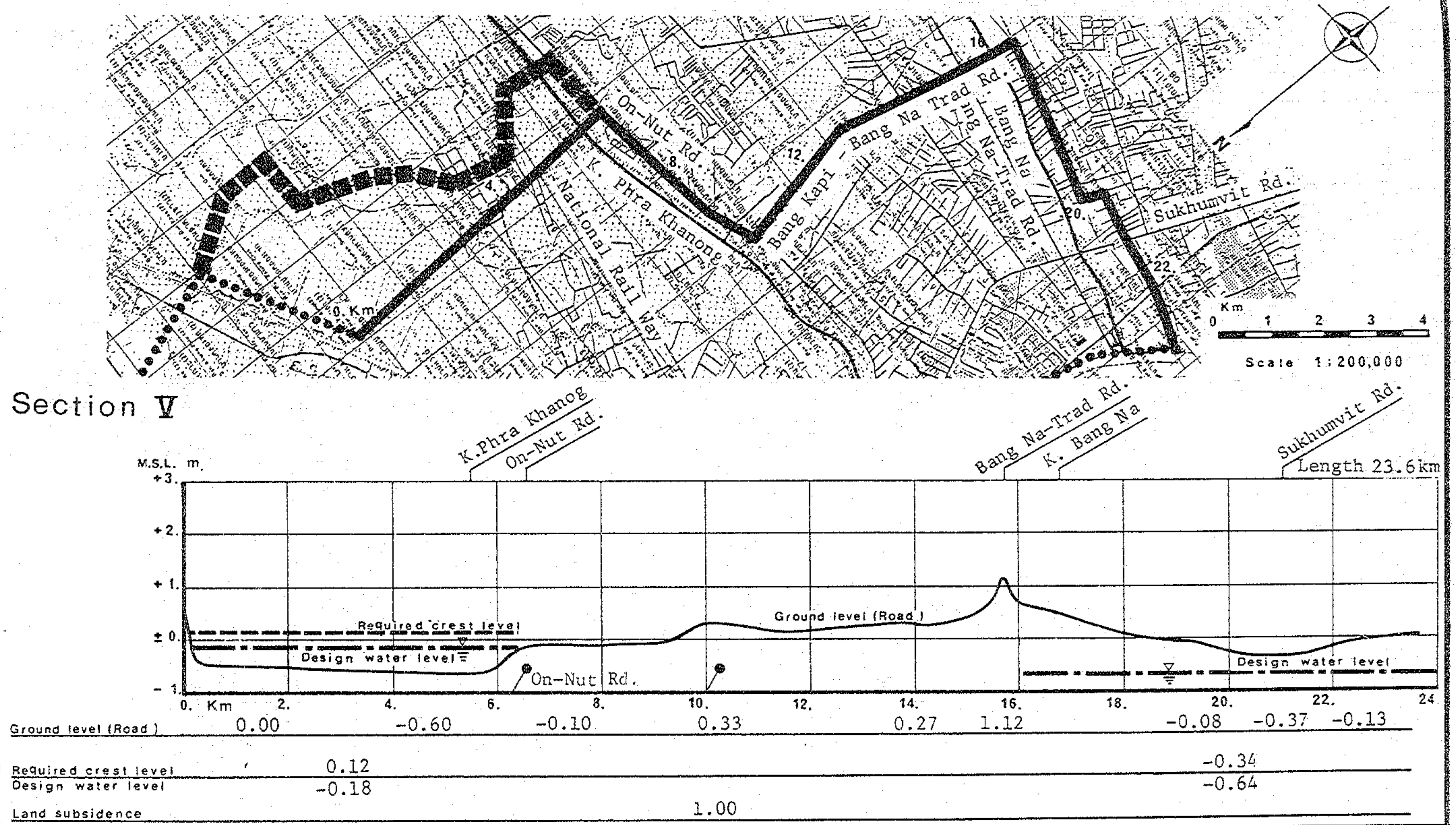
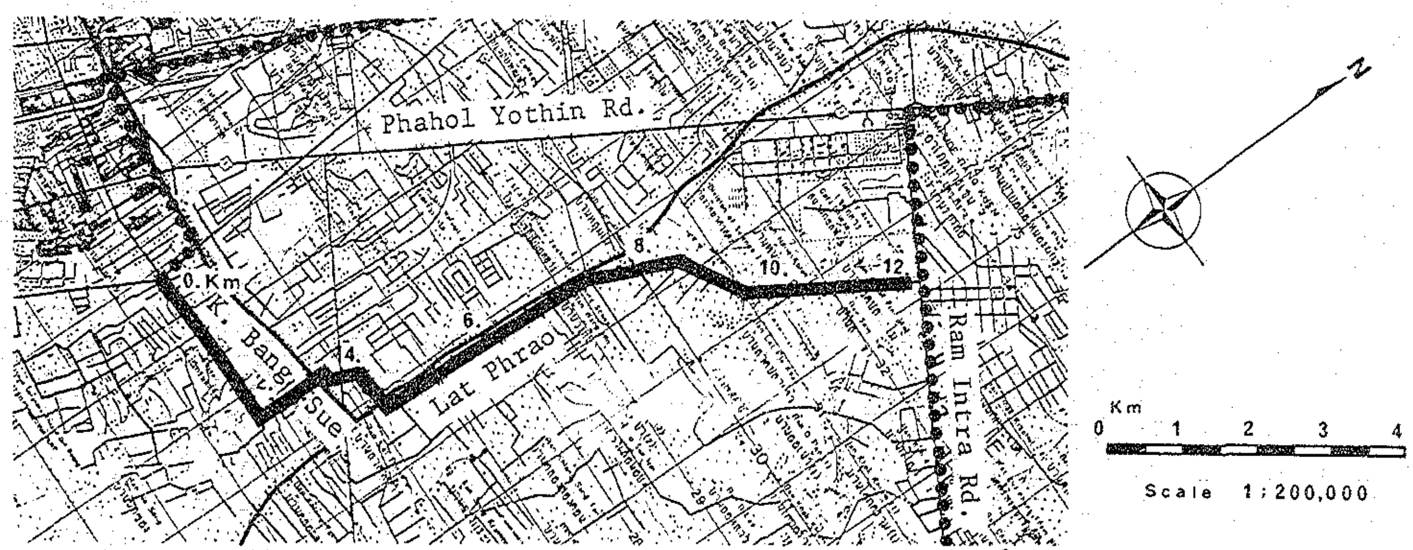
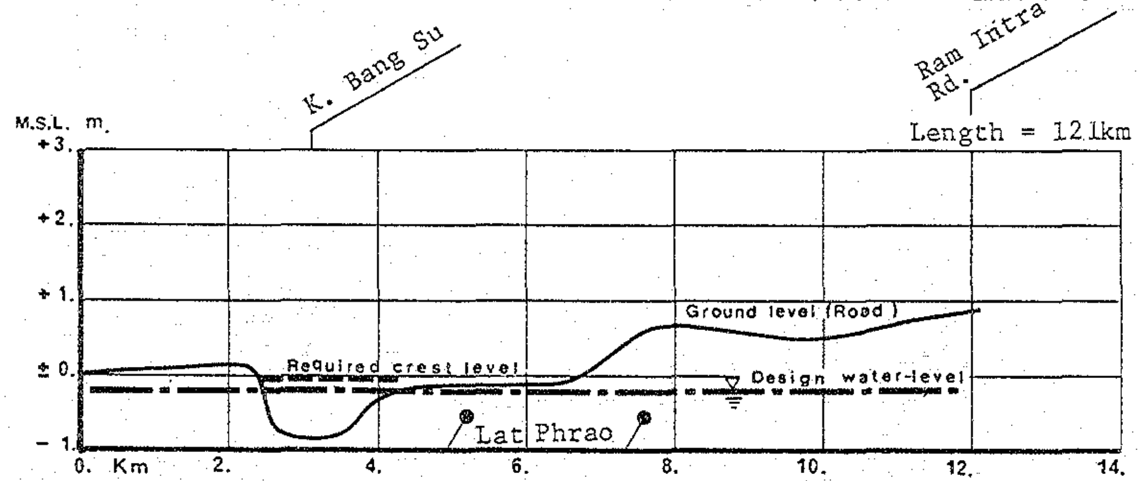


Note: The barrier alignment (▮▮▮), utilizing the existing road is adopted for part of section V, instead of the originallystudied alignment (▪▪▪ / ●●●) running on the future extension of the Outer Ring Road.

Fig. G.7 ALIGNMENT AND PROFILE OF FLOOD PROTECTION BARRIER-5 (PATERNA KARN AND BANG NA DRAINAGE AREA)

MASTER PLAN ON FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK



