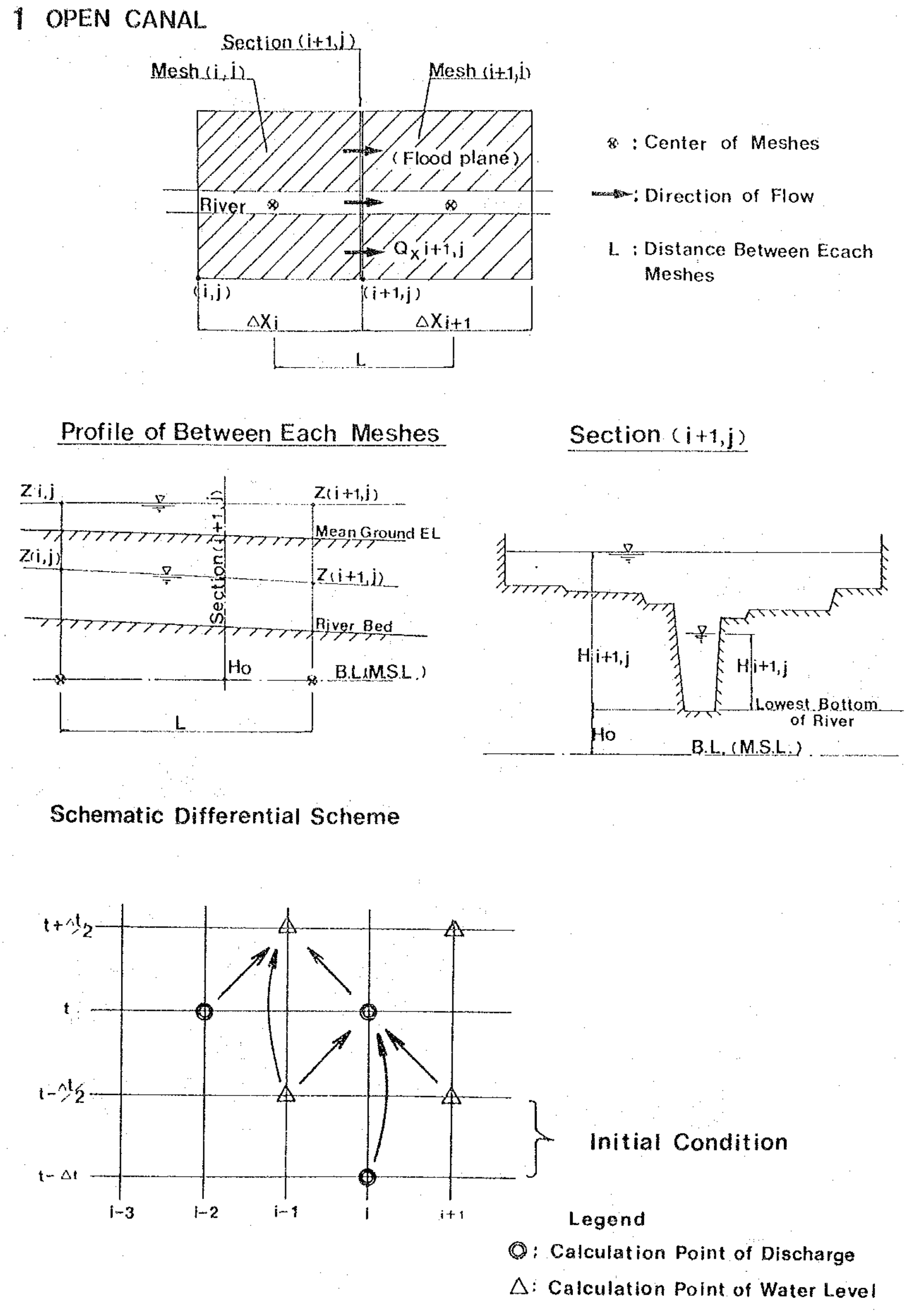
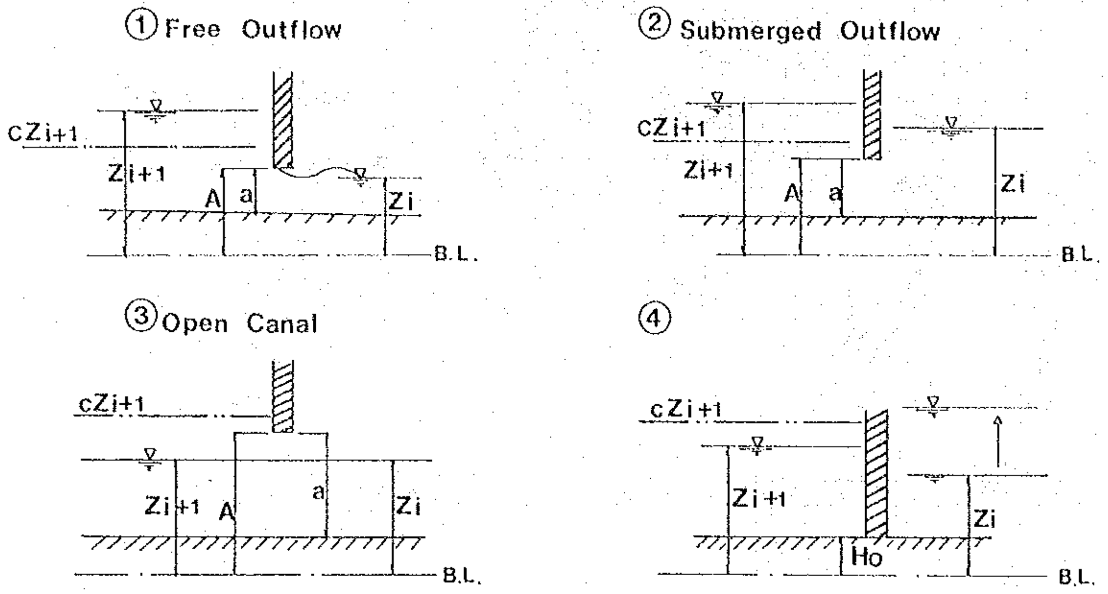


FIG. E.3 Schematic Description for Open Canal Link

FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK

2 GATE



$Z_{i+1} > Z_i$ Condition

① $Z_i \leqq A$

$$Q_{i+1} = maB\sqrt{2g(Z_{i+1} - A)}$$

② $Z_i > A$

$$Q_{i+1} = maB\sqrt{2g\Delta H}$$

③ $Z_{i+1} \leqq A$

Q_{i+1}: Same as Open Canal Condition

④ $A \leqq H_0$

$$Q_{i+1} = 0$$

Legend

- B : Width of Gate
- m : Coefficient of Gate
- a : Height of Gate Opening
- ΔH : $Z_{i+1} - Z_i$
- cZ_{i+1}: Critical Water Level for Full Open

Gate Control

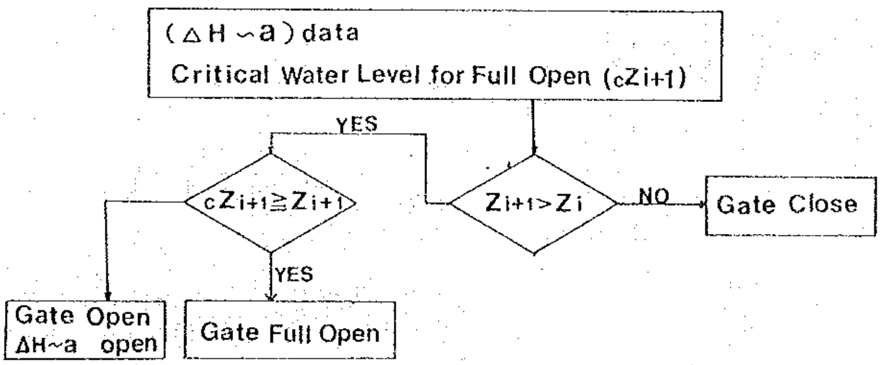
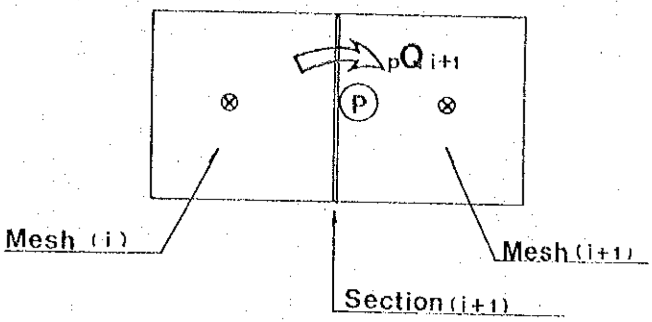
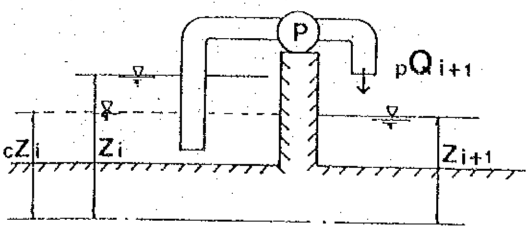


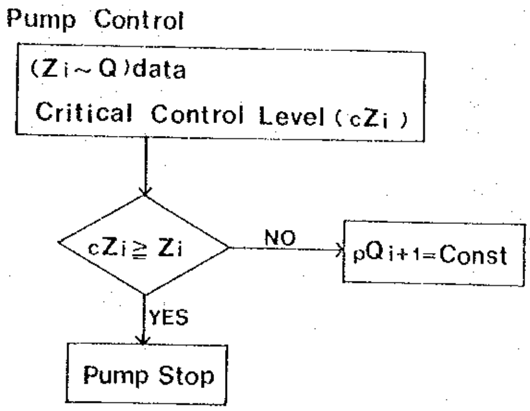
FIG. E.4	Schematic Description for Gate Link

FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK

3 PUMP

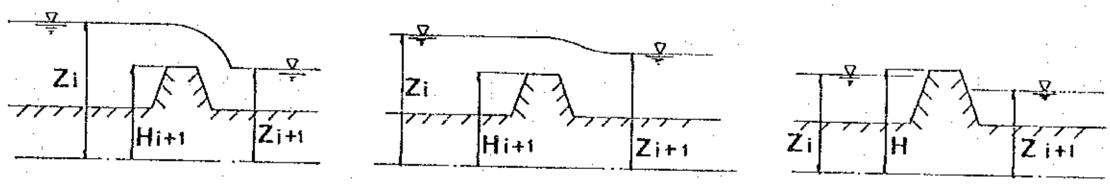






4 WEIR

① Complete Overflow ② Submerged Overflow ③ Not Flow Condition



$Z_i > Z_{i+1}$ Condition

◎ $Z_i > Z_{i+1}$

① $Z_i > H$ and $(Z_{i+1}-H)/(Z_i-H) \leqq 2/3$

$Q_{i+1} = \mu\beta(Z_i - H)\sqrt{2g(Z_i - H)}$ $\mu =$,

② $Z_i > H$ and $(Z_{i+1}-H)/(Z_i-H) > 2/3$

$Q_{i+1} = \mu'\beta(Z_i - H)\sqrt{2g(Z_i - Z_{i+1})}$ $\mu' \fallingdotseq$

③ $Z_i \leqq H$

$Q_{i+1} = 0$

∴ μ: Coefficient of Overflow

FIG. E.5 **Schematic Description for Pump and Weir Link**

FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK

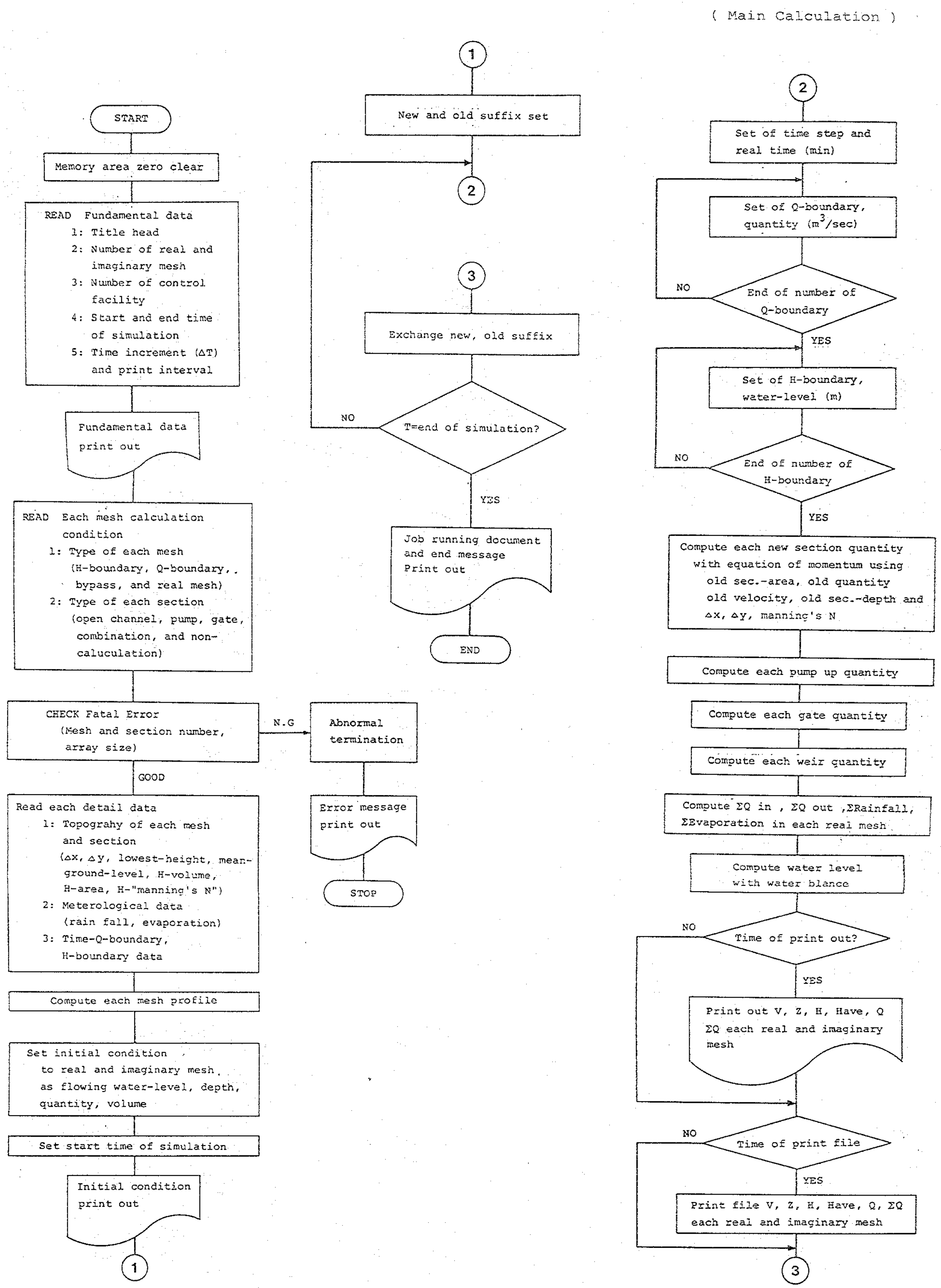


FIG. E.6 ..w Chart for Main Program of Bi-Dimensional Model

FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK

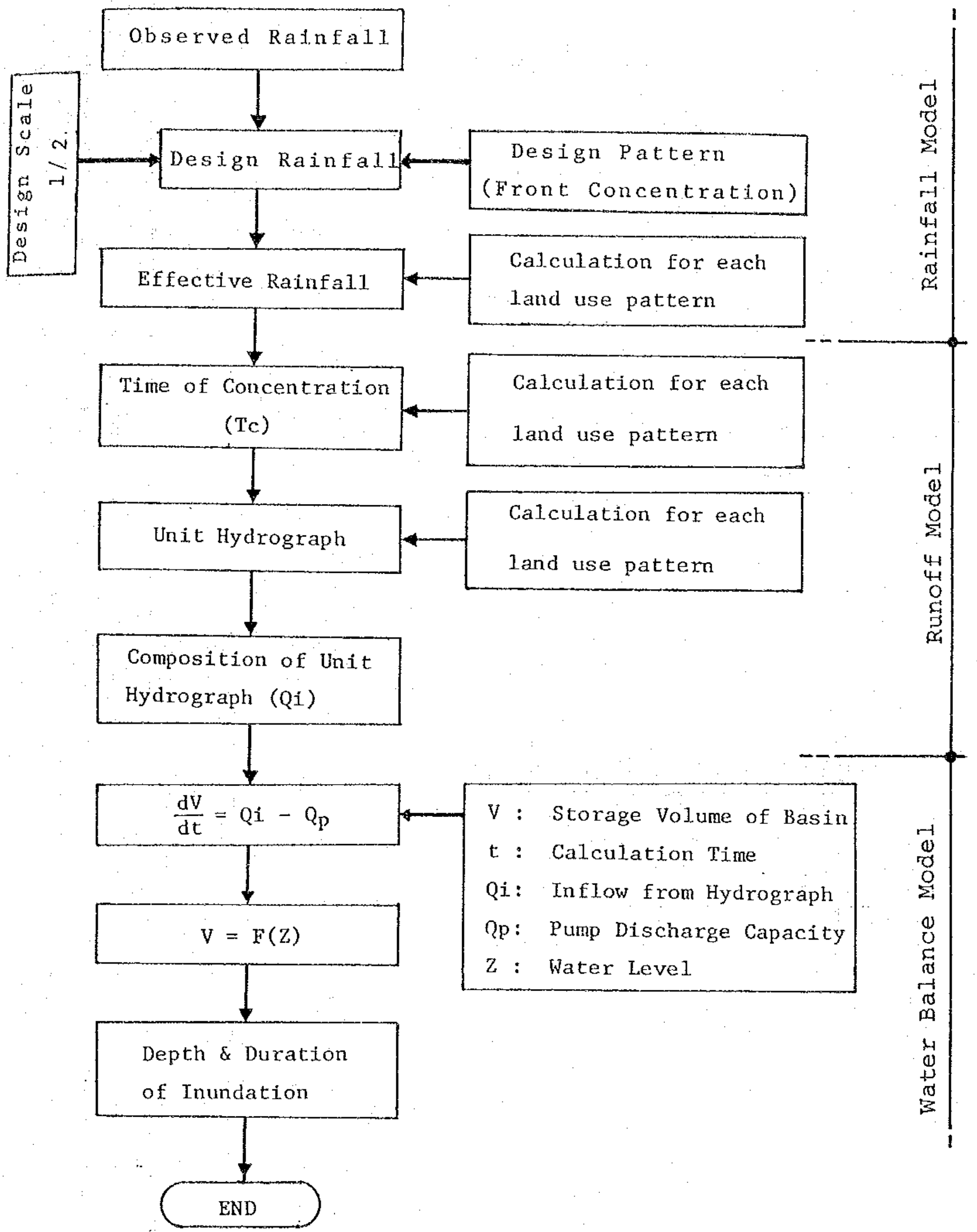
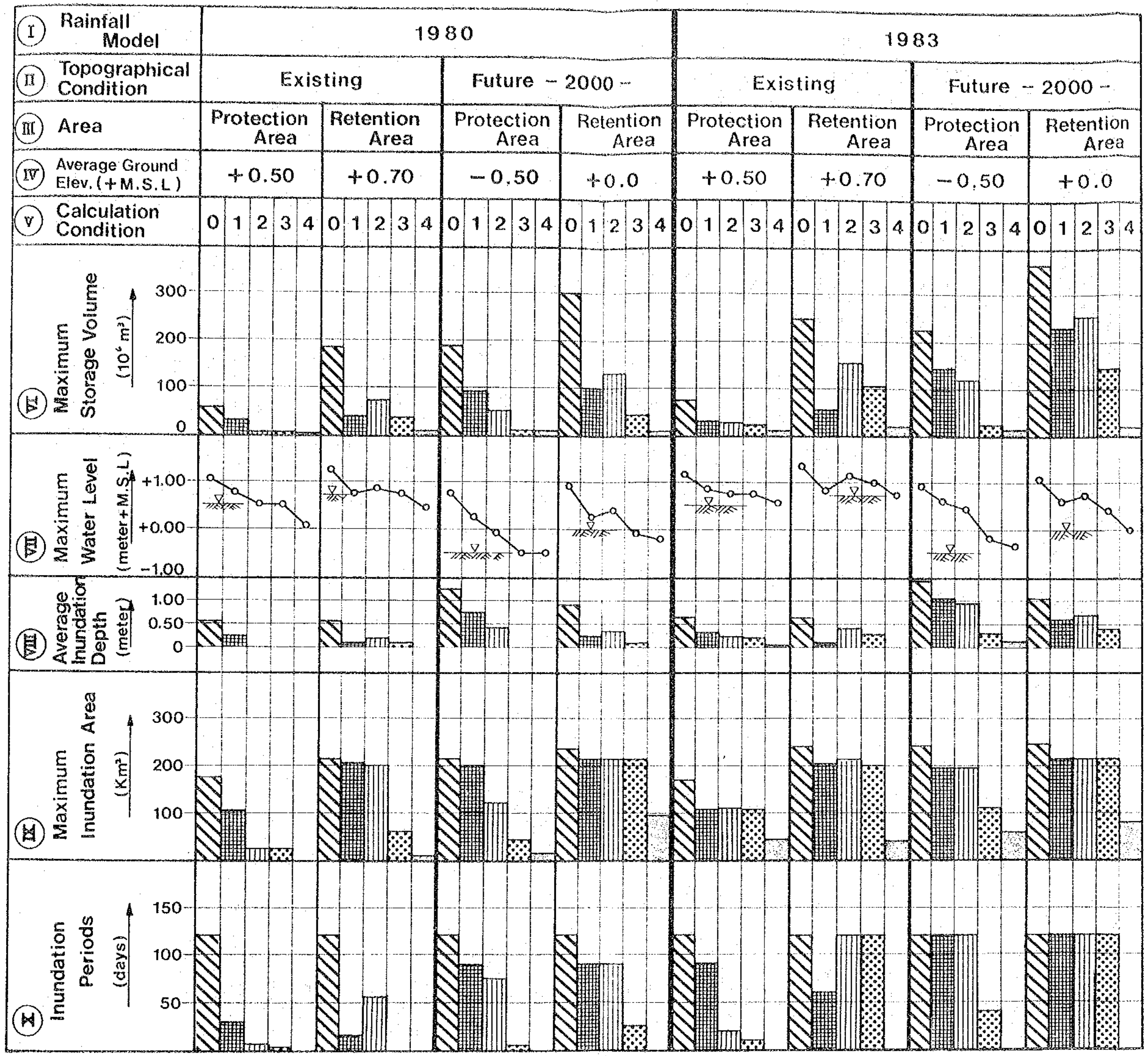


FIG. E.7 **Flow Chart for Polder Drainage Study**

FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK



Calculation Condition

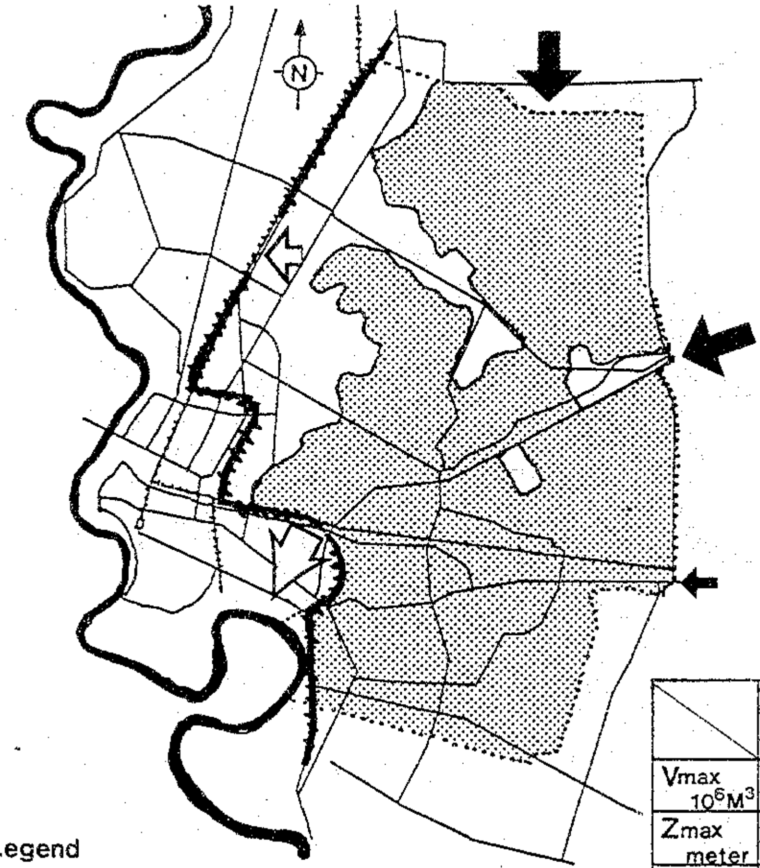
Calculation Condition		Condition of Barriers		Capacity of Drainage Facility			
				Retention Area		Protection Area	
		1st Barrier	2nd Barrier	Gate (m)	Pump (m^3/s)	Gate (m)	Pump (m^3/s)
0	No Barrier	x	x	–	–	30	16.0
1	Impact of the Green Belt Project	o	x	–	–	30	16.0
2	Impact of Conser-vation of Storm-Water Retention Area	o	o	6	1.5	24	14.5
3	Impact of Improvement of Trunk Drainage Facilities	o	o	6	20.0	24	50.0
4		o	o	6	100.0	24	200.0

1. Calculation Model for this figure is Two Basin Model.
2. Calculation period
   For 1980 Rainfall Model.....Aug. 1 - Nov. 30
   For 1983 Rainfall Model.....Aug. 1 - Oct. 31
3. Rainfall Models are daily areal average rainfall based on observed data.
4. Calculation Condition
5. ▽ : This Mark shows average ground elevation

FIG. E.8 Result of Hydrological and Hydraulic Modeling using Two Basin Model

FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK

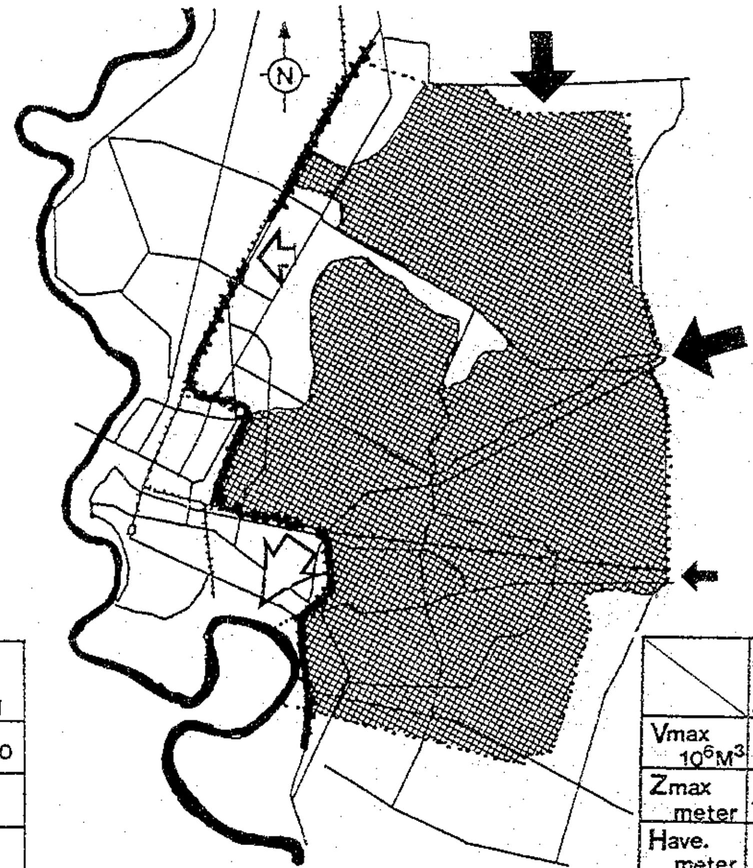
Topographical Condition; Existing -1983-



	Protec-tion Area	Reten-tion Area	Total
Vmax 10^6M^3	56	184	240
Zmax meter	+1.02	+1.21	
Have. meter	0.52	0.51	

Case	1st.Barrier Green Belt	2nd.Barrier	Drainage Facilities
101	X	X	Gw=30m Qp=16 m^3/s

Topographical Condition; Future -2000-



	Protec-tion Area	Reten-tion Area	Total
Vmax 10^6M^3	183	300	483
Zmax meter	+0.76	+0.90	
Have. meter	1.26	0.90	

Case	1st.Barrier Green Belt	2nd.Barrier	Drainage Facilities
102F-01	X	X	Gw=30m Qp=16 $m^3/$

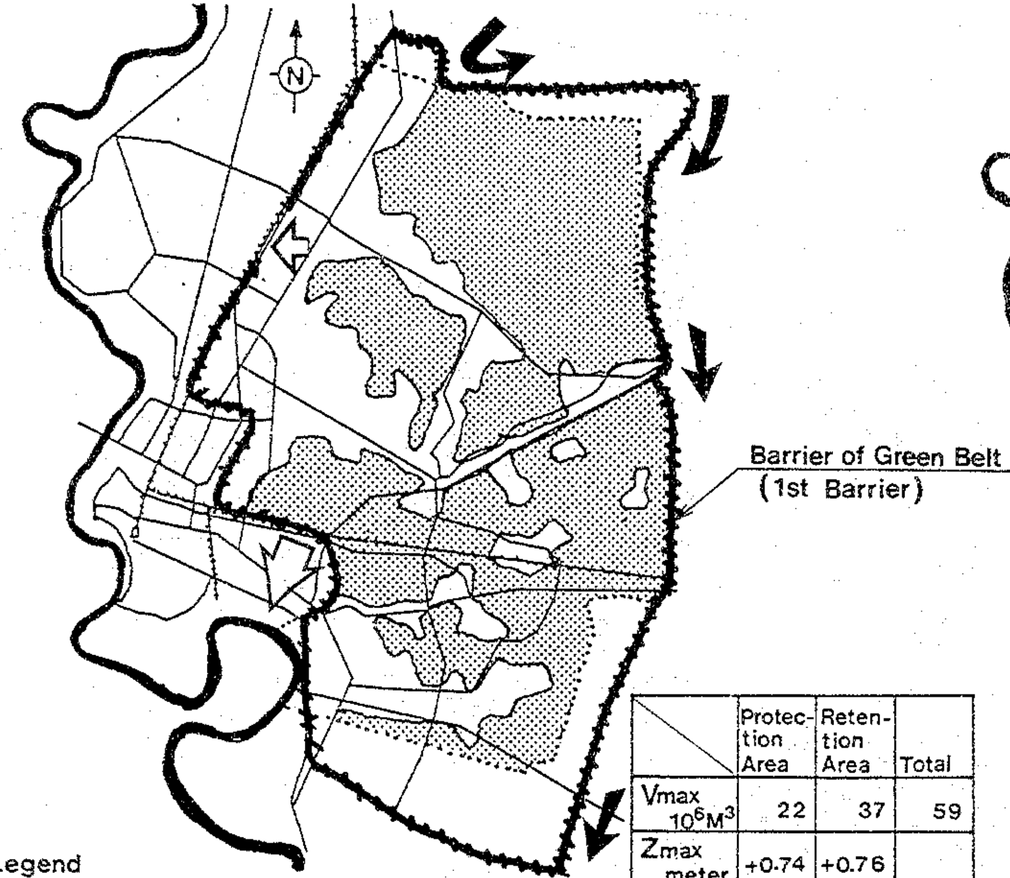
Legend

- : Inflow from Outer Area
- : Outflow from Study Area
- : Inundated Area

FIG. E.9 Inundated Condition without Green Belt (1st Barrier) (Rainfall in 1980)

FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK

Topographical Condition; Existing -1983-



	Protection Area	Retention Area	Total
Vmax 10^6M^3	22	37	59
Zmax meter	+0.74	+0.76	
Have. meter	0.24	0.06	

Case	1st.Barrier Green Belt	2nd.Barrier	Drainage Facilities
102	O	X	Gw=30m Qp=16

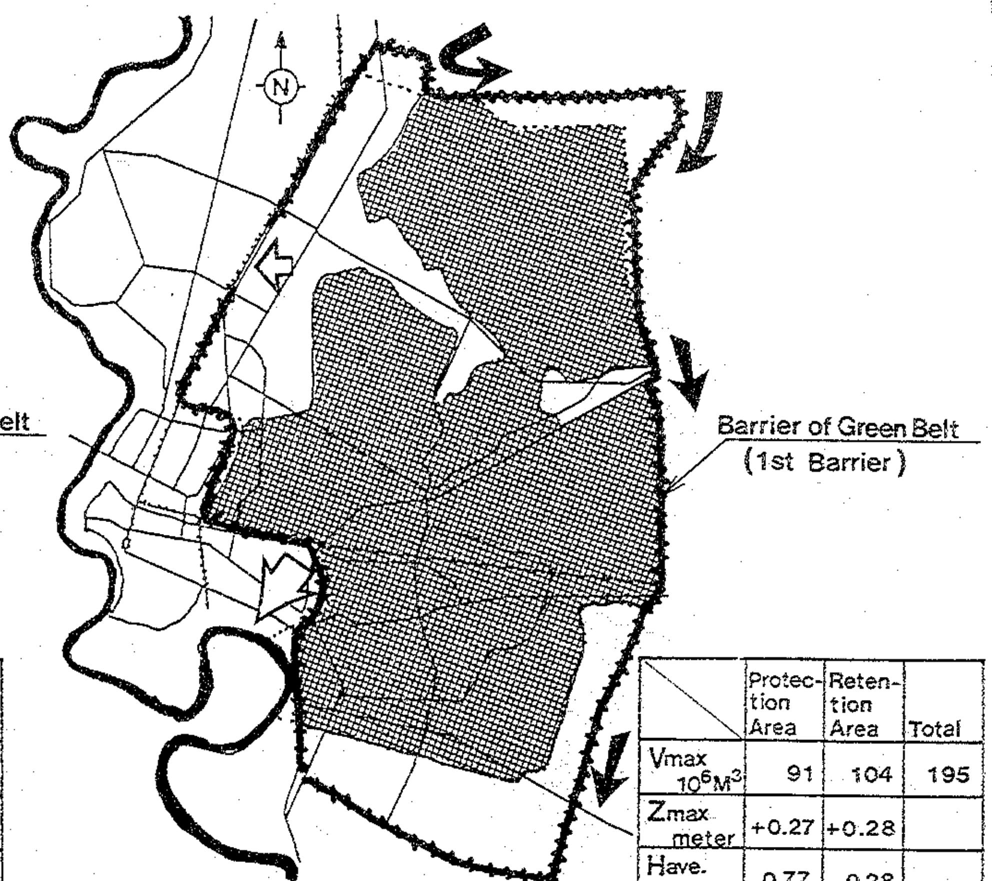
Legend

: Inflow from Outer Area

: Outflow from Study Area

: Inundated Area

Topographical Condition; Future -2000-



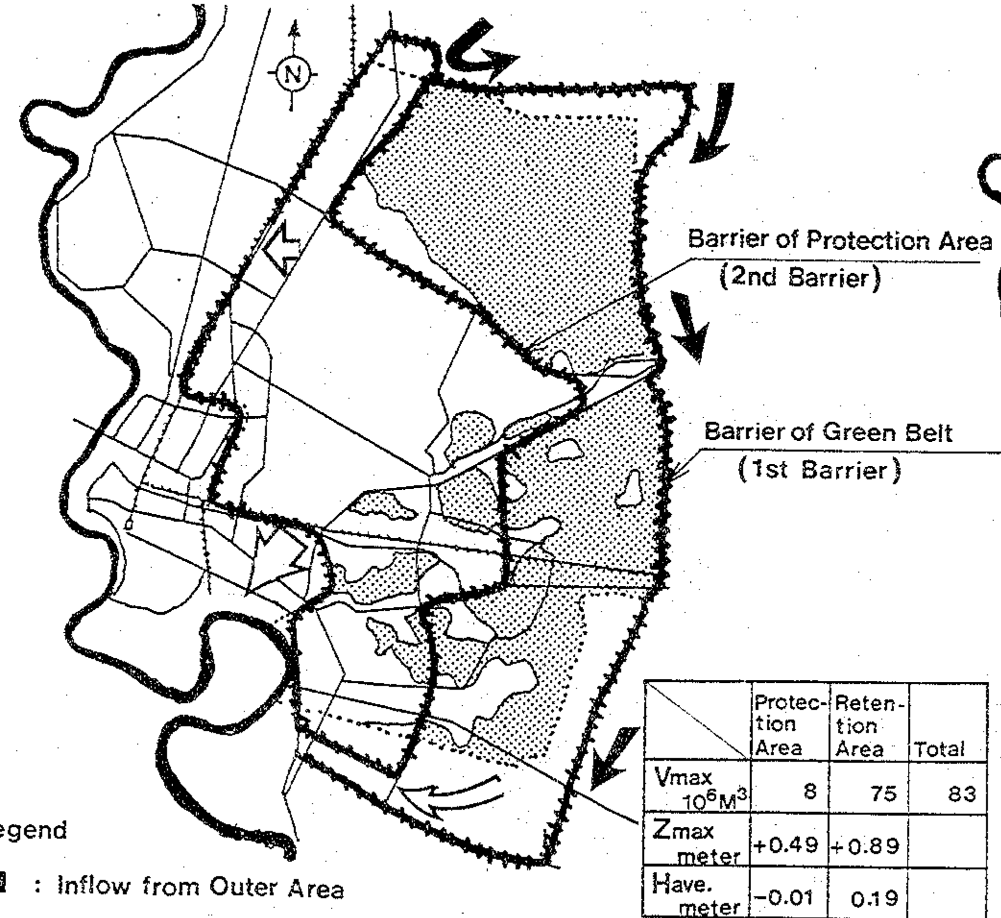
	Protection Area	Retention Area	Total
Vmax 10^6M^3	91	104	195
Zmax meter	+0.27	+0.28	
Have. meter	0.77	0.28	

Case	1st.Barrier Green Belt	2nd.Barrier	Drainage Facilities
102F-02	O	X	Gw=30m Qp=16m^3/s

FIG. E.10 Inundated Condition with Green Belt (1st Barrier) (Rainfall in 1980)

FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK

Topographical Condition; Existing -1983-



	Protection Area	Retention Area	Total
V_{max} $10^6 M^3$	8	75	83
Z_{max} meter	+0.49	+0.89	
$H_{ave.}$ meter	-0.01	0.19	

Case	1st. Barrier Green Belt	2nd. Barrier	Drainage Facilities
103-11	○	○	$G_W = 24^m$ $Q_P = 14.5 m^3/s$ $G_W = 6^m$ $Q_P = 1.5 m^3/s$

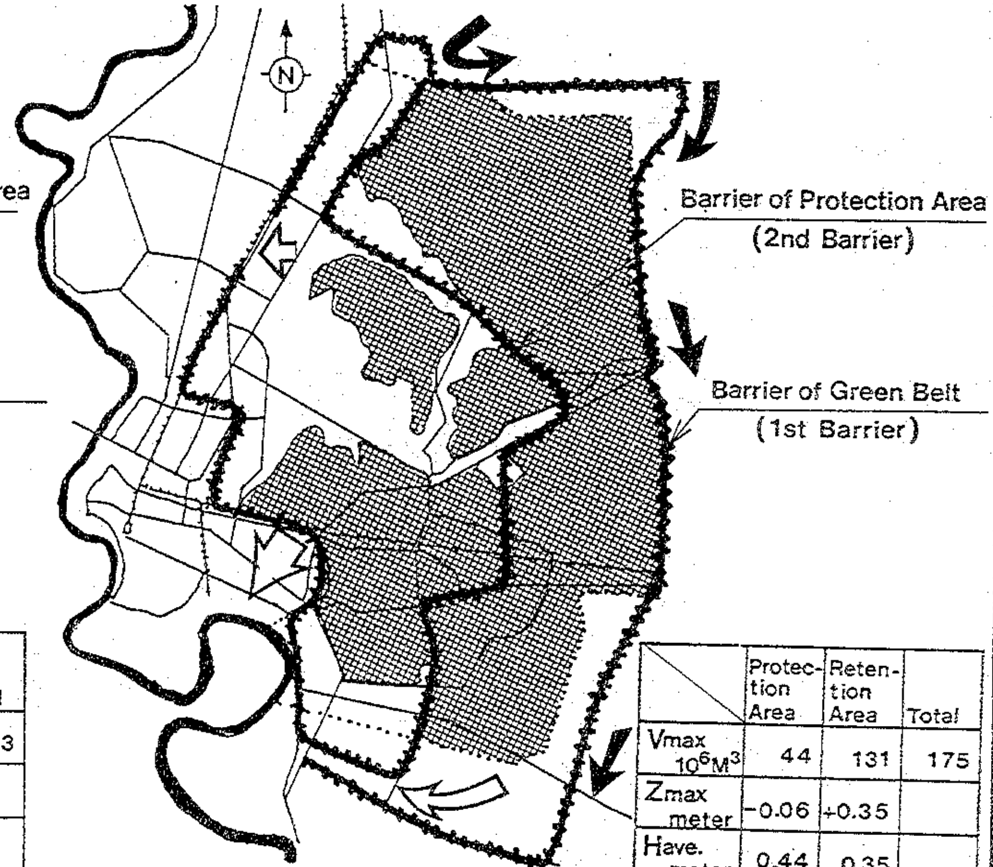
Legend

: Inflow from Outer Area

: Outflow from Study Area

: Inundated Area

Topographical Condition; Future -2000-



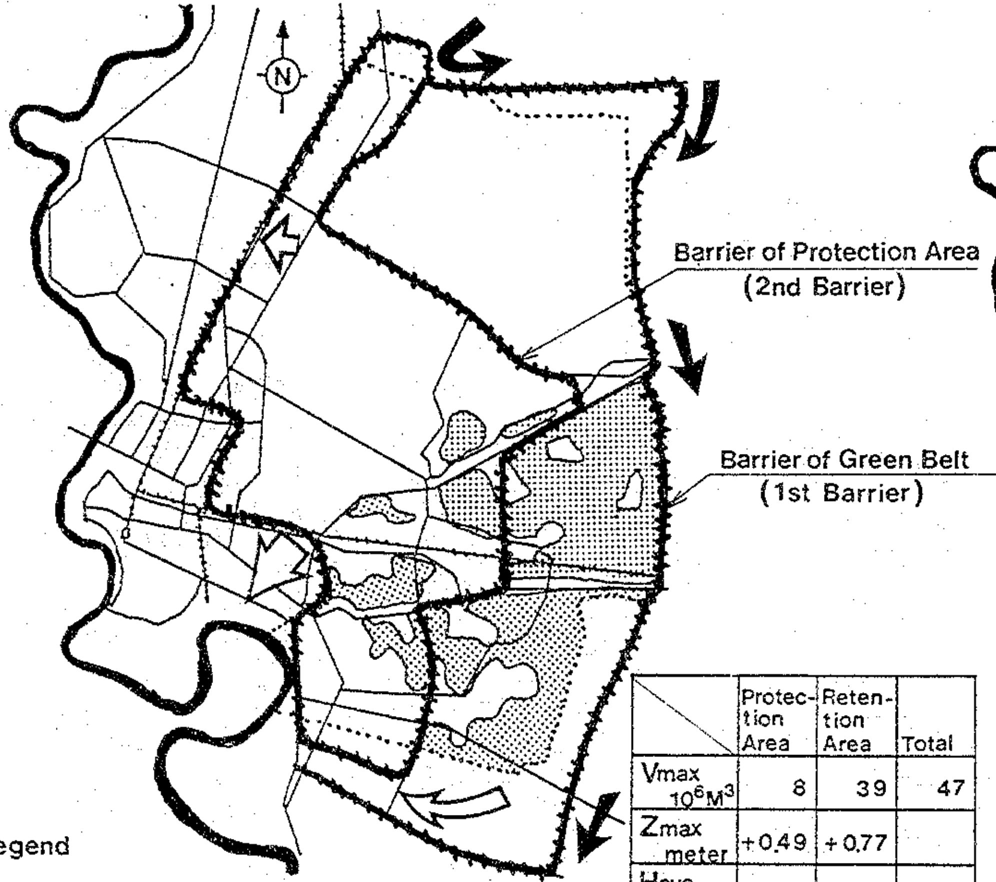
	Protection Area	Retention Area	Total
V_{max} $10^6 M^3$	44	131	175
Z_{max} meter	-0.06	+0.35	
$H_{ave.}$ meter	0.44	0.35	

Case	1st. Barrier Green Belt	2nd. Barrier	Drainage Facilities
102F-11	○	○	$G_W = 24^m$ $Q_P = 14.5 m^3/s$ $G_W = 6^m$ $Q_P = 1.5 m^3/s$

FIG. E.11 Inundated Condition with Barrier of Protection Area (2nd Barrier)
(Rainfall in 1980)

FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK

Topographical Condition; Existing -1983-

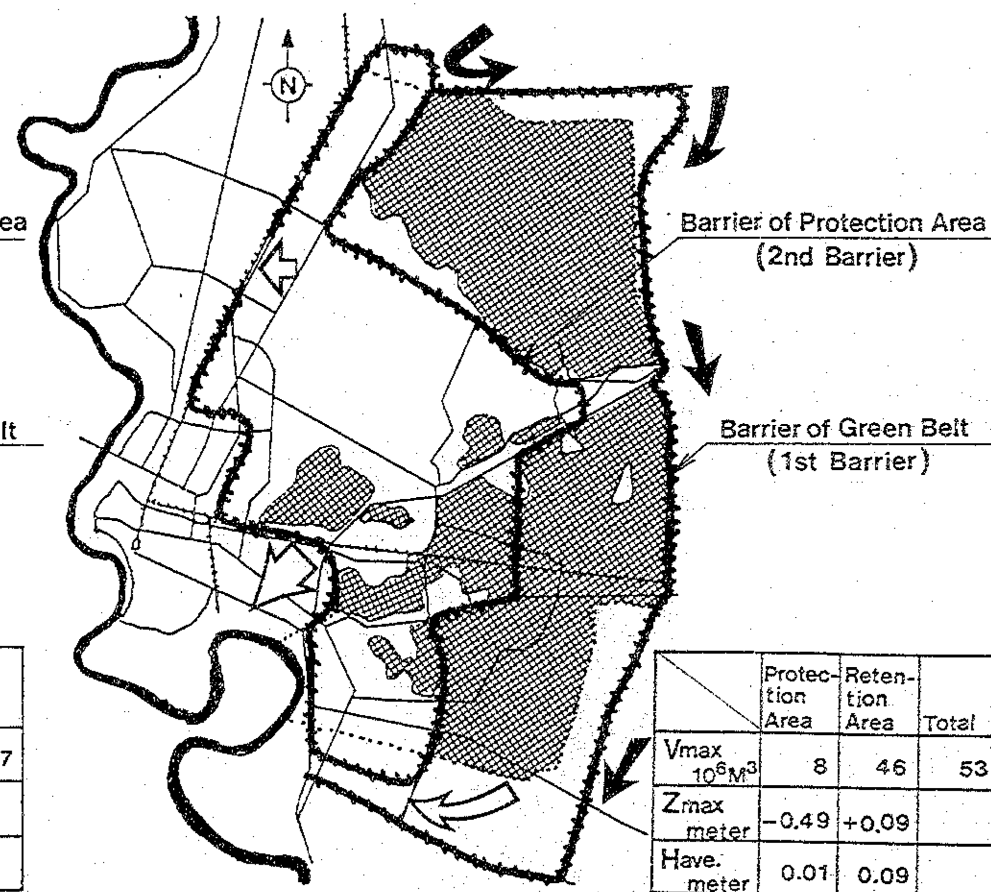


	Protection Area	Retention Area	Total
Vmax $10^6 M^3$	8	39	47
Zmax meter	+0.49	+0.77	
Have. meter	-0.01	0.07	

Case	1st. Barrier Green Belt	2nd. Barrier	Drainage Facilities
103-14	O	O	$G_W = 24^m$ $Q_P = 50 m^3/s$
			$G_W = 6^m$ $Q_P = 20 m^3/s$

Legend
: Inflow from Outer Area
: Outflow from Study Area
: Inundated Area

Topographical Condition; Future -2000-



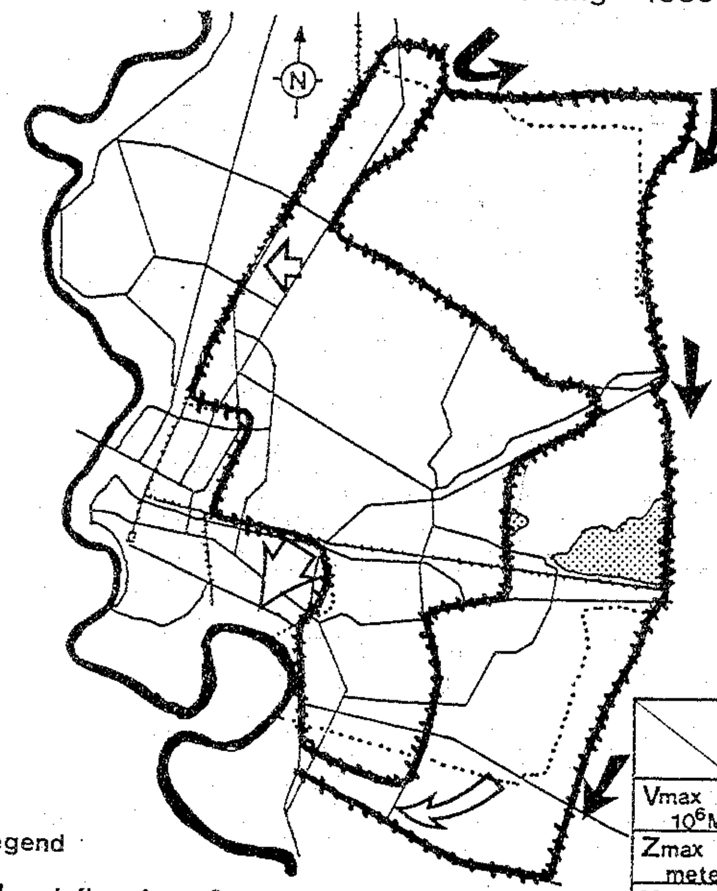
	Protection Area	Retention Area	Total
Vmax $10^6 M^3$	8	46	53
Zmax meter	-0.49	+0.09	
Have. meter	0.01	0.09	

Case	1st. Barrier Green Belt	2nd. Barrier	Drainage Facilities
102F-14	O	O	$G_W = 30^m$ $Q_P = 50 m^3/s$
			$G_W = 12^m$ $Q_P = 20^m$

FIG. E.12 Inundated Condition with Improvement of Capacity of Drainage Facilities —(1)(Rainfall in 1980)

FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK

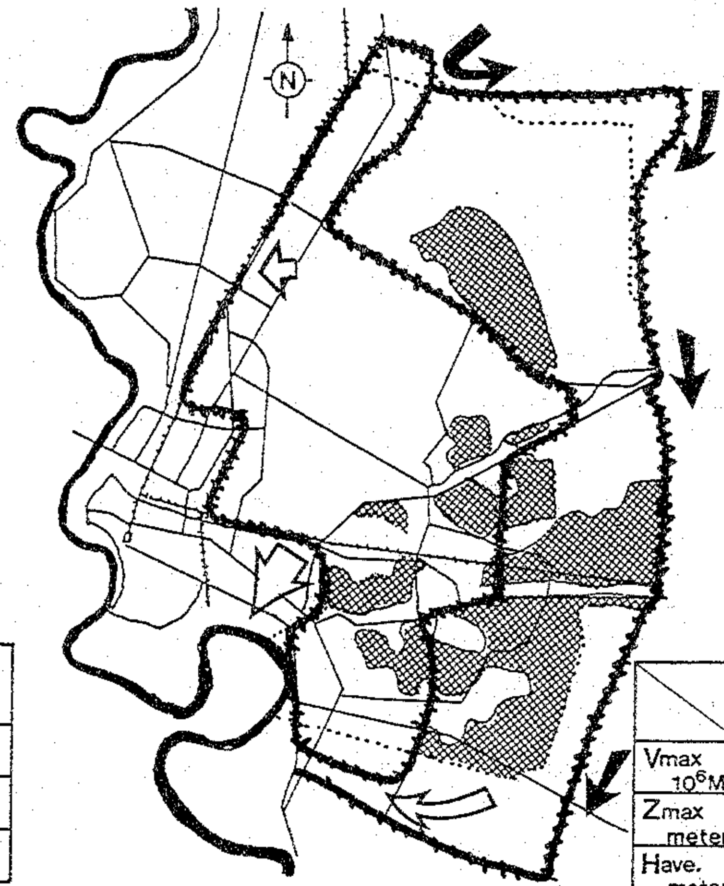
Topographical Condition; Existing -1983-



	Protection Area	Retention Area	Total
Vmax $10^6 M^3$	5	6	11
Zmax meter	+0.05	+0.49	
Have. meter	-0.45	-0.21	

Case	1st.Barrier Green Belt	2nd.Barrier	Drainage Facilities
103-16	o	o	Gw=24^m Qp=200m^3/s Gw= 6^m Qp=100m^3/s

Topographical Condition; Future -2000-



	Protection Area	Retention Area	Total
Vmax $10^6 M^3$	8	6	14
Zmax meter	-0.50	-0.25	
Have. meter	0.0	-0.25	

Case	1st.Barrier Green Belt	2nd.Barrier	Drainage Facilities
102F-16	o	o	Gw=30^m Qp=200m^3/s Gw=12^m Qp=100^m

Legend

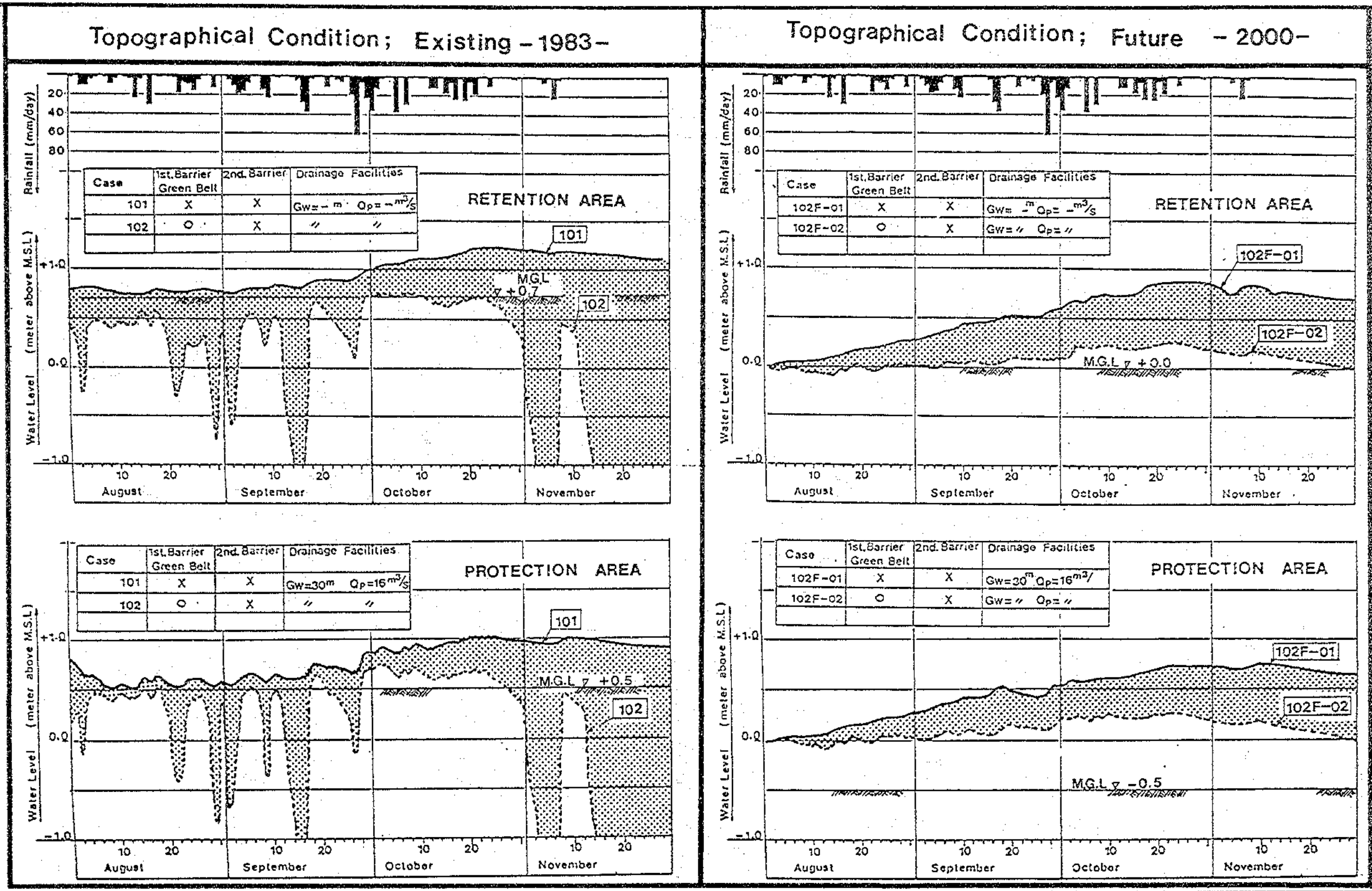
: Inflow from Outer Area

: Outflow from Study Area

: Inundated Area

FIG. E.13 Inundated Condition with Improvement of Capacity of Drainage Facilities —(2) (Rainfall in 1980)

FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK



Legend

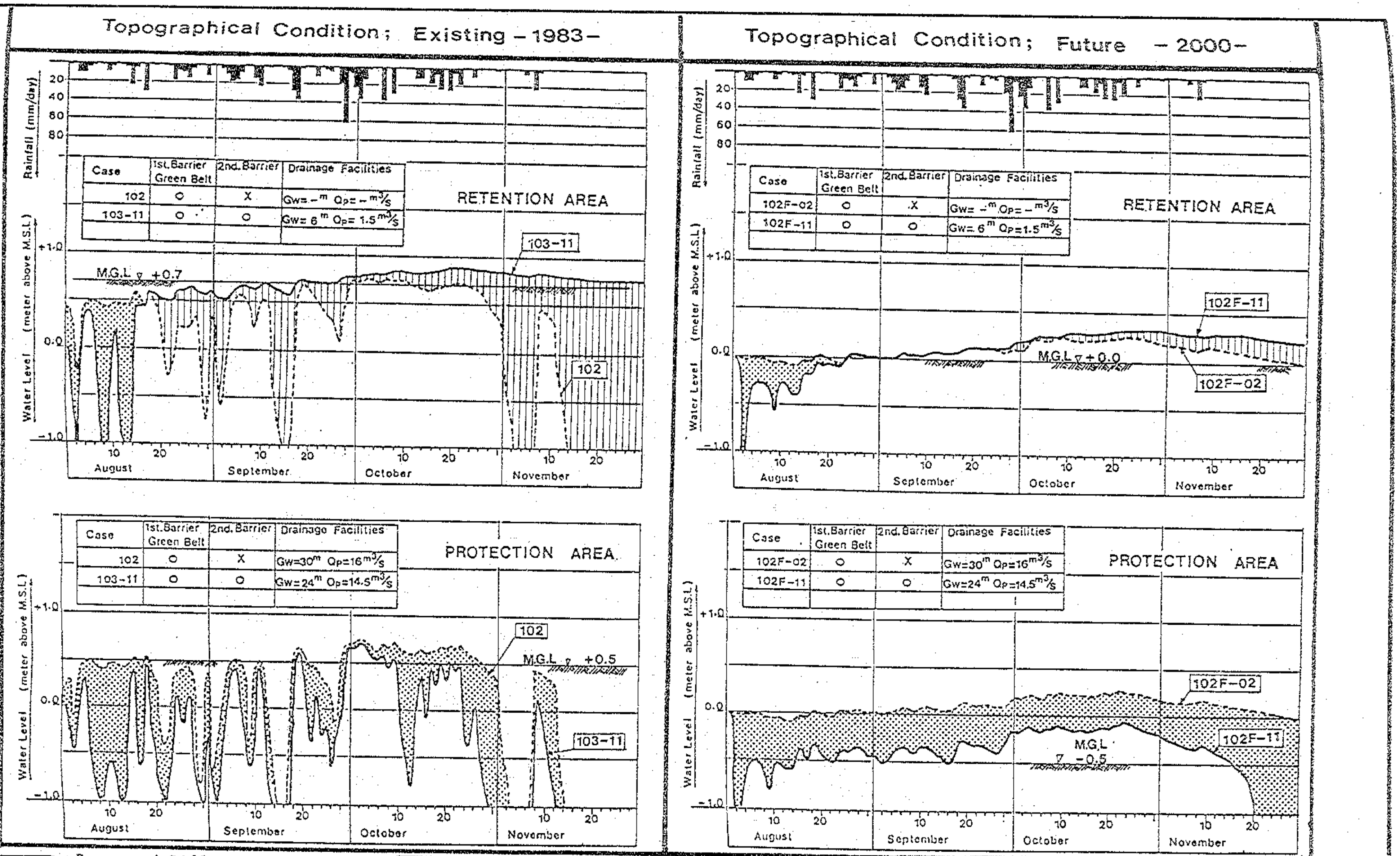
: Decreased Difference of Simulated Water Level

MGL : Mean Ground Elevation above M.S.L

FIG. E.14

Flood Water Levels with & without 1st Barrier (Green Belt) (Rainfall in 1980)

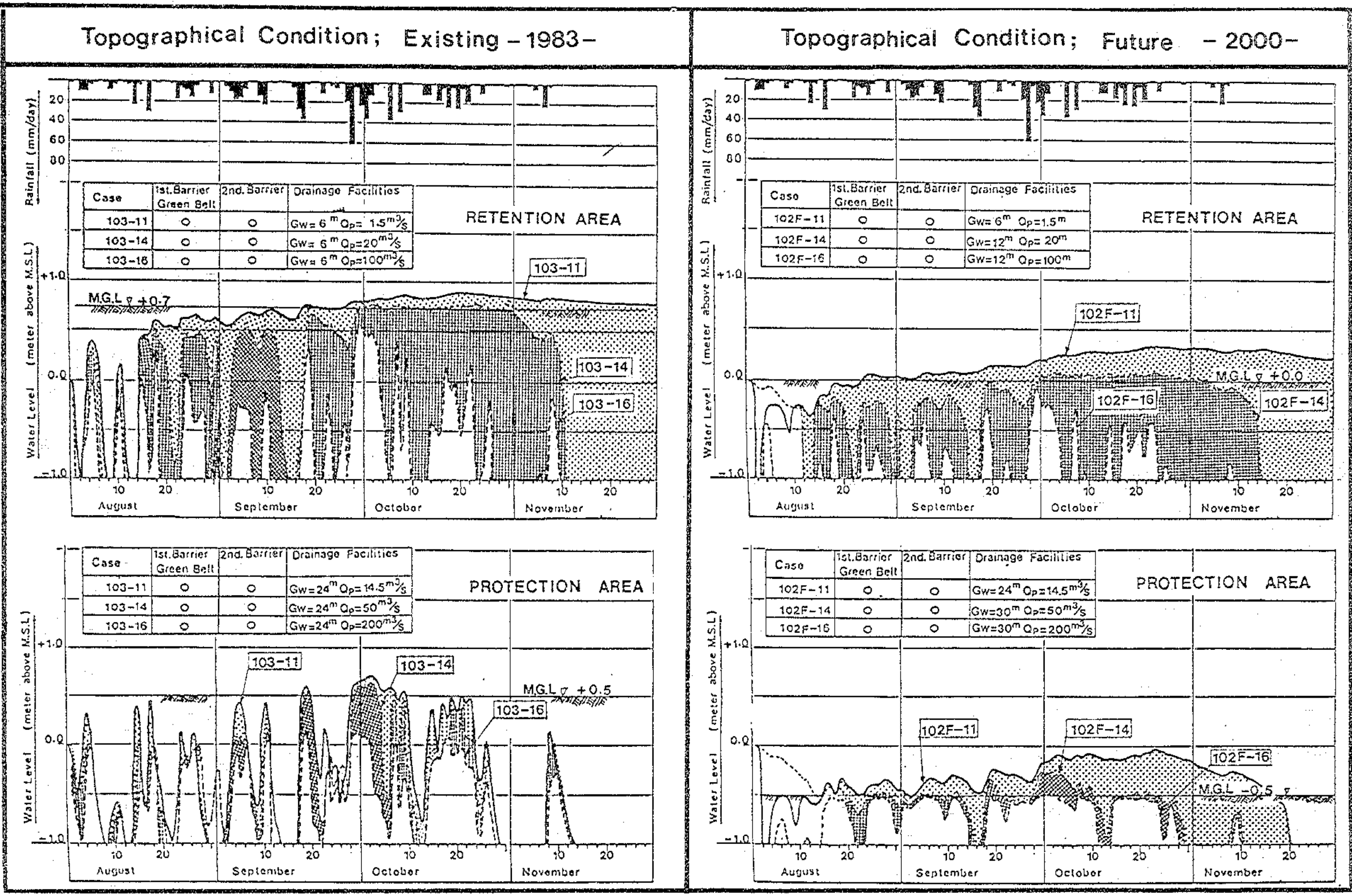
FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK



Legend
: Decreased Difference of Simulated Water Level
: Increased Difference of Simulated WAter Level
MGL : Mean Ground Elevation above M.S.L

FIG. E.15 Flood Water Levels with & without 2nd Barrier (Rainfall in 1980)

FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK



Legend

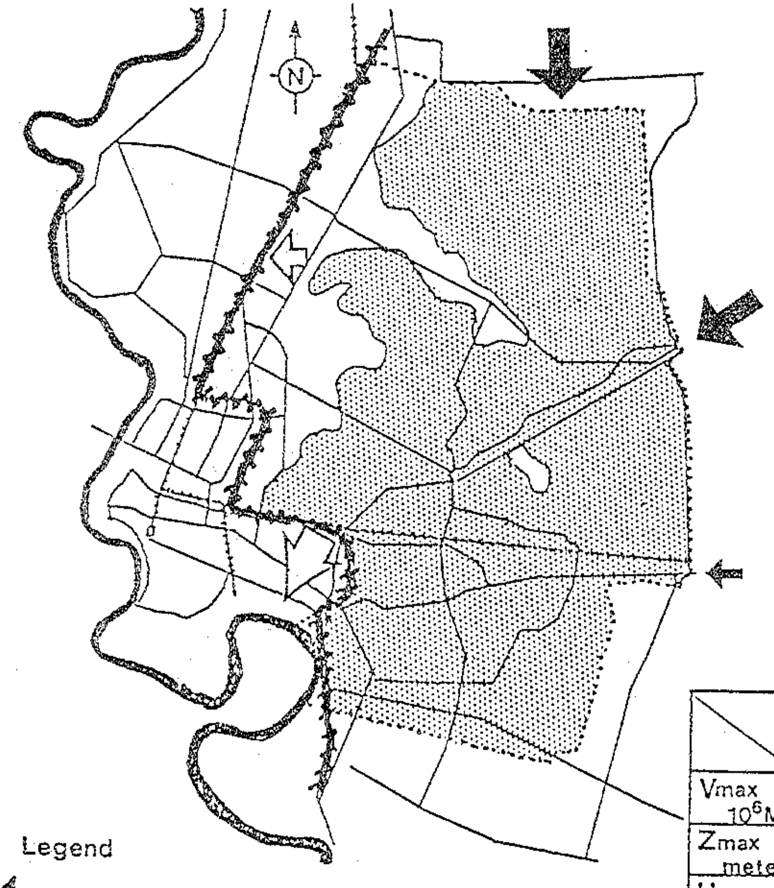
Decreased Difference of Simulated Water Level

MGL : Mean Ground Elevation above M.S.L

FIG. E.16 Flood Water Levels with Improvement of Capacity of Drainage Facilities (Rainfall in 1980)

FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK

Topographical Condition; Existing -1983-



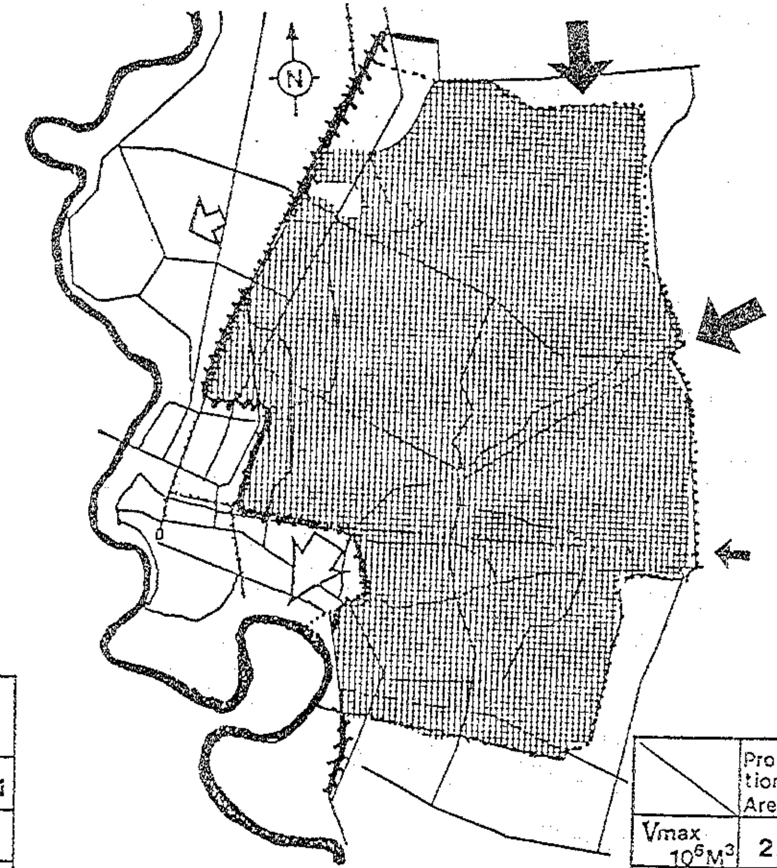
Legend

- ; Inflow from Outer Area
- ; Outflow from Study Area
- ; Inundate Area

	Protec-tion Area	Reten-tion Area	Total
Vmax 10^6M^3	73	248	321
Zmax meter	+1.17	+1.37	
Have. meter	0.67	0.67	

Case	1st.Barrier Green Belt	2nd.Barrier	Drainage Facilities
001	X	X	Gw=30m Qp=16m^3/s

Topographical Condition; Future -2000-



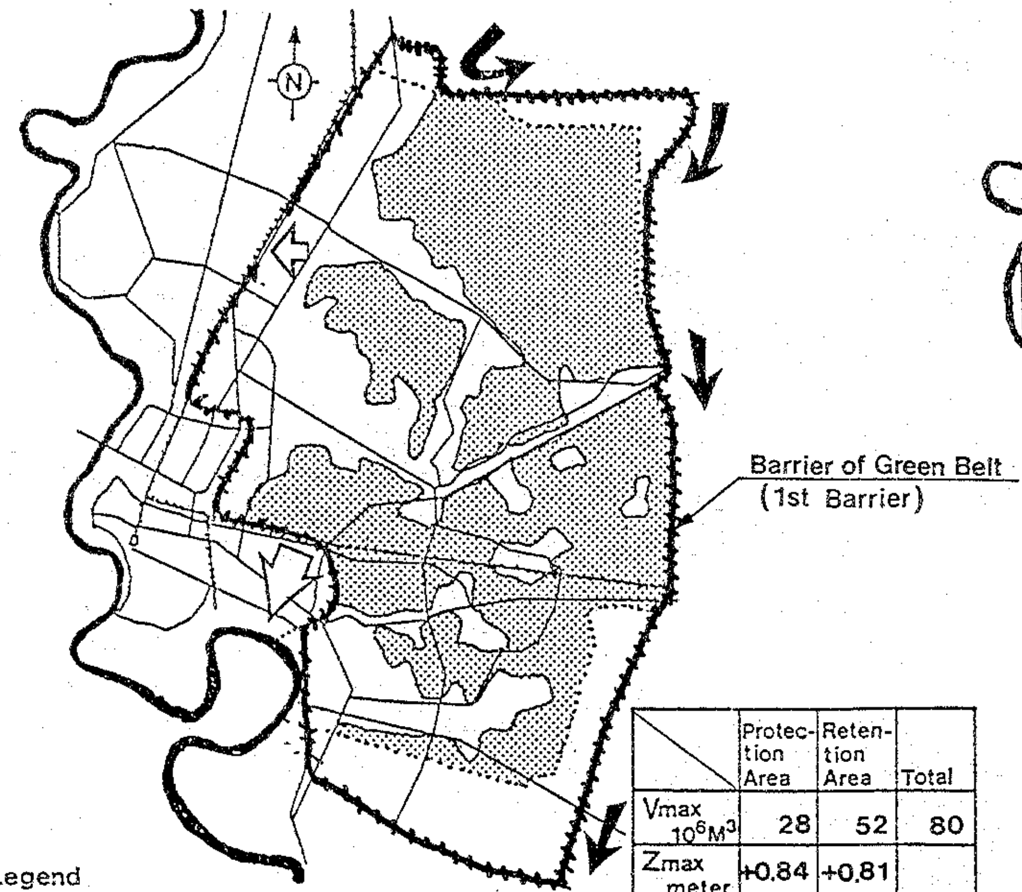
	Protec-tion Area	Reten-tion Area	Total
Vmax 10^6M^3	224	362	586
Zmax meter	+0.93	+1.06	
Have. meter	1.43	1.06	

Case	1st.Barrier Green Belt	2nd.Barrier	Drainage Facilities
002F-01	X	X	Gw=30m Qp=16m^3/

FIG. E.17 Inundated Condition without Green Belt (1st Barrier) (Rainfall in 1983)

FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK

Topographical Condition; Existing -1983-

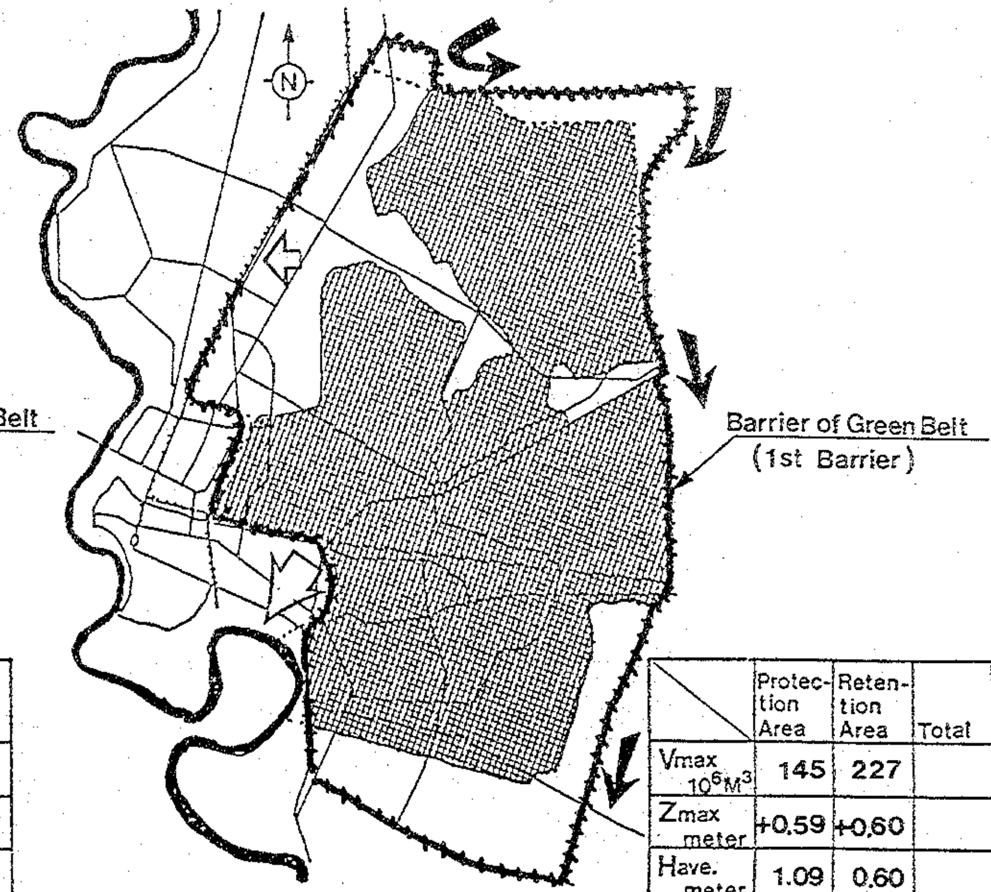


	Protec-tion Area	Reten-tion Area	Total
Vmax $10^6 M^3$	28	52	80
Zmax meter	+0.84	+0.81	
Have. meter	0.34	0.11	

Case	1st.Barrier Green Belt	2nd.Barrier	Drainage Facilities
002	O	X	Gw=30^m Qp=16

Legend
: Inflow from Outer Area
: Outflow from Study Area
: Inundate Area

Topographical Condition; Future -2000-

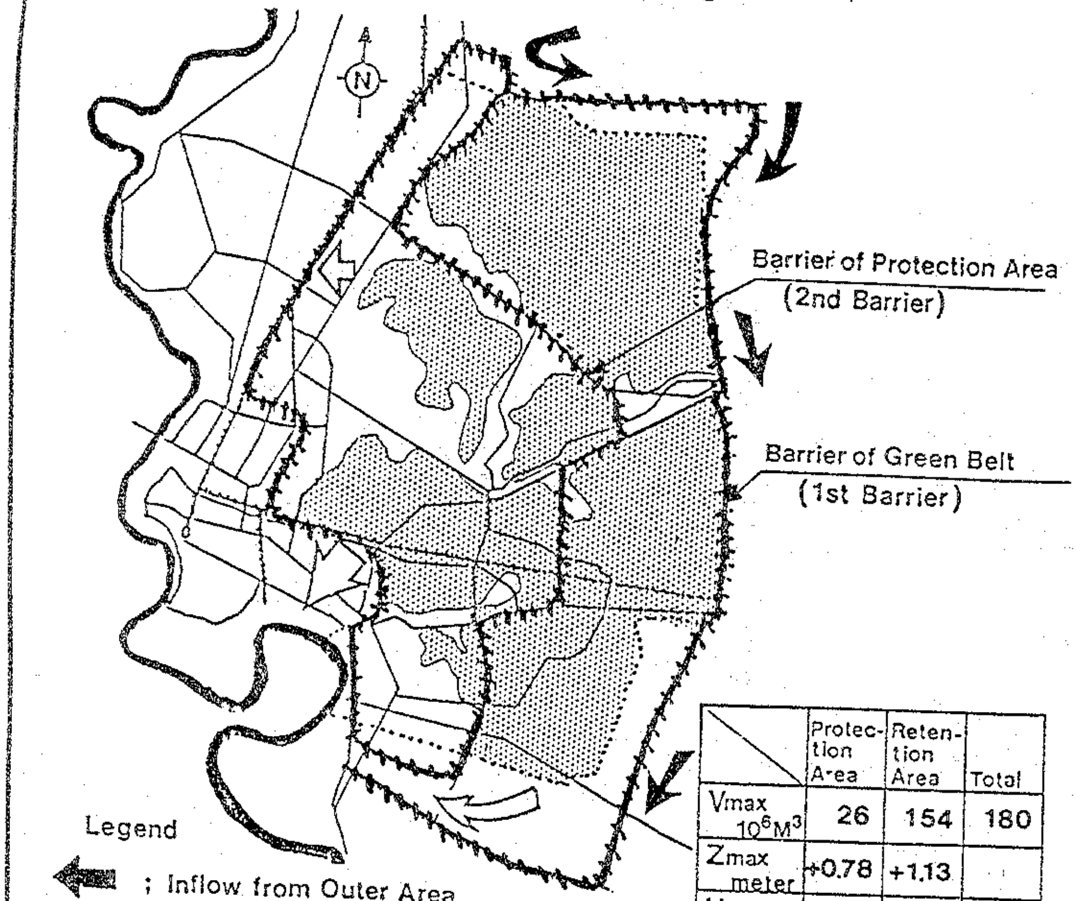


	Protec-tion Area	Reten-tion Area	Total
Vmax $10^6 M^3$	145	227	
Zmax meter	+0.59	+0.60	
Have. meter	1.09	0.60	

Case	1st.Barrier Green Belt	2nd.Barrier	Drainage Facilities
002F-02	O	X	Gw=30^m Qp=16m³/s

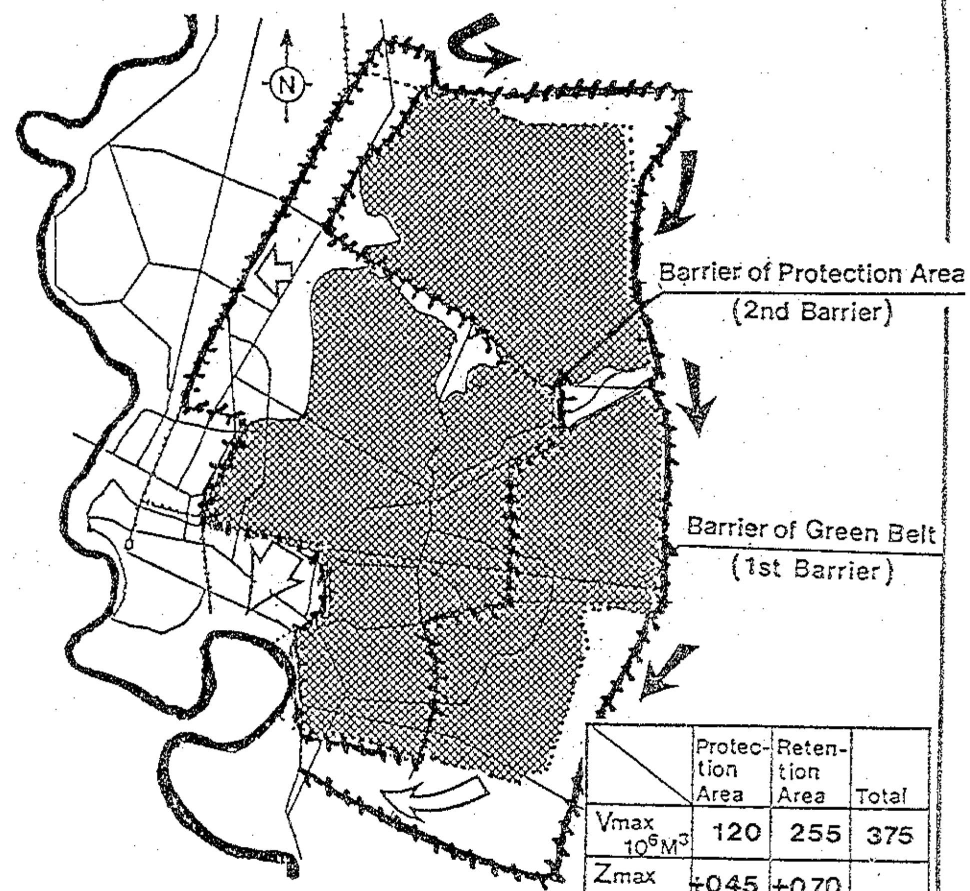
FIG. E.18 Inundated Condition with Green Belt (1st Barrier) (Rainfall in 1983)

FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK



	Protec-tion Area	Reten-tion Area	Total
Vmax $10^6 M^3$	26	154	180
Zmax meter	+0.78	+1.13	
Have. meter	0.28	0.43	

Case	1st. Barrier Green Belt	2nd. Barrier	Drainage Facilities
003-11	o	o	$Gw = 24^m$ $Q_P = 14.5 m^3/s$
			$Gw = 6^m$ $Q_P = 1.5 m^3/s$



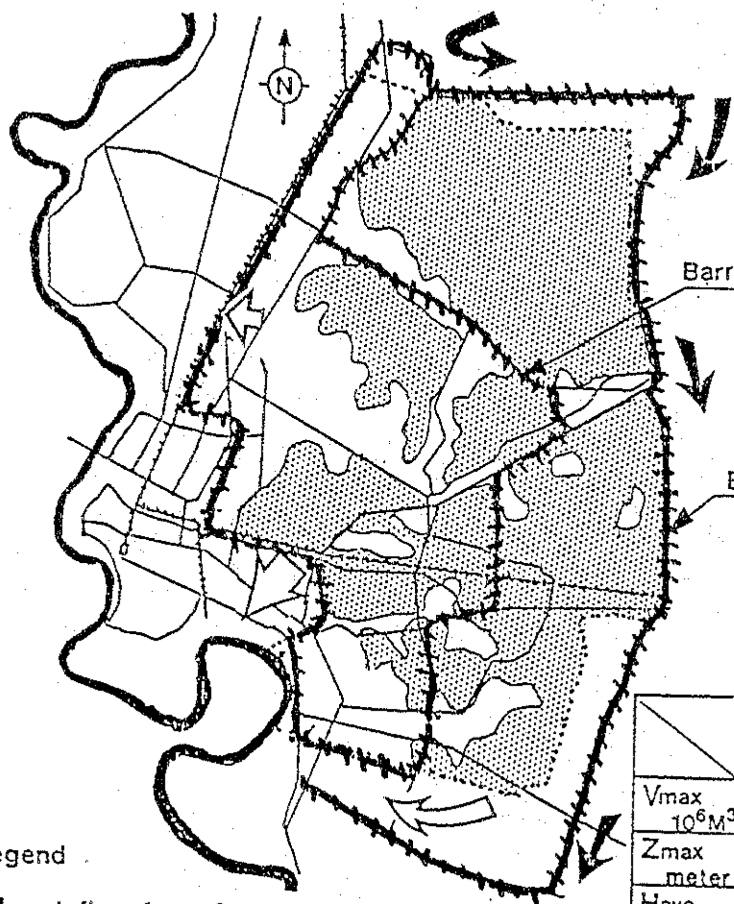
	Protec-tion Area	Reten-tion Area	Total
Vmax $10^6 M^3$	120	255	375
Zmax meter	+0.45	+0.70	
Have. meter	0.95	0.70	

Case	1st. Barrier Green Belt	2nd. Barrier	Drainage Facilities
002F-11	o	o	$Gw = 24^m$ $Q_P = 14.5 m^3/s$
			$Gw = 6^m$ $Q_P = 1.5 m^3/s$

FIG. E.19 Inundated Condition with Barrier of Protection Area (2nd Barrier) (Rainfall in 1983)

FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK

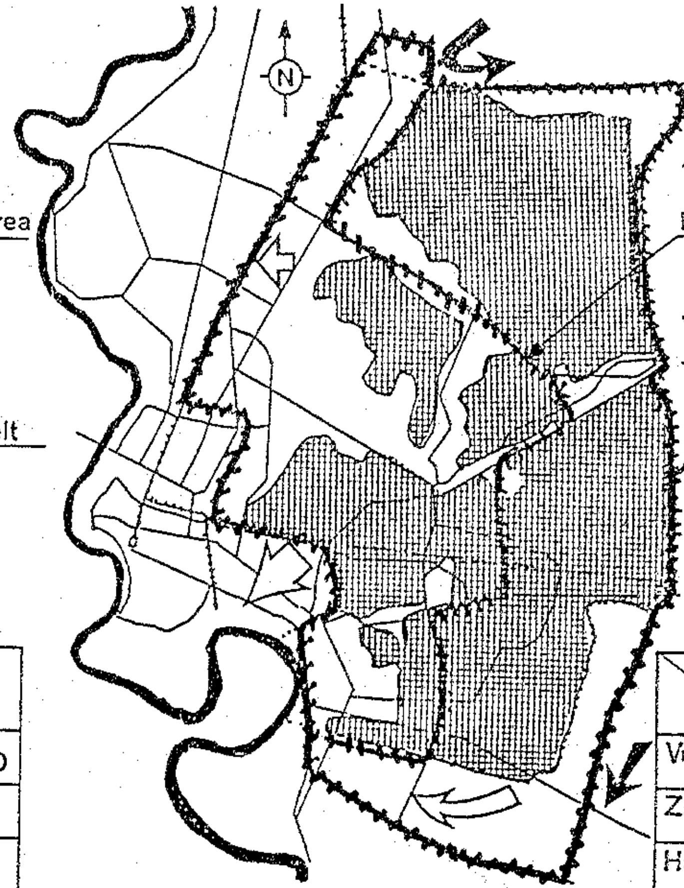
Topographical Condition; Existing -1983-



	Protec-tion Area	Reten-tion Area	Total
Vmax $10^6 M^3$	23	107	130
Zmax meter	+0.75	+0.99	
Have. meter	0.25	0.29	

Case	1st.Barrier Green Belt	2nd.Barrier	Drainage Facilities
003-14	○	○	Gw=24^m Qp=50 m^3/s
			Gw=6 ^m Qp=20 m^3/s

Topographical Condition; Future -2000-



	Protec-tion Area	Reten-tion Area	Total
Vmax $10^6 M^3$	26	142	168
Zmax meter	-0.21	+0.39	
Have. meter	0.29	0.39	

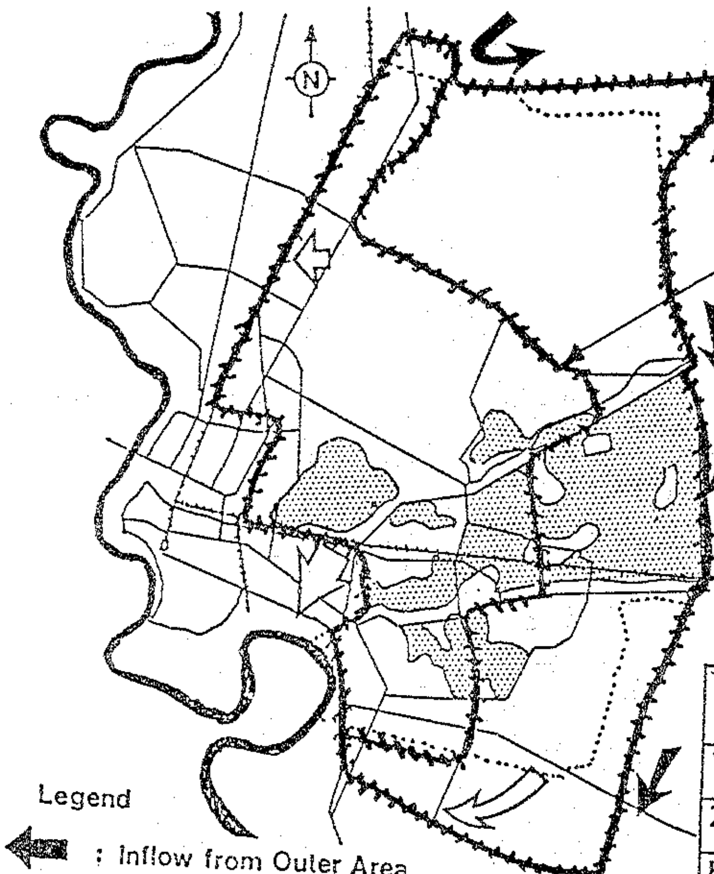
Case	1st.Barrier Green Belt	2nd.Barrier	Drainage Facilities
002F-14	○	○	Gw=30^m Qp=50 m^3/s
			Gw=12^m Qp=20^m

Legend
- : Inflow from Outer Area
- : Outflow from Study Area
- : Inundate Area

FIG. E.20 Inundated Condition with Improvement of Capacity of Drainage Facilities —(1) (Rainfall in 1983)

FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK

Topographical Condition; Existing -1983-

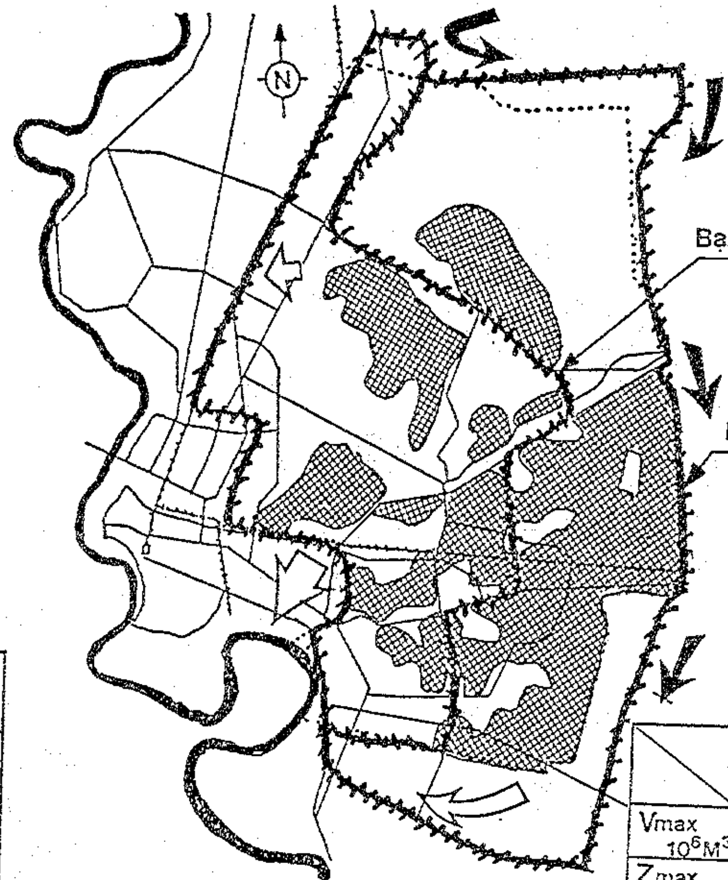


	Protection Area	Retention Area	Total
Vmax $10^6 M^3$	11	20	31
Zmax meter	+0.57	+0.70	
Have. meter	0.07	0.00	

Case	1st.Barrier Green Belt	2nd.Barrier	Drainage Facilities
003-16	o	o	Gw=24^m Qp=200m^3/s
			Gw= 6^m Qp=100m^3/s

Legend
: Inflow from Outer Area
: Outflow from Study Area
: Inundate Area

Topographical Condition; Future -2000-

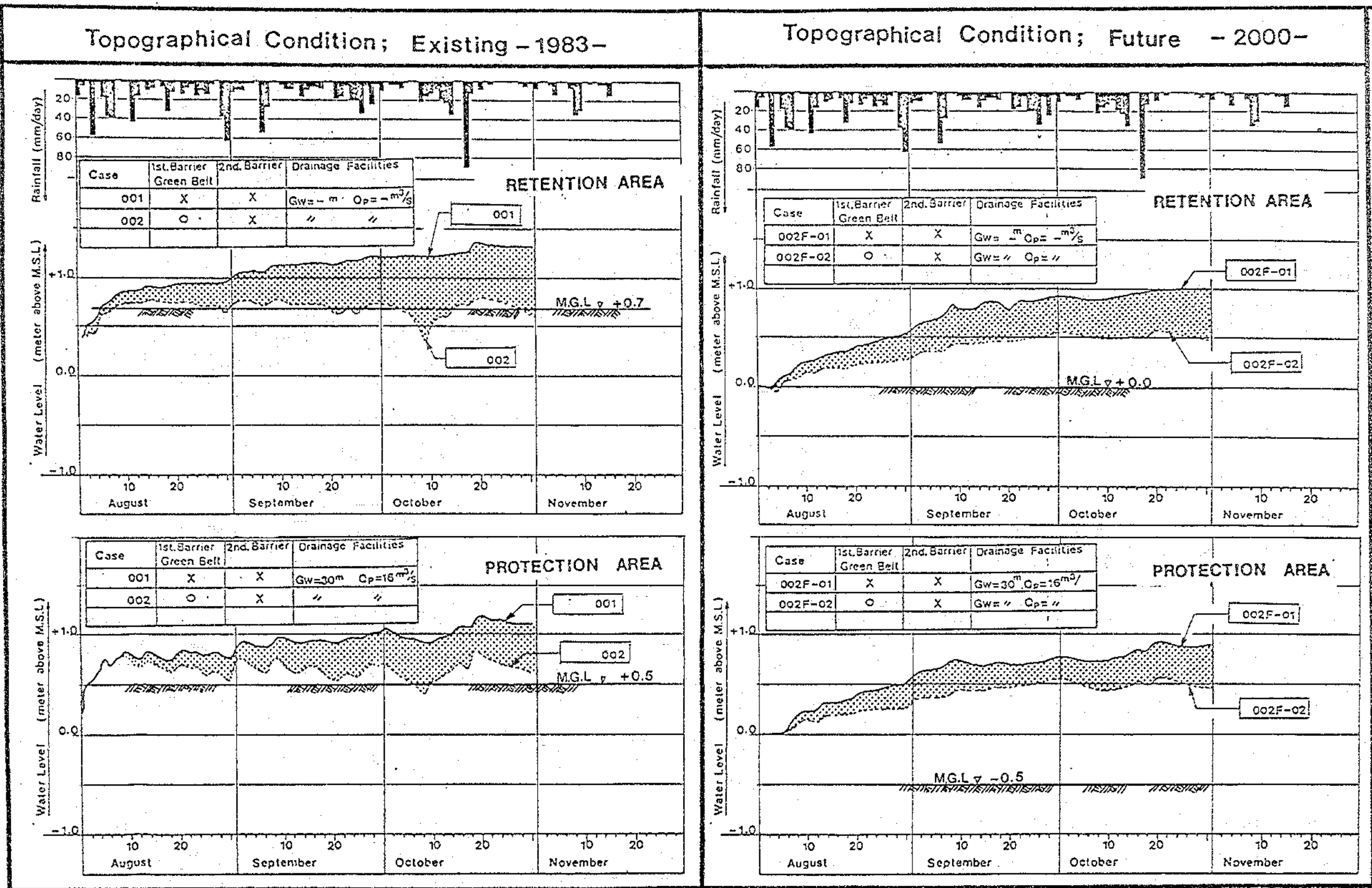


	Protection Area	Retention Area	Total
Vmax $10^6 M^3$	14	20	34
Zmax meter	-0.36	+0.01	
Have. meter	0.14	0.01	

Case	1st.Barrier Green Belt	2nd.Barrier	Drainage Facilities
002F-16	o	o	Gw=30^m Qp=200m^3/s
			Gw=12^m Qp=100^m

FIG. E.21 Inundated Condition with Improvement of Capacity of Drainage Facilities —(2) (Rainfall in 1983)

FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK



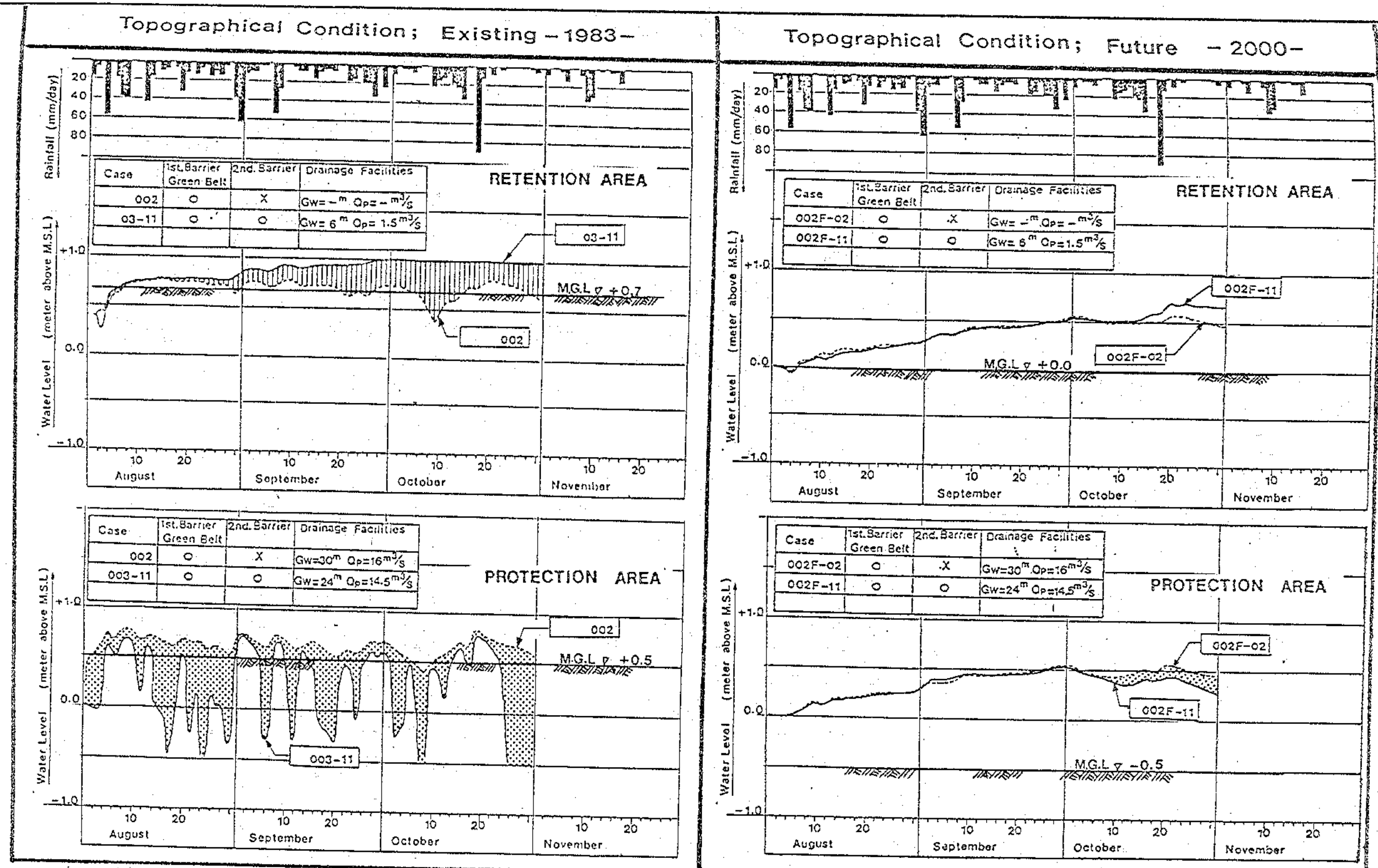
Legend

▒ : Decreased Difference of Simulated Water Level

MGL : Mean Ground Elevation above M.S.L

FIG. E.22 Flood Water Levels with & without 1st Barrier (Green Belt) (Rainfall in 1983)

FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK



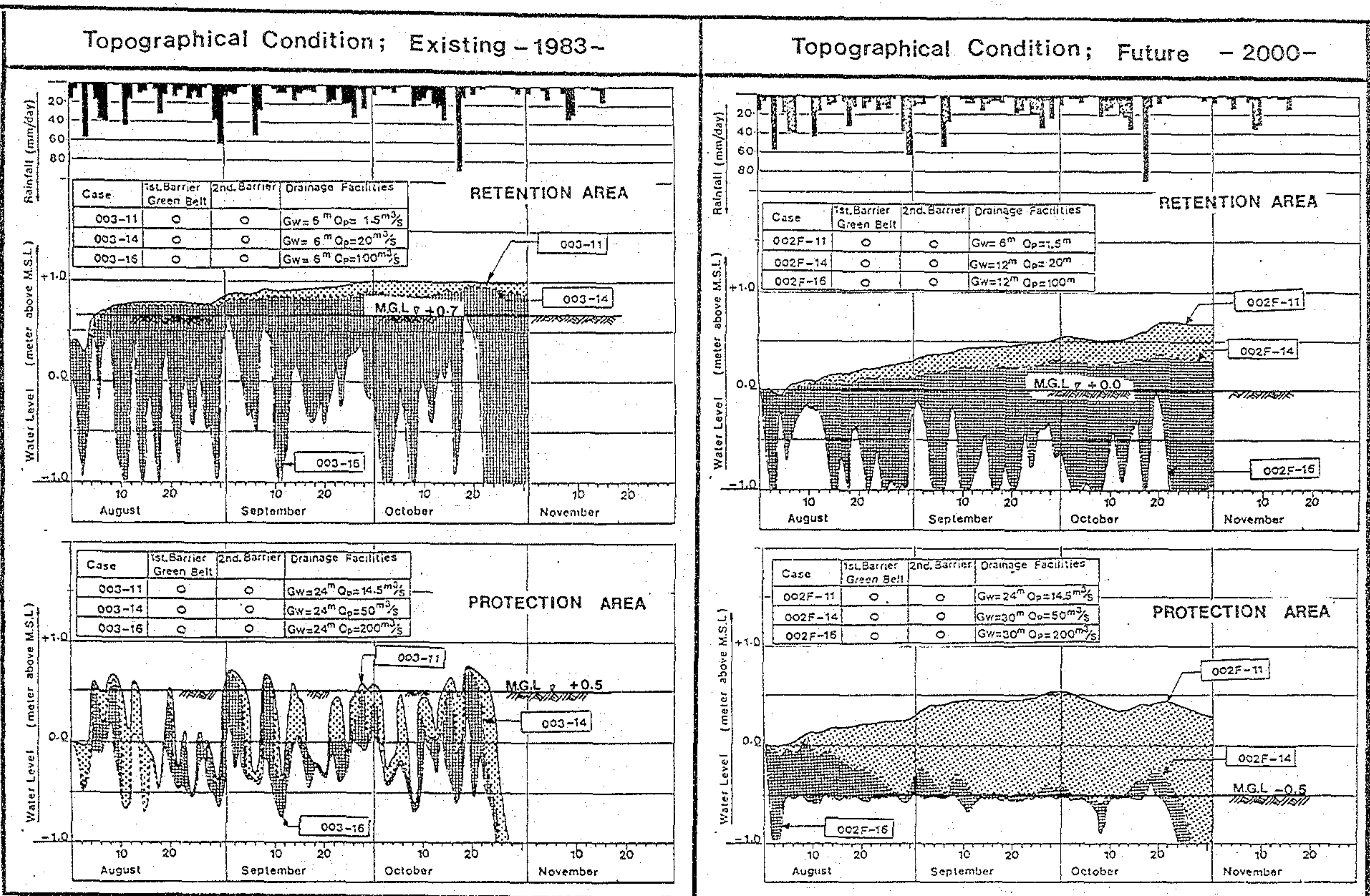
Legend

- : Decreased Difference of Simulated Water Level
- : Increased Difference of Simulated WAter Level

MGL : Mean Ground Elevation above M.S.L

FIG. E.23 Flood Water Levels with & without 2nd Barrier (Rainfall in 1983)

FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK



Legend

Decreased Difference of Simulated Water Level

MGL : Mean Ground Elevation above M.S.L

FIG. E.24

Flood Water Levels with Improvement of Capacity of Drainage Facilities (Rainfall in 1983)

FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK

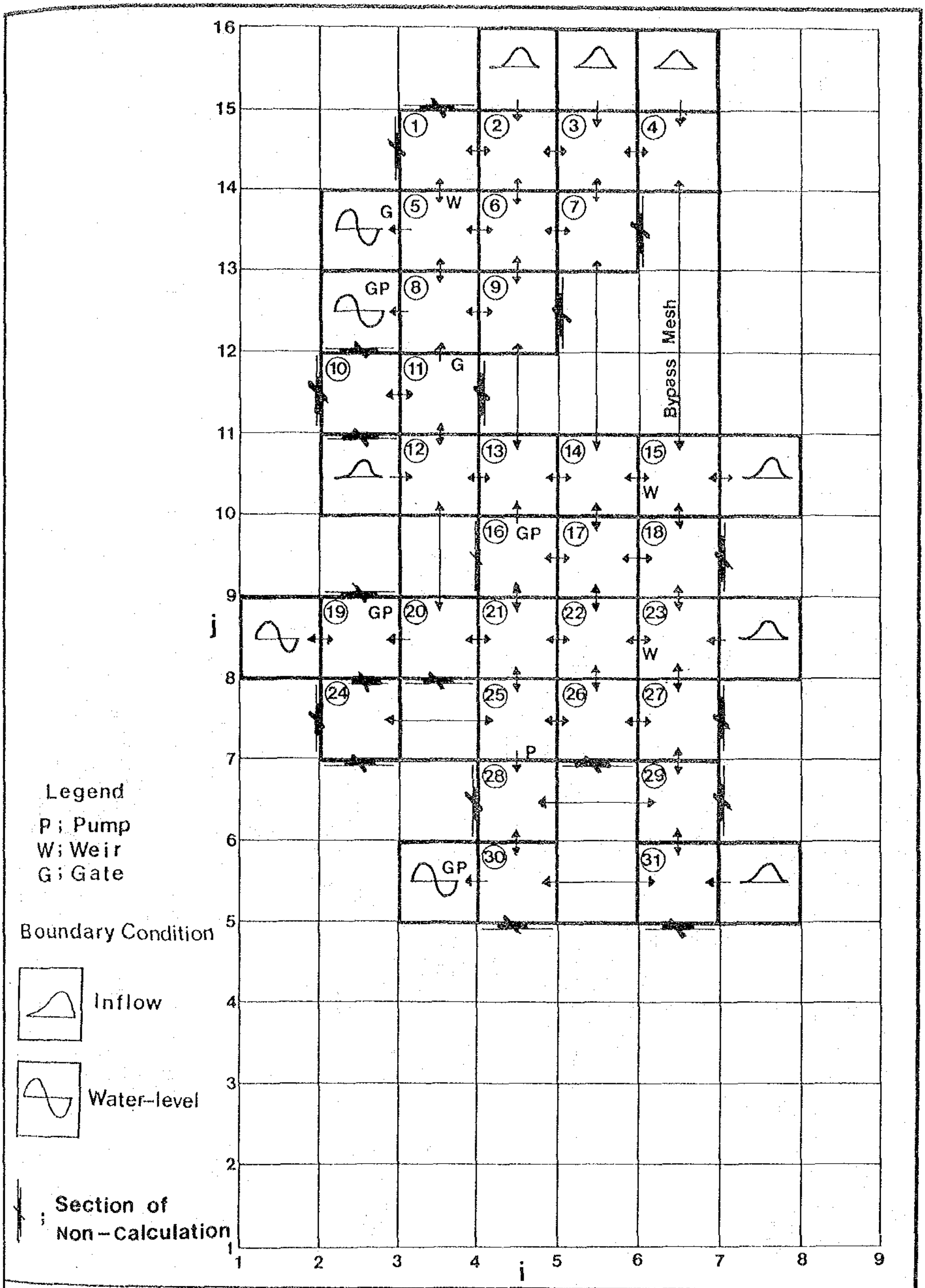


FIG. E.25 **Mesh Arrangement for Calibration of 1983 Flood**

FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK

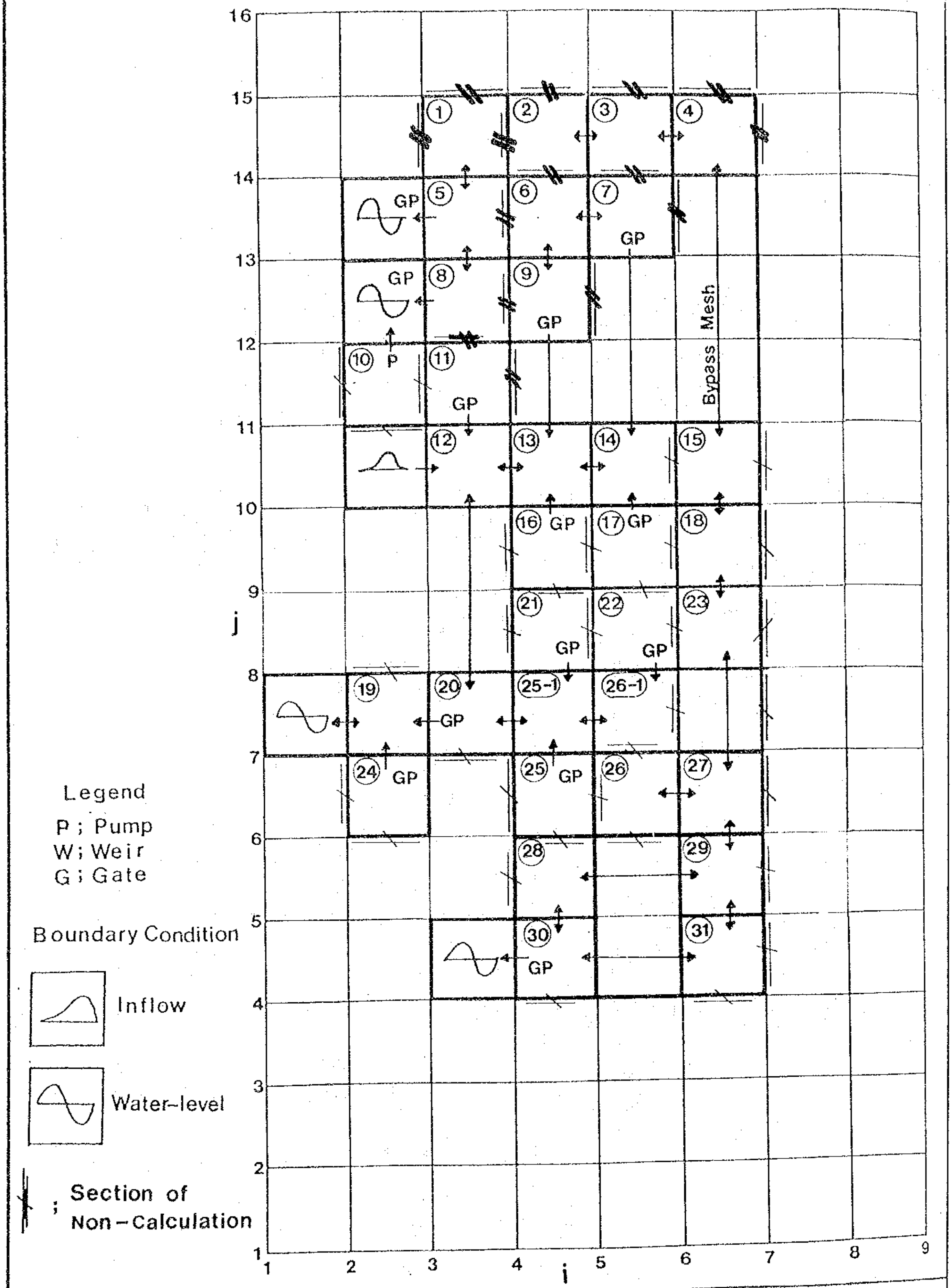
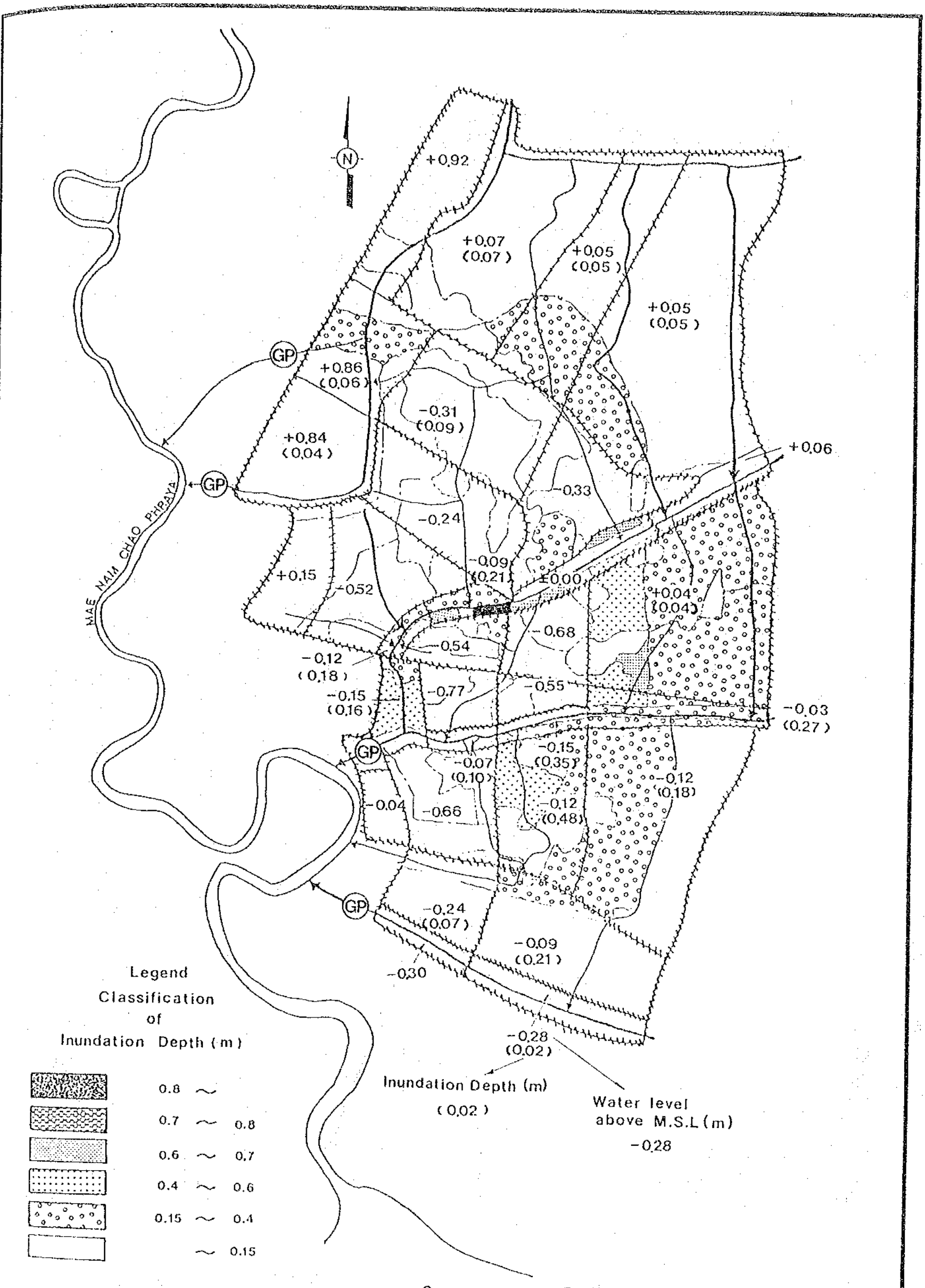


FIG. E. 26 Mesh Arrangement for Calculation of Alternative-III

FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK



Occurrence Date : September 29

FIG. E.27 **Simulated Water Level and Inundation Depth for Alternative-III**

FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK

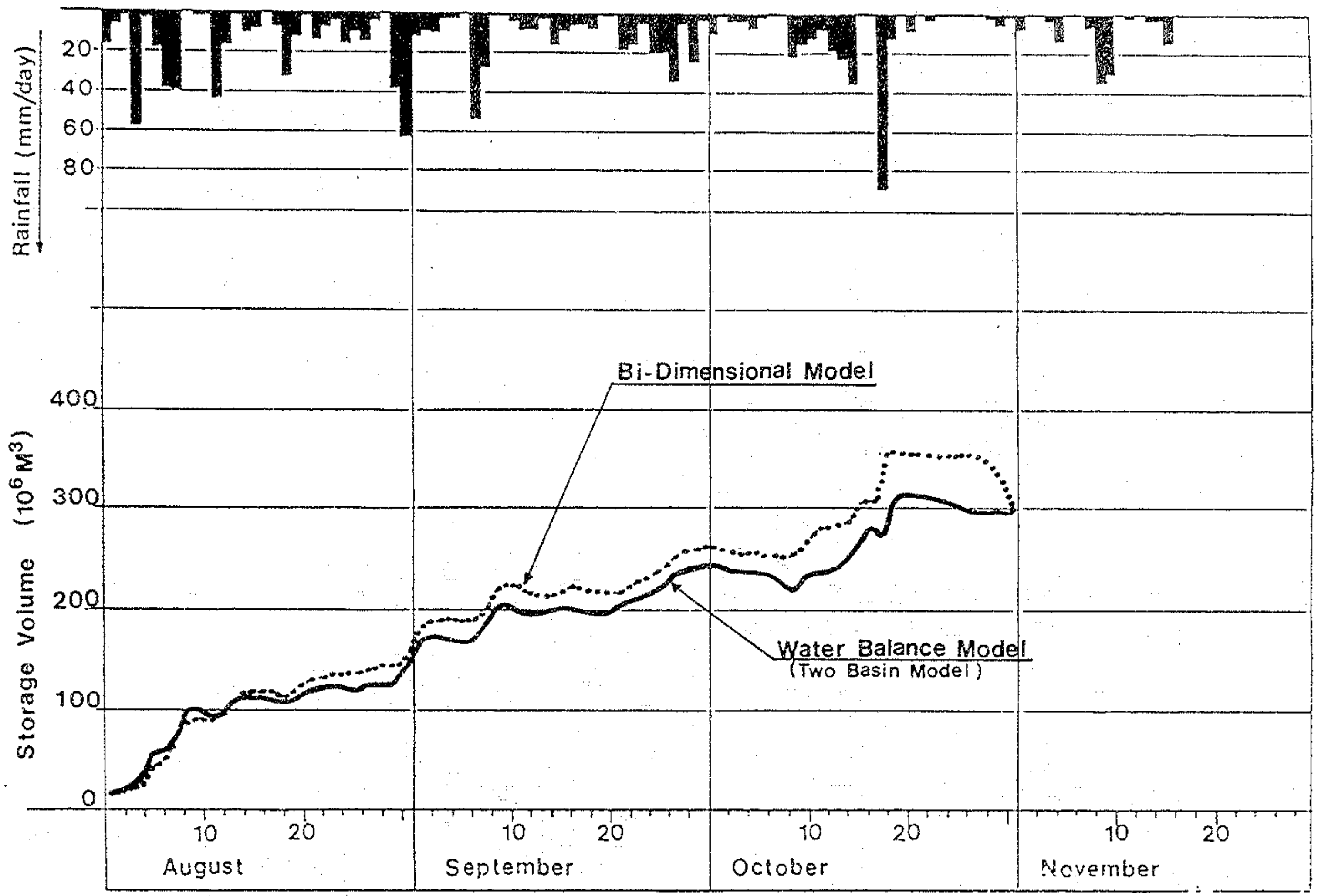
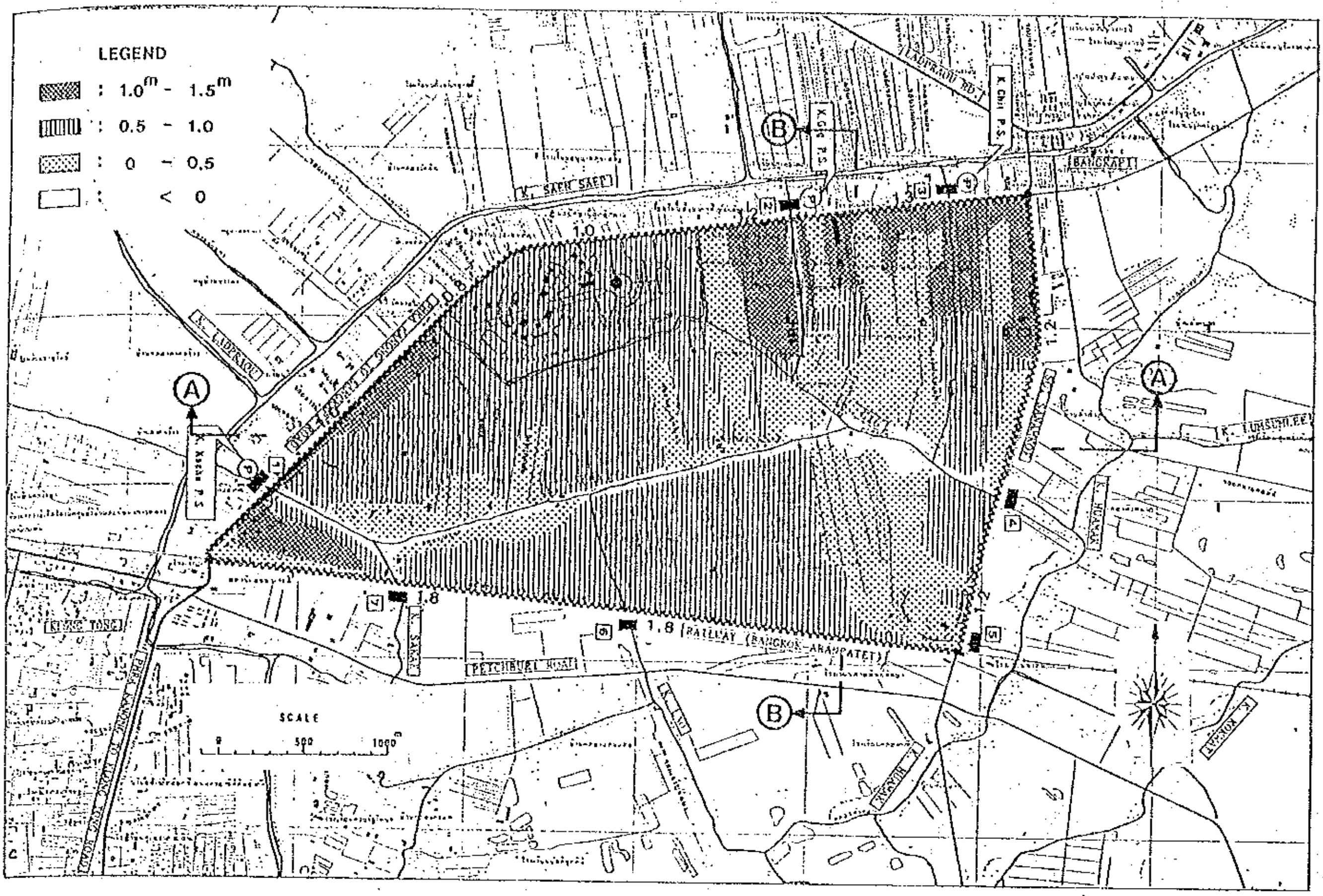


FIG. E.28 Comparison of Simulated Storage Volumes in 1983 Flood between Two Basin Modle & Bi-Dimensional Model

FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK



Ground Elevation

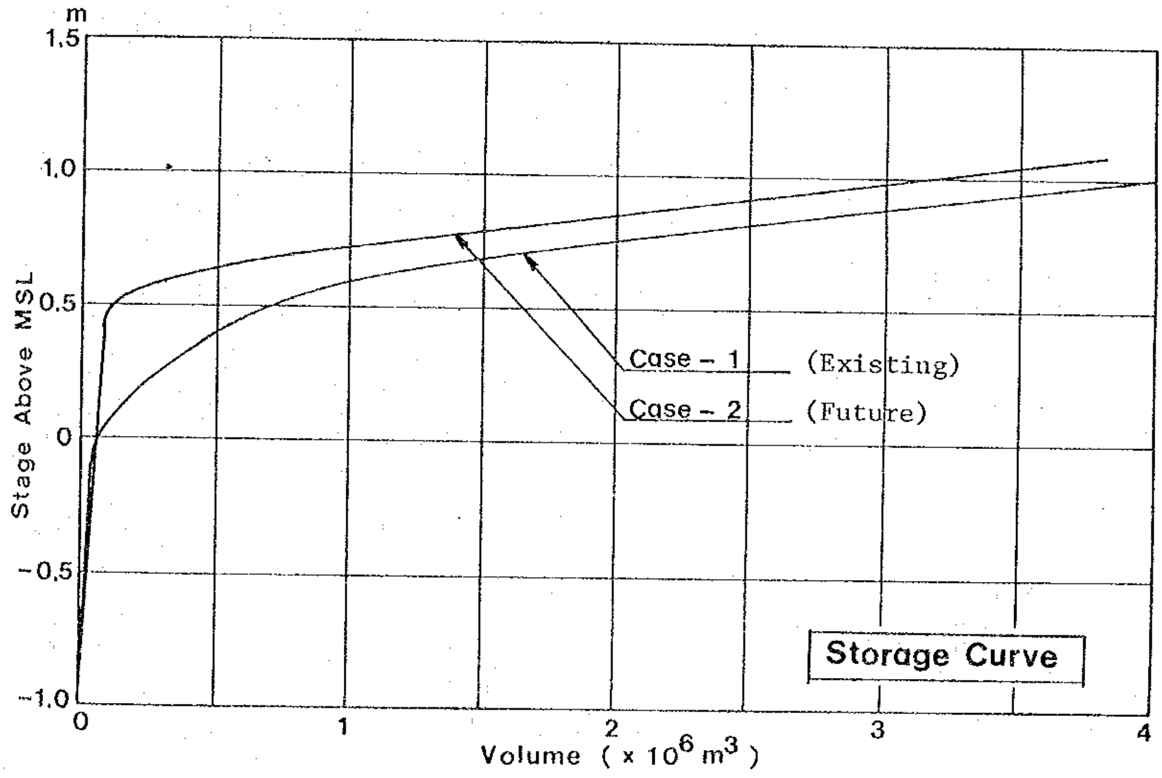


FIG. E.29 **Existing Topographical Condition in Ramkamhaeng Site**

FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK

APPENDIX F

Hydrological Survey

Appendix F Hydrological Survey

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List of Figures

1. General

As described in chapter 6 of main Report, the major hydrological cause of flood in the Study Area were found to be the following:

(1) Extreme rainfall
(2) High water level in the Chao Phraya River
(3) Inflow from outer area
(4) Insufficient drainage capacity

The study presented in this Appendix has been aimed at establishing the hydrological conditions, for the hydraulic study of the drainage system. The following tasks were therefore undertaken:

(1) Collection of hydrological data, rainfall and water levels in the Chao Phraya River and main klongs.

(2) Evaluation of the general characteristics of hydrological phenomena.

(3) Estimation of hydrologic probability using frequency analysis.

(4) Hydrologic observation of inflow from outer area.

(5) Estimation for discharge capacity of main klongs.

2. Data Collection

2.1 Rainfall

2.1.1 Existing and Newly Installed Rain Gauge Stations

A large number of rain gauge stations in and around the Study Area have been installed by the Meteorological Department, DDS and other agencies. These stations are using the recording or non-recording type gauges.

DDS collects the daily rainfall data from 63 gauging stations which use the rain gauges of the tipping bucket type. Unfortunately, as these stations were only established recently, in 1980 and 1981, rainfall data over a long period is not available.

The Data of 73 existing rain gauge stations located around Bangkok area by the Meterological Department are available. Their locations are indicated in Fig. F.1. Amongst the 73 stations, 12 stations are using the automatic recording gauge and the others are a non-recording gauge in manual type. Tables F.1.(1) to F.1.(4) list each station. The Core Area in Bangkok has the highest density of stations and west part of the Study Area is also high. However, stations in the east, northeast and southeast parts are few.

In this study, two new automatic recording rain gauges have been installed at the Ramkhamhaeng Stadium in the Model Area described in Appendix G and in the northeast at Kanayao police station in the Study Area for the following reasons.

(a) At present a non-recording station of the manual type is located at Ramkhamhaeng University in the Model Area. It is impossible to obtain the short duration rainfall intensity of 10, 20, 30. 60 minutes duration, which are needed in the hydrological study of the polder.

(b) As before mentioned, the density of stations at northeast part in the Study Area is very low. So one new rain gauge has been installed as a supplement any station.

The details of new rain gauge such as installation work, specification of instruments, recommendations for maintenance and measuring, have been described in Section 6.

2.1.2 Selection of Representative Rain Gauge Stations

It is required to provide reliable information, on not only the maximum spot rainfall but also the average areal rainfall, because of the extensive size of the Study Area.

In this Study, among 73 stations, 7 stations ie. Don Muang, Bang Khen, Bangkok, Bang Na, Bang Kapi, Min Buri and Lat Krabang are selected for the following reasons.

(a) Judging from the scale of the Study Area, 7 representative stations are adequate for a preliminary study.

(b) Each station is to be selected in such way that they are evenly distributed over the Study Area.

(c) These stations should be have reliable rainfall data for as long a period as possible.

Their locations are indicated in Fig. F.2.

For calculating the average areal rainfall in the Study Area, Thiesson method, weighted mean method, is adopted. Fig. F.2 shows the Thiessen polygon and the area controlled by each station.

2.1.3 Collection of Data

Annual, monthly and daily rainfall data at 7 stations are collected. Hourly and rainfall intensity data in the very short duration are collected at Bangkok Station, because other stations have no short duration data. The list of all rainfall data collected is presented in Table F.2.

Table F.1.(1) : List of Rain Gauge Station

No.	Name of Gauge Station	Name of Agency	Kind of Measuring	Established Year	Available Data	Remarks
1	METEOROLOGICAL DEPARTMENT	METEOROLOGICA	AUTOMATIC	1965	Hourly	
2	YANNAWES VITTHAYAKHOM SCHOOL	DEPARTMENT	"	1970	Daily	
3	KIM NGUAN HUAD SHOP					CANCEL
4	KLANG HOSPITAL	"	"	1977	Daily	
5	PHISICAL TRAINING DEPARTMENT	"	"	1977	Daily	
6	DOMESTIC ANIMAL DEPARTMENT	"	"	1977	Daily	
7	FERTILIZER FACTORY OF BMA	"	"	1977	Daily	
8	RUNG RUANG COMMERCIAL SHOP					CANCEL
9	ANALYSIS & EXPERIMENT SECTION OF THAILAND	"	"	1977	Daily	
10	PLUG SEK O'SOD FACTORY					CANCEL
11	METEOROLOGICAL DEPARTMENT (BANGNA)	"	"	1965	Daily	
12	DON MUANG AIR PORT	"	"	1974*	Daily	
13	BANG KHEN	"	"	1966	Daily	
	PORT AUTHORITY OF THAILAND	"	"	1977	Daily	
14	PRA KHANONG WATER GAGE	"	NORMAL	1974	Daily	
15	SUKHUMVIT HOSPITAL	"	"		Daily	
16	PRA KHANONG SCHOOL	"	"	1974	Daily	
17	FIRSTONE COMPANY	"	"	1977	Daily	
18	PRA PRADAENG DISTRICT	"	"	1970	Daily	
19	WAT YAI TA IN	"	"	1970	Daily	
20	CHONG NON TRI SCHOOL	"	"	1974	Daily	
21	RATSA BURANA DISTRICT	"	"	1974	Daily	

Table F.1.(2) : List of Rain Gauge Station

No.	Name of Gauge Station	Name of Agency	Kind of Measuring	Established Year	Available Data	Remarks
22	THAILAND IRON WORK COMPANY	DEPARTMENT	NORMAL	1977	Daily	
23	SOMCHIT SUK SA SCHOOL	"	"	1974	Daily	
24	SOMDEJ CHAO PHRAYA TEACHER COLLEGE	"	"	1974	Daily	
25	KLONG SAN DISTRICT	"	"	1974	Daily	
26	BANGKOK CRISTAIN COLLEGE	"	"	1974	Daily	
27	ARMED FORCE ACADEMY PREPARATORY SCHOOL	"	"	1974	Daily	
28	THAI RED CROSS	"	"	1977	Daily	
29	JARUSATHAIN STADUIM					CANCEL
30	MATER DEI SCHOOL	"	"	1974	Daily	
31	PHATUMWAN WATER GAGE	"	"	1974	Daily	
32	MANANGKASILA HOUSE	"	"	1974	Daily	
33	TECHNOLOGY & TRADITIONAL INSTITUTE (PO CHANG)	"	"	1974	Daily	
34	THE ROYAL HOUSEHOLD HALL	"	"	1977	Daily	
35	KOSITI SAMOSORN SCHOOL	"	"	1974	Daily	
36	SRI ULAI SCHOOL	"	"	1974	Daily	
37	MINISTRY OF EDUCATION	"	"	1974	Daily	
38	CHITLADA SCHOOL	"	"	1974	Daily	
39	WAR VETERANS ORGANIZATION OF THAILAND (NEAR VICTORY MONUMENT)	"	"	1977	Daily	
40	CHALERM SART SUKSA SCHOOL	"	"	1974	Daily	
41	BANGKAPHI TRANSFORMER STATION	"	"	1974	Daily	

Table F.1.(3) : List of Rain Gauge Station

No.	Name of Gauge Station	Name of Agency	Kind of Measuring	Established Year	Available Data	Remarks
42	KEHANAKORN HOUSING	DEPARTMENT	NORMAL	1977	Daily	
43	THUNG SETTHI VILLAGE	"	"	1977	Daily	CANCEL
44	BANGPLI TRANSFORMER STATION	"	"	1956	Daily	
45	LAT KRABANG DISTRICT	"	"	1956	Daily	
46	MINBURI DISTRICT	"	"	1956	Daily	
47	KLONG KUM SCHOOL	"	"		Daily	
48	BANGKAPHI DISTRICT	"	"	1956	Daily	
49	RAMKHAMHAENG UNIVERSITY	"	"	1974	Daily	
50	CHANG KOL WITHAYA SCHOOL	"	"	1974	Daily	
51	KHUA KARUN NURSE SCHOOL	"	"	1977	Daily	
52	SIAM COMMERCIAL SCHOOL	"	"	1974	Daily	
53	SAMAKKEE SUTHAWART SCHOOL	"	"	1977	Daily	
54	YOTHIN BURANA SCHOOL	"	"	1974	Daily	
55	PUBLIC RELATION SCHOOL	"	"	1974	Daily	
56	CIVIL AVIATION TRAINING CENTER	"	"	1974	Daily	
57	DIN DEANG (DEPARTMENT OF SAMITARY)	"	AUTOMATIC	1970	Daily	
58	CHAN HOON BAMPHEN SCHOOL					CANCEL
59	KURU SAPHA PRINTING OFFICE	"	NORMAL	1977	Daily	
60	WAT BUNGTHONG LANG SCHOOL	"	"	1977	Daily	
61	PATAWIKORNWITHAYA SCHOOL	"	"	1977	Daily	
62	TA KE DA FACTORY	METEOROLOGICA	"	1977	Daily	
63	WAT NUANCHAN (WAT = TEMPLE)	DEPARTMENT	"	1977	Daily	
64	BANLATPRAO SCHOOL	"	"	1970	Daily	

Table F.1.(4) : List of Rain Gauge Station

No.	Name of Gauge Station	Name of Agency	Kind of Measuring	Established Year	Available Data	Remarks
65	CHAN KASEM TEACHER COLLEGE	DEPARTMENT	NORMAL	1974	Daily	
66	MN. SUB DIVISION CAR CENTER	"	"	1974	Daily	
67	PHATHOMNIWET SCHOOL	"	"	1977	Daily	
68	ELECTRICAL SUPPLY AUTHORITY	"	"	1974	Daily	
69	KEMAPHIRA TARAM SCHOOL	"	"	1970	Daily	
70	NONTHABURI PROVINCE OFFICE	"	"	1974	Daily	
71	NONTHABURI TECHICAL INSTITUTE	"	"	1974	Daily	
72	NONTHABURI OVERSEAS RADIO RECEIVING STATION	"	"	1974	Daily	
73	CHEST HOSPITAL					CANCEL
74	ATOMIC ENERGY FOR PEACE	"	"	1974	Daily	
75	LAT PLA KAO SCHOOL	"	"	1977	Daily	
76	POLICE AVIATION DIVISION	"	"	1977	Daily	
77	BANGKHEN HEALTH CENTER	"	"	1977	Daily	
78	MAUNG THONG HOUSING					CANCEL
79	WAT LAKSI SCHOOL	"	"	1977	Daily	
80	WAT RATNIYOMTAM SCHOOL	"	"	1977	Daily	
81	BAN NUA MON SCHOOL			1979		

Table F.2 List of Rainfall Data Collected

No.	Type of Data	Length of Record
1.	Location map of rain gauge stations belong to Meteological Dept. in Bangkok Area	
2.	Annual and monthly rainfall in Bangkok Area	1951 - 1982
3.	Daily rainfall data at ·	
	(1) Daon Muang	1951 - 1983
	(2) Bang Khen	1967 - 1983
	(3) Bangkok Metoropolis	1951 - 1983
	(4) Bang Na	1966 - 1983
	(5) Bang Kapi	1956 - 1983
	(6) Min Buri	1956 - 1983
	(7) Lat Krabang	1957 - 1983
	(8) 43 stations	1978, 1980, 1982
4.	Hourly rainfall data at Bangkok Metropolis	1965 - 1982
5.	Annual maximum rainfall of durations varying from 5 mm. to 24 hours at Bangkok Metropolis	1937 - 1982

2.2 Water Level of Chao Phraya River and Main Klongs

2.2.1 Existing and Newly Installed Water Level Gauge Stations

(1) Chao Phraya River

At present, 12 existing water stage stations which belong to the Port Authority of Thailand (PAT), Hydrographic Department of Royal Thai Navy (HDRTN) and Royal Irrigation Department (RID) are located along the Lower Chao Phraya River from river mouth (0 km) to Bang Sai (110 km). PAT controls the down-stream side from near the Memorial Bridge as marine area and RID controls the up-stream side from that point. Most of the stations started data before 1940 by recording gauge. Fig. F.3 shows the location of gauging stations on lower Chao Phraya River. List of these stations is shown in Table F.3

(2) Main Klongs

Existing water level stations which belong to DDS and RID along the klongs in the core of Bangkok and Study Area are located at 30 points.

However, most of the stations are located in the core area and have been in use for only 2 years except Prakhanong and Sam Rong Flood Gate Stations belonging to RID. Measurements are made by the usual staff gauge system except for one station (Klong Kasem Pumping Station).

Fig. F-4 shows the location of existing gauging stations and lists of these stations are shown in Table F.4.(1) and F.4.(2)

In this Study, twelve new automatic recording water level gauge (eleven-Richard type and one-water pressure type) have been installed at the hydrologicaly important points in the Study Area taking into account the following reasons:

(a) As mentioned before, most of the DDS's existing gauging stations are inside the core area in Bangkok and there are few gauging stations in the Study Area.

(b) Information on the discharge flow of the main klongs in the directions east to west and north to south is required in the hydrological study.

(c) The number of existing gauging stations and the obtained data are insufficient to understand the hydraulic phenomenon which will be essential for the analysis.

The location of new gauging stations is indicated in Fig. F-4. The details of these stations, installation work, specification of instruments, maintenance and measuring, has been given in Section 6.

2.2.2 Collection of Data

River stage data were collected through DDS from PAT, HDRTN and RID for the hydraulic analysis. Water level data at main klongs were mainly collected at K. Ton pumping station (DDS), K. Phrakhanong Flood Gate (RID) and K. Sam Rong Flood Gate (RID). The list of all water level data collected is shown in Table F.5.

Table: F.3 List of Existing Water Stage Station (Chao Phraya River)

No.	Name of Station	Name of Agency	Kind of Mesuring	Installed Year	Re Data	Remarks
1	Bangkok Bar	Port Authority	Automatic	1940	Hourly data	
2	Fort Phrachul	"	"	"	"	
3	Pak Nam	"	"	"	"	
4	Phra Pra Daeng	"	"	"	"	
5	Bangkok Harbour	"	"	"	"	
6	Sathu Pradit	"	"	1977	"	
7	Memorial Bridge	RID	"	1940	"	
8	Hydrografic Department	Hydrografic Dep.			"	
9	RID Office	RID			"	
10	Rama VI Bridge	"			"	
11	Pak Kret	"			"	
12	Bang Sai	"			"	

Table: F.4(1) List of Existing Water Stage Station (Klong)

No.	Name of Station	Name of Agency	Kind of Mesuring	Established Year	Available Data	Remarks
1.	Rama 4 (P_m)	DDS	normal staff gauge	1981	hourly	
2.	Klong Orachorn (G_k)	DDS	"	1981	hourly	
3.	Klung Kasem (P_m)	DDS	Automatic	1977	hourly	GRAPH
4.	Tewet (C_t)	DDS	normal stagg gauge	-	"	Gate is under const.
5.	Bang Lam Phu (C_t)	DDS	"	-	"	DATA COLLECTED
6.	Ong Ang (C_t)	DDS	"	-	"	IN 1981
7.	Pak Klong Talat (G_k)	DDS	"	-	"	
8.	Pra Pin Klao (G_k)	DDS	"	-	-	
9.	Dusit (C_t)	DDS	"	1981	"	Not complete
10.	Samsen (C_t) & Rama 6 (P_s)	DDS	"	1982	"	
11.	Victory Monument (P_s)	DDS	"	1982	"	
12.	Saphan Phrom Yothi (P_s) & Sump)	DDS	"	1981	"	
13.	Bang Sue (C_t)	DDS	"	1982	"	
14.	Bang Khen (C_t)	DDS	"	1982	"	
15.	Chong Non Tri (C_t)	DDS	"	-	-	Not collected data

Table:F.4 (2) List of Existing Water Stage Station (Klong)

No.	Name of Station	Name of Agency	Kind of Mesuring	Established Year	Available Data	Remarks
16.	Nang Lin Chi (P_s)	DDS	normal staff gauge	1982	hourly	
17.	Sa Thu Pradit (P_s)	DDS	"	1982	"	
18.	Klong Kruai	DDS	"	1982	"	
19.	Saem Saep (C_t)	DDS	"	1981	"	
20.	Klong Tan (P_s)	DDS	"	1981	"	
21.	Ekamai (P_s)	DDS	"	1982	"	
22.	Thong Lo (P_s)	DDS	"	1982	"	
23.	Asoke (P_s)	DDS	"	1982	"	
24.	Praksamakki (P_s)	DDS	"	1982	"	
25.	Ban Kluai Thai (P_s)	DDS	"	1981	"	
26.	Phra Kanong (P_s)	DDS	"	1981	"	
27.	Klong Toi (C_r)	DDS	"	1981	"	
28.	Klong Prakanong (G_k)	RID	"		"	
29.	Klong Kha Cha (C_t)	DDS	"	1982	-	Not collected data
30.	Klong Sam Rong (G_k)	RID	"			

Table F.5 List of River Stage Data Collected

No.	Type of Data	Length of Record
1.	Location map of river stage stations of Lower Chao Phraya River.	
2.	Hourly water levels month Aug.-Nov. at:	
	(1) Bangkok Bar	1970, 1975 - 1980
	(2) Fort Phrachul	1970, 1975, 1978, 1980
	(3) Pak Num	1970, 1975, 1978, 1980
	(4) Phra Pra Daeng	1970, 1975, 1978, 1980
	(5) Bangkok Port (Bangkok Harbour)	1970, 1975, 1978 - 1982
	(6) Sathu Pradit	1978, 1980
3.	Monthly H.H.W.L, M.W.L and L.L.W.L at:	
	(1) Bangkok Bar	1940 - 1982
	(2) Fort Phrachul	1940 - 1982
	(3) Pak Num	1940 - 1982
	(4) Phra Pra Daeng	1940 - 1982
	(5) Bangkok Port (Bangkok Harbour)	1940 - 1982
	(6) Sathu Pradit	1976 - 1982
	(7) Hydrographic Department (except M.W.L)	1940 - 1982
	(8) Memorial Bridge (except M.W.L)	1940 - 1982
	(10) RID Sam Sen (except M.W.L)	1942 - 1982
4.	Daily water Levels and discharge-flow at following stations of Chao Phraya River and Pa Sak River	
	(1) Muang Nakhon Sawan	1963,
	(2) Bang Bang Kaeo	1963,

3. Chao Phraya River

3.1 Chao Phraya River and Its Tributaries

The Chao Phraya River basin occupies most of the northern region and the central part of Thailand as shown in Fig. F.5. The main course of the Chao Phraya River originates from the northern rivers, Ping, Wang, Yom and Nan, which descend into the upper plain of the central valley of Thailand. These rivers then merge to become the Chao Phraya river at Nakhon Sawan. About 100 km downstream near Chainat province, the river enters the central part of the lower Chao Phraya basin which is a vast flood plain. The drainage area of the Chao Phraya River basin is about 162,000 sq.km.

The length of the Chao Phraya river from Nakhon Sawan down to the Gulf of Thailand is roughly 370 km. The Ping itself has a length of 600 km and the Nan of 610 km. The Bhumipol dam and Sirikit dam were built on the Ping and Nan rivers respectively to store flood waters to generate hydroelectric power and to release water for irrigation, navigation, water supply and salinity control purposes. On the Wang river, the Kiu Lom dam was constructed mainly for irrigation purposes.

At Chai Nat, Chai Nat dom (Chao Phraya dam) was constructed to divert the river flow into the extensive irrigation schemes located downstream along both sides of the Chao Phraya river.

The gradient is extremely flat in the lower Chao Phraya basin and the main river cannot keep the water level within its own channel once a certain gauging height is reached and surpassed. The river throws out several branches to take the water, beginning between Naknon Sawan and Chai Nat.

The first distrubutary is the Suphan or Tha Chin River which starts its course about 55 km south of Nakon Sawan on the right bank. The river covers a distance of about 200 km, meandering most of the way. It runs parallel to the Chao Phraya but it does not begin to flow until the main river has risen about 3.5 m above its minimum level.

The second branch leaving the western bank is the Noi River. The extreme lowlands of the plain starts from here and it is rather difficult to follow the river course. The whole area is criss-crossed by broad and narrow rivers, rivulets, branches and artificial channels. The Noi River runs parallel to the Chao Phraya, and joins the main river. It receives water and starts flowing only when the main river has risen about 2.5 m above its minimum level.

All the eastern branches and tributaries meet at Ayutthaya to form a broad river (Pasak River) flowing south to meet the western branches.

Between Ayutthaya and the Gulf, there are no natural distributaries but a great number of canals that branch off east and west and ebb and flow with the tide. For about 80 km inland the river is subject to strong tidal influence.

3.1.2 River Flows

Thai rivers usually have the first rise in May or June to about 2-3 m above minimum river level within a period of only 1-3 weeks, after which there is a fall of 1-2 m during July. The second rise follows gradually and reaches its maximum at the end of August or beginning of September. Then the rivers usually overflow the banks for a short period, gradually subsiding to the normal low level in November.

The curve of the rise and fall of water level in the Chao Phraya is fairly smooth, the falling curve is flatter than the rising curve and the maximum level is not attained until October in the upper reaches and November in the lower reaches. The explanation is that when the water level rises, a fair quantity of water escapes into distributaries and branches in a consecutive order, this water overflows the distributaries banks and spreads out as a vast sheet of water into the low-lying areas on both banks of the Chao Phraya.

Table F.6, Table F.7 and Figure 2.8 show the characteristics and discharge regime of the Chao Phraya river and its tributaries respectively.

Table F.6 Discharge regime of the Chao Phraya River and Its Tributaries (m^3/second)

N Name of river and period	J	F	M	A	M	J	J	A	S	O	N	D
Chao Phraya												
(Nakhon Sawan) (1963-70)	222	212	210	188	255	446	613	1,062	2,080	2,080	1,054	430
Chao Phraya												
(Chai Nat) (1963-70)	111	57.2	80.7	76.2	131	234	255	450	1,077	1,653	637	285
Ping (1952-62)	60.7	38.4	20.3	18.3	67.6	114	125	323	686	539	186	116
Wang (1952-69)	5.13	3.15	1.62	1.10	14.1	28.8	17.4	78.9	169	119	36.1	14.9
Yom (1952-70)	8.18	5.69	3.45	3.91	24.8	45.6	55.1	192	396	153	45.9	17.8
Nan (1950-70)	49.1	35.7	25.4	24.2	65.4	154	297	724	1,019	583	205	88.7
Pan Sak (1958-70)	14.6	14.0	11.3	9.77	16.6	21.4	40.5	67.4	284	360	59.1	20.1

Source : Royal Irrigation Department

Table F.7 Characteristics of the Chao-Phraya River and Its Tributaries

Name of River	Gauging station (m) Period of record	Catchment area at gauging station (km^2)	Difference between high and low water level (m)	Discharge in m^3./second			Ratio min./max.	Annual runoff (million m^3)	Drainage in m^3/km in one year
				Mean	Min.	Max.			
Chao Phraya	Nakhon Sawan (21) 1963-70	110,569	6.50	719	131	2,812	1 : 21	22,693	205,238
Chao Phraya	Chai Nat (16) 1963-70	120.693	6.70	426	45.0	2,276	1 : 51	13,449	111,431
Ping	Wang Kra Chao (141) 1952-62	26,396	3.60	191	9.52	1,675	1 : 176	6,077	230,224
Wang	Ban Wang Khrai (133) 1952-69	10,407	4.80	41.1	0.51[a]	433	1 : 849	1,305	130,500
Yom	Kaeng Luang (69) 1952-70	12,658	6.80	68.2	0.91	1,256	1 : 1380	2,404	189,919
Nam	Muang Phitaanulok (45) 1950-70								
Pa Sak	Kaeng Khai (20) 1958-70	14,522	6.50	74.5	3.91	654	1 : 167	2,351	161,892

(a) Years with absolute drought omitted.

Source : Royal Irrigation Department

3.1.4 Flood Protection system in the Chao Phraya River

In the upper reaches, the Bhumipol dam (effective storage volume, 8,600 million cubic meter), Sirikit dam (8,800 MCM) and Kiu Lom dam (106 MCM) were constructed in 1964, 1972, and 1972 respectively. While the former two dams were constructed mainly for hydro-energy, these dams contribute a flood control of 500 CMS. There are no opportunities for new storage projects which prevents increases in the degree of control of flows in the Chao Phraya basin.

The central plain is classified into two delta, old delta and young delta. The former is stretching from Chainat to Ayutthaya where four rows of natural levee and bachward areas in the northsouth direction had long been developed. An Embankment of one to two meters height has been constructed from Chainat to Ayutthaya, and the low-lying area surrounded by the embankment has been deliberately rendered flood-prone and so forms a conservation area.

The young delta extends from Ayutthaya to the Gulf of Thailand an extremely flat and low area. In the young delta, water fed from the Chao Phraya has helped paddy to grow, and there is no embankment at all.

Rice harvests are subject to considerable variation as the annual runoff of the river greatly fluctuates from year to year. In the central plain, the greatest need is to reduce the risk of drought and excessive flood. The Chao Phraya Dam system was intended to regulate the natural flooding which occurs every year and spread it over a wider area, not to produce off season water.

The discharge quantity in a 10-year return period at Chainat is 5.400 CMS, while the discharge quantity required for rice harvests is about 3,550 CMS. The exess water of 1,850 CMS is retained in the conservation area as mentioned above. As the floods usually last for one month, storage volume becomes over 4 billion cubic meters, equivalent to one-eight of the annual runoff of the Chao Phraya, while the regulated discharge of two dams, the Bhumipol and the Sirikit, are 500 CMS. (Fig. F.6)

3.1.5 Flood Control Schemes Aimed at Lowering Flood Levels on the Chao Phraya River (Fig. F.7)

The Asian Institute of Technology (AIT) is now undertaking an 18-month long study which is called the "Flood Routing and Control Alternatives for the Chao Phraya River for Bangkok" for NESDB. This study will be studied under the condition that no any adverse effect will be made on the irrigated area. It will also not consider such "headwater" schemes as reforestation or reservoir construction.

An inception report for this study which started in early 1983, is due at the end August 1983. The following alternatives are reportedly considered in this study.

a. a diversion canal from approximately river km 80 via Klong Ban Mai and thence through the so-called Green Belt to the Gulf of Thailand.

b. a tidal barrier on the Chao Phraya upstream of the Bangkok port

c. a gated short-cut of the Chao Phraya river bend (short-cutting the river from approximately km 18 to km 34).

d. dikes along the Lower Chao Phraya.

e. dredging and widening of the downstream part of the Lower Chao Phraya.

Diversion canal of a 500 m^3/sec lowered flood water levels at Bangkok only in the order of 10 cm according to AIT. When this is compared to high flood discharge at Bangkok, which are in the range of 3,500 to 4,000 m^3/sec, it is clear that an extremely large diversion canal will be required to bring about an appreciably reduction in flood levels at Bangkok. Also the other alternatives individually, are considered to bring only minor relief. Several would have to be combined to result in a reduction of flood levels on the scale required, viz. 0.5 to 1.0 m.

Considering that the above studies have uncertaintees with regard to an eventual follow-up, the hydrological and hydraulic analysis for JICA study is conducted on a present condition basis with respect to flood water levels in the Chao Phraya River.

4. Rainfall

4.1 General Characterlistics

4.1.1 Annual Rainfall and Rainy Days

According to the data collected between 1951 to 1982, the annual rainfall and rainy days in the Study Area is approximately 1300 mm to 1450 mm and 90 days to130 days. The former is not so large a difference between each gauging station except Bangkok Station, however, the latter is very different when comparing automatic and manual gauging stations. Average areal annual rainfall in the Study Area is calculated approximately 1360 mm by means of arithemetic mean method. Table F.8, F.9 and Fig. F.8 show the annual rainfall and rainy days in the Study Area.

4.1.2 Monthly Rainfall and Rainy Days

The rainstorm in the Study Area is under the influence of the seasonal monsoon wind. The rainy season prevails from mid-May to mid-October as the southwest monsoon brings a stream of warm moist air from the Indian Ocean. During the rainy season, approximately 85% of yearly rainfall is recorded, approximately 300 mm in September, 150 mm to 200 mm in May, June, July and October.

Tropical storms and depressions reach the Gulf of Thailand in August, September and October. However, the rainfall directly associated with these storms has much less intensity than the rainfall associated with the southwest monsoon.

Average monthly rainfall and rainy days in the Study Area are shown in Table F.10, F.11 and Fig. F.9.

Table F.8 Annual Rainfall in The Study Area

Unit : mm/year

Station / Year	Don Muang	Bang Khen	Bangkok	Bang Na	Bang Kapi	Minburi	Lat Krabang	Average Study Area
1951	1827.0	-	1647.0	-	-	-	-	1737.0
1952	1827.1	-	1516.0	-	-	-	-	1671.6
1953	1586.7	-	1584.0	-	-	-	-	1585.4
1954	1290.7	-	1495.0	-	-	-	-	1392.9
1955	1354.5	-	1508.8	-	-	-	-	1431.7
1956	1954.7	-	1371.9	-	1637.9	1618.8	1650.4	1646.7
1957	2051.0	-	1956.7	-	1843.4	2049.8	1835.9	1947.4
1958	1169.7	-	1296.5	-	1193.4	1342.4	1309.3	1262.3
1959	1544.1	-	1273.8	-	1592.0	1341.5	1277.5	1405.8
1960	1436.8	-	1646.0	-	801.2	1387.8	1401.5	1334.5
1961	1418.6	-	1449.2	-	987.3	1191.0	1581.5	1325.5
1962	1544.0	-	1377.0	-	1610.0	1343.0	1679.6	1510.7
1963	1513.0	-	1540.5	-	1616.5	1675.1	1821.2	1633.3
1964	1404.8	-	1858.6	-	1400.3	1612.5	1329.3	1521.1
1965	1302.0	-	1702.6	-	1756.8	1329.9	1533.4	1524.9
1966	1260.7	-	1667.3	1004.6	1394.4	896.3	1675.1	1316.4
1967	1454.1	1116.7	875.5	1133.3	1013.8	976.8	984.7	1079.3
1968	1250.9	No Report	1320.0	1334.9	1351.9	1558.6	1289.1	1350.9
1969	1193.5	1318.9	1135.0	1097.8	1055.9	1011.2	1127.9	1134.3
1970	1902.2	1492.6	1885.0	1408.9	1585.9	1706.0	* 931.9	1558.9
1971	1223.9	1546.1	1483.9	1316.8	1402.1	1259.5	* 753.4	1283.7
1972	1478.8	1827.3	1652.3	1682.7	No Report	No Report	No Report	1660.3
1973	901.0	1053.7	1089.9	1186.0	888.4	1225.9	*575.2	1057.5
1974	1127.7	1399.6	1519.1	1213.0	No Report	1161.0	No Report	1284.1
1975	945.0	1538.0	1377.8	1114.6	1451.4	1552.1	*483.9	1329.8
1976	1177.6	1652.8	1634.7	1535.2	1337.8	1530.4	*421.2	1478.1
1977	885.8	1011.8	1040.1	1112.6	542.9	845.8	*343.0	906.5
1978	1246.2	1100.2	1236.4	1300.8	1426.1	1362.7	*479.4	1278.7
1979	584.9	967.9	1133.4	1134.3	1019.4	916.0	*301.5	959.3
1980	1331.5	1407.7	1471.0	1279.9	1421.6	1416.5	*434.7	1387.9
1981	1209.6	1380.2	1592.7	1506.5	1255.2	1440.6	No Report	1397.5
1982	1087.8	1615.9	1829.6	1453.7	1729.6	1443.4	No Report	1526.7
Annual	1358.9	1361.9	1474.0	1283.4	1334.0	1353.5	1364.6	1361.5

Note 1. The data in worked * should be not considered for calculating the Average Annual Rainfall.
2. Annual Rainfall in Study Area is calculated in arithmetic mean method.

Source : Meteorological Department

Table F.9 Annual Rainy Days in The Study Area

Unit : day/year

Year \ Station	Don Muang	Bang Khen	Bangkok	Bang Na	Bang Kapi	Minburi	Lat Krabang	Average Study Area
1951	130		126					128
1952	145		143					144
1953	159		152					156
1954	127		132					130
1955	141		126					134
1956	148		137		88	95	79	109
1957	140		133		79	86	87	105
1958	110		125		71	74	69	90
1959	124		118		61	74	93	118
1960	114		123		44	63	89	87
1961	143		136		81	72	81	103
1962	121		121		100	67	72	96
1963	132		131		92	78	78	102
1964	117		150		90	75	74	101
1965	126		143		97	100	80	109
1966	137		141	85	100	112	96	112
1967	122	111	122	120	83	110	85	108
1968	124	No Report	118	115	79	106	64	101
1969	118	128	123	131	95	103	53	107
1970	133	136	153	147	99	92	* 54	116
1971	119	117	132	129	80	78	* 31	98
1972	113	112	146	131	No Report	No Report	No Report	126
1973	110	107	125	125	58	118	*34	107
1974	113	123	139	116	No Report	87	No Report	116
1975	120	128	130	116	72	91	*32	110
1976	119	120	139	123	80	104	*24	114
1977	96	98	107	88	46	67	*25	84
1978	114	128	133	102	74	93	*37	107
1979	72	80	95	86	50	55	*24	93
1980	108	106	109	90	88	94	*36	99
1981	124	126	145	123	63	112	*	116
1982	110	134	139	125	83	107	*	116
Annual Average	123	117	131	115	78	89	74	104

Note 1. The data in marked * should be not considered for calculating the Average Annual Rainy Days.
2. Annual Rainy Days in Study Area is calculated in arithmetic mean method.

Source : Meteorological Department

Table F.10 Average Monthly Rainfall at Each Station and in the Study Area

Unit : mm/month

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Averages
Don Muang	6.9	19.2	31.6	62.3	162.8	154.3	164.4	205.8	287.1	212.8	37.5	14.2	1358.9
Bang Khen	8.7	10.5	22.3	85.6	186.5	164.4	188.6	190.4	280.2	157.1	50.3	17.3	1361.9
Bangkok	9.7	29.7	28.3	71.3	194.1	158.3	171.1	197.2	334.0	223.3	47.5	9.0	1474.0
Bang Na	10.8	30.0	19.3	70.3	195.4	135.5	134.3	160.0	275.5	174.9	65.2	12.2	1283.4
Bang Kapi	13.1	26.2	18.6	75.5	163.5	150.0	161.8	191.4	295.1	193.6	32.5	12.7	1334.0
Minburi	10.9	23.1	13.5	84.4	194.3	155.6	157.7	185.5	288.9	190.1	36.4	13.1	1353.5
Lat Krabang	7.5	23.9	12.7	75.6	191.3	154.2	165.6	216.3	293.7	193.9	37.2	14.5	1386.4
Study Area	9.7	23.2	20.9	75.0	184.0	153.3	163.4	192.4	293.5	192.2	43.8	13.3	1364.6

Note The period of monthly rainfall data in each station to be used is as follows.

. (1) Don Muang : 1951 - 1982 (32 years)
. (2) Bang Khen : 1967, 1969 - 1982 (15 years)
. (3) Bangkok : 1951 - 1982 (32 years)
. (4) Bang Na : 1966 - 1982 (17 years)
. (5) Bang Kapi : 1956 - 1971, 1973, 1975 - 1982 (25 years)
. (6) Minburi : 1956 - 1971, 1973 - 1982 (26 years)
. (7) Lat Krabang : 1956 - 1971 (16 years)

Source : Meteorological Department

Table F.11 Monthly and Annual Rainfall Days in the Study Area

Unit : day/month

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
Don Muang	1.2	2.3	3.0	6.2	14.6	15.2	17.6	19.5	20.9	15.2	5.7	1.5	122.9
Bang Khen	1.1	1.6	2.3	6.1	14.7	15.3	16.7	18.1	19.6	13.7	6.3	1.3	116.8
Bangkok	1.6	3.0	3.3	6.6	15.8	16.8	18.3	20.5	21.3	16.8	5.9	1.3	131.2
Bang Na	0.9	2.6	3.0	5.7	14.8	14.7	16.1	16.8	19.1	14.8	5.4	1.2	114.8
Bang Kapi	0.6	1.0	1.1	3.6	10.0	9.7	11.6	12.5	15.3	9.4	2.6	0.6	78.0
Minburi	0.5	1.3	1.4	4.1	11.8	10.8	13.5	14.3	16.3	10.9	3.1	0.6	88.6
Lat Krabang	0.3	1.4	0.6	3.8	10.0	8.6	10.1	11.8	15.3	9.1	2.4	0.7	74.1
Study Area	0.9	1.9	2.1	5.2	13.1	13.0	14.8	16.2	18.3	12.8	4.5	1.0	103.8

Note The period of monthly rainfall data in each station to be used is as follows.

- (1) Don Muang : 1951 - 1982 (32 years)
- (2) Bang Khen : 1967, 1969 - 1982 (15 years)
- (3) Bangkok : 1951 - 1982 (32 years)
- (4) Bang Na : 1966 - 1982 (17 years)
- (5) Bang Kapi : 1956 - 1971, 1973, 1975 - 1982 (25 years)
- (6) Minburi : 1956 - 1971, 1973 - 1982 (26 years)
- (7) Lat Krabang : 1956 - 1971 (16 years)

Source : Meteorological Department

4.1.3 Rainfall in Recent Heavy Floods

The recent heavy floods in Bangkok occured in 1964, 1975, 1978, 1980, 1982 and 1983. In this Study, four heavy floods in 1978, 1980, 1982 and 1983 are selected as typical floods and monthly, weekly and daily rainfall data presented in Table F.12, Fig. F.10 to Fig. F.14 were collected. 1983 flood, which is the recent heaviest flood, occured during this study so that the hydrological information has been collected as far as possible. Some data, for example, for November could not be collected, as those were under preparation by DDS.

For weekly and daily rainfall areal variation of precipitation is observed and heavy rainfall, which is of rather short duration, is clearly observed to occur usually in a narrow limited area. In the hydrological analysis for the short term rainfall, it is therefore, necessary to consider the areal characteristic of precipitation.

4.1.4 Duration and Time Distribution

The study of duration and time distribution for heavy rainfall was carried out by using 52 samples having values more than 60 mm/day and 15 samples above 90 mm/day based on the hourly data at Bangkok Station between 1965 and 1980.

As the result the rainfall duration having high frequency for heavy rainfall is within 9 hr. As for seasonal characteristics the rainfall from April to July has high frequency for the short duration rainfall and that of August to November has high frequency for the short duration and the long duration. Fig. 15 shows the time distribution and frequency of daily rainfall in Bangkok area.

Table F.12 Monthly Rainfall for Heavy Flooded Year in 1978, 1980, 1982 and 1983

Unit : mm/month

Station	Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Don Muang	Average	6.9	19.2	31.6	62.3	162.3	154.3	164.4	205.8	287.1	212.8	37.5	14.2	1359
	1978	6.1	103.3	0	18.0	237.7	79.7	294.7	96.1	289.9	117.6	3.1	0	1246
	1980	0	0	12.7	22.5	96.9	238.4	89.2	196.6	394.3	224.3	56.6	0	1332
	1982	0	0	27.5	157.6	153.7	198.7	95.6	93.9	156.4	172.1	30.7	1.4	1088
	1983	0	0	0	0	198.6	135.3	160.5	414.3	237.2	266.4			
Bangkhen	Average	8.7	10.5	22.3	85.6	186.5	164.4	188.6	190.4	280.2	157.1	50.3	17.3	1362
	1978	32.0	57.5	0	41.6	173.3	116.1	307.3	73.9	239.7	48.9	9.9	0	1102
	1980	0	0	25.4	42.2	117.5	336.7	158.5	157.8	325.0	176.2	68.4	0	1408
	1982	0	0.5	82.2	179.5	238.2	225.1	230.2	144.6	183.6	272.4	57.6	2.0	1616
	1983								515.7	430.5	350.7			
Bangkok	Average	9.7	29.7	28.3	71.3	194.1	158.8	171.1	197.2	334.0	223.3	47.5	9.0	1474
	1978	23.5	103.6	1.0	13.0	245.3	255.2	135.1	81.9	274.7	102.5	0.6	0	1236
	1980	0	0.3	4.0	52.5	29.9	267.5	205.5	200.6	352.3	324.5	33.9	0	1471
	1982	0	19.7	176.0	223.2	235.5	187.8	199.2	220.7	254.8	248.8	44.3	19.6	1830
	1983	0.3	0	29.0	0	47.7	161.4	230.2	574.5	453.8	484.2			
Bang Na	Average	10.8	30.0	19.3	70.3	195.4	135.5	134.3	160.0	275.5	174.9	65.2	12.2	1283
	1978	51.7	140.5	0	8.4	249.7	132.8	91.3	58.1	484.8	74.7	8.8	0	1301
	1980	0	0	3.8	61.1	22.9	242.5	66.3	275.6	259.4	326.2	22.1	0	1280
	1982	0	11.7	51.1	157.7	148.1	182.5	193.7	171.5	194.9	242.0	98.5	2.0	1453.7
	1983								556.7	293.4	325.7			
Bang Kapi	Average	13.1	26.2	18.6	75.5	163.5	150.0	161.8	191.4	295.1	193.6	32.5	12.7	1334
	1978	147.5	92.0	0	40.2	233.8	114.1	220.6	95.5	340.3	139.7	2.4	0	1426
	1980	0	0	0	38.5	117.2	342.5	124.3	202.9	300.6	273.8	20.8	0	1421
	1982	0	0	105.0	159.7	108.7	147.1	172.8	176.4	323.1	334.5	102.7	0	1730
	1983								510.6	335.2	out of order			
Minburi	Average	10.9	23.1	13.5	84.4	194.3	155.6	157.7	185.5	288.9	190.1	36.4	13.1	1354
	1978	15.9	129.4	0	96.2	239.7	76.6	170.0	110.9	376.2	121.4	25.4	0	1363
	1980	0	0	20.9	85.7	133.9	165.8	202.7	143.0	315.2	335.5	13.8	0	1417
	1982	0	0	34.6	136.7	188.3	194.6	178.2	206.4	312.2	162.8	29.6	0	1443
	1983								304.8	320.1	205.7			
Average Area & Raingall	Avarage	9.7	23.2	20.9	75.0	184.0	153.3	163.4	192.4	293.5	192.2	43.8	13.3	1365
	1978	60.0	103.8	0	43.8	229.1	110.1	212.6	90.0	321.4	119.2	9.5	0	1319
	1980	0	0	11.2	50.8	100.9	269.5	137.5	191.5	318.9	274.3	32.9	0	1388
	1982	0	2.6	70.1	189.0	164.4	184.2	175.0	166.7	252.9	246.6	65.1	1.7	1517
	1983								460.4	331.5				

4.2 Probability

The calculation of probability for daily, 3-day, monthly, 3-month and yearly spot and average areal rainfall in the Study Area was carried out to get the design rain storm in the polder and Klong drainage system.

Based on the annual maximum rainfall, the probability obtained was plotted on the lognormal probability paper. The plots are presented in Fig. F.16 and F.17 by least squares method with Thomas plotting.

It is found that the average areal rainfall frequency in the Study Area is approximately 30% less than that of spot rainfall. This means that the precipitation area usually is not so extensive.

4.3 Rainfall Intensity-Duration Curve

Based on the rainfall in short term duration at Bangkok Station between 1937 and 1982, the probable rainfall of 5, 10, 15 and 30 minutes and 1,2,6,12 and 24 hours duration were estimated by means of least squares method with Thomas plotting. The probable rainfall depth for various return period are summarised in Table F.13.

Table F. 13 Rainfall depth in mm and intensities in mm/hr for various storm durations and return periods

Return period in Years	Stormduration								
	5 min	10 min	15 min	30 min	1 hr	2 hrs	6 hrs	12 hrs	24 hrs
2	11.3 (135.5)	20.2 (121.1)	25.0 (99.8)	42.5 (84.9)	58.7 (58.7)	72.4 (36.2)	85.8 (14.3)	90.0 (7.5)	93.6 (3.9)
5	14.1 (168.9)	25.3 (152.0)	31.7 (126.7)	54.3 (108.6)	76.0 (76.0)	95.0 (47.5)	114.0 (19.0)	120.0 (10.0)	122.4 (5.1)
7	14.9 (178.3)	26.9 (161.4)	33.7 (134.9)	58.0 (115.9)	81.5 (81.5)	102.2 (51.1)	123.0 (20.5)	129.6 (10.8)	134.4 (5.6)
10	15.7 (188.3)	28.4 (170.2)	35.7 (142.7)	61.5 (122.9)	86.8 (86.8)	109.2 (54.6)	132.0 (22.0)	139.2 (11.6)	144.0 (6.0)
20	17.1 (204.9)	31.0 (185.9)	39.2 (156.9)	67.9 (135.7)	96.5 (96.5)	122.4 (61.2)	149.4 (24.9)	157.2 (13.1)	163.2 (6.8)

(--) average rainfall intensities in mm/hr

The rainfall intensity-duration formula was adopted by the Talbat Type.

$$I = \frac{a}{t+b}$$

Where I = rainfall intencity (mm/hr)

t = duration (min)

a,b = constant based on the areal characteristics

The constants, a and b, in the rainfall intensity-duration formulas for various return period were estimated by means of least squares method. The result is indicated in Table F.14.

Table F.14 Constant (a and b) Value in various return period.

Constant	Return Period in Years				
	2	5	7	10	20
a	5,690	7,600	8,230	8,850	10,040
b	37	40	41	42	44

The rainfall intensity-duration curves for various return period are shown in Fig F.18.

5 Water Level

5.1 River Stage

5.1.1 Tidal Range and the discharge from the Study Area

The Study Area is located in the tidal zone in the Chao Phraya River and the discharge from the Study Area is governed by the river stage which is affected by the tide in the Gulf of Thailand. According to the tidal information presented in Table F-15 obtained from P.A.T, mean tidal range at Bangkok Port, located at the mouth of Klong Phra Khanong is as follows;

$$M.T.R = M.H.W - M.L.W$$
$$= 0.89 - (-0.71) = 1.60 \text{ m}$$

where, M.T.R = mean tidal range in meter
M.H.W = mean high water level in meter above MSL
M.L.W = mean low water level in meter above MSL

Judging from the relationship with M.H.W, M.L.W. and the existing average ground elevation in the Study Area, of 0.5 m and 0.7 m in the protection and retention area respectively, it is impossible to control floods by natural discharge without pumping discharge. Especially in future the effect of the pumping discharge will be higher than the natural discharge, due to land subsidence.

5.1.2 Annual H.H.W.L, M.W.L and L.L.W.L

Annual H.H.W.L, M.W.L and L.L.W.L at five gauging stations belong to P.A.T, Hydrographic Dept. and RID, were studied based on the water level data during the period 1940 to 1982. As a result of the study, the followings have been pointed out.

Table F.15 TIDAL INFORMATION

Unit : Meter above Mean Sea Level

STATION / TIDES	BANGKOK BAR	FORT PHRACHUL	PAKNAM	PHRA PRADAENG	BANGKOK HARBOUR	MEMORIAL BRIDGE	HYDROGRA FIC. DEPT.	RID OFF.	RAMA VI BRIDGE	PAKKRET	BANGSAI
HIGHEST HIGH WATER	+2.28 (1970.12)	+2.22 (1970.12)	+2.04 (1970.12)	+1.93 (1970.12) (1978.10)	+1.93 (1978.10)	+2.27 (1942.10)	+2.42 (1942.10)				+3.99 (1942.10)
MEAN HIGH WATER SPRING	+1.41	+1.39	+1.35	+1.31	+1.28						
MEAN HIGH WATER NEAP	+0.95	+0.94	+0.97	+0.95	+0.95						
MEAN HIGH WATER	+0.94	+0.95	+0.91	+0.94	+0.89						
MEAN TIDE LEVEL	+0.09	+0.13	+0.11	+0.17	+0.23						
MEAN SEA LEVEL (KOLAK STANDARD)	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00				±0.00
MEAN LOW WATER	-0.78	-0.63	-0.65	-0.54	-0.48						
MEAN LOW WATER NEAP	-0.88	-0.83	-0.75	-0.72	-0.71						
MEAN LOW WATER SPRING	-1.48	-1.29	-1.22	-1.15	-1.04						
LOWEST LOW WATER	-2.42 (1956.7)	-1.79 (1956.7)	-1.90 (1968.7)	-1.78 (1967.5)	-1.72 (1968.7)	-1.75 (1964.8)	-1.74 (1964.8)				-1.38 (1963.7)
MEAN SPRING RANGE	2.90	2.67	2.57	2.45	2.34						
MEAN NEAP RANGE	1.83	1.76	1.71	1.66	1.66						
MEAN RANGE	2.44	2.24	2.18	2.04	1.99						

(a) Annual Mean Water Levels (MWLs) at PAT's station did not differ from each other before 1968. However, they have been increasing every year at almost the same rate. Annual MWL of 1983 is 0.30 to 0.40 meter higher than of before 1968.

(b) It is considered that this increase has been caused by land subsidence at the stations. According to the checking survey by the Study Team, the recorded mean sea level at Bangkok Port is 0.39 m higher than corrected level on August in 1983.

(c) Therefore, P.A.T's water level data must be adjusted between 1968 and 1983. In this Study, the linear trend was assumed and the data was corrected.

(d) In case of Hydrographic Dept. and RID data, this data was adopted without the adjustment, because of no checking survey.

Annual H.H.W.L, M.W.L, L.L.W.L at five stations between 1940 and 1982 and effect of land subsidence on water level of Chao Phraya River during 1968 to 1982 are shown in Fig. F.19 and Fig. F.20.

5.1.3 Seasonal Variation at Water Level in the Chao Phraya River

Every year, the water level in the Chao Phraya River beings to rise gradually near the end of August, reaching a peak in November and after that, falling slowly until the end of December. This phenomenon is mainly caused by the run-off from the upstream reaches of the Chao Phraya River and the tide in the Gulf of Thailand.

Fig. F.21 and Fig. F.22 present the seasonal variation of the water level at Bangkok Port in the typical flood year, 1978, 1980, 1982 and 1983.

In this season, the discharge from the Study Area to the Chao Phraya River are usually carried out by the assistance of the operation of gates and pumps as shown in Fig. F.23 and Fig. F.24.

5.1.4 Estimation of Probable Water Level

Based on the annual maximum H.H.W.L, M.W.L and L.L.W.L at five stations, for which the data at Bangkok Port only was adjusted, the probable water level of the Chao Phraya River was estimated using the Thomas plotting method shown in Fig. F. 25.

According to the calculation,it has been proven that the flood water level between the mouth of the Chao Phraya River and the Rama IV Bridge (mouth of the Klong Bang Khen, 58 km upstream from the river mouth) does not very much in less than a 10 year return period due to the influence of the tide in the Gulf of Thailand as shown in Fig. F.26.

5.2 Klong Water Level

5.2.1 Investigation on DDS and RID data

As mentioned in Section 2 : Data collection, water level data in the klongs could only be obtained since 1981 except at the Klong Phrakanong and the Klong Sam Rong Flood Gate which belong to the RID. Therefore, the study of the kind carried out at the river stage are impossible. Furthermore, as every gauging station is influenced by land subsidence, suitable adjustments are necessary to correct the MSL. According to the checking survey by the Study Team, water levels at the Klong Phrakanong F.G, the Klong Sam Rong F.G and the Klong Ton P.S were necessary to adjust -0.930 m, -0.650 m and -0.580 m respectively.

5.2.2 Observed Water Level in 1983

As described before, twelve new recording water level gauges have been installed at the hydrologically important points in the main klongs and suitable data have been obtained from the beginning of August in 1983. Fig. F.27 to Fig. F.40 indicate the variation of water level for main klongs. These data were used to verify the hydraulic calculation model in combination with rainfall presented in chapter 12 in main Report and to grasp the discharge situation of main klongs mentioned in chapter 4.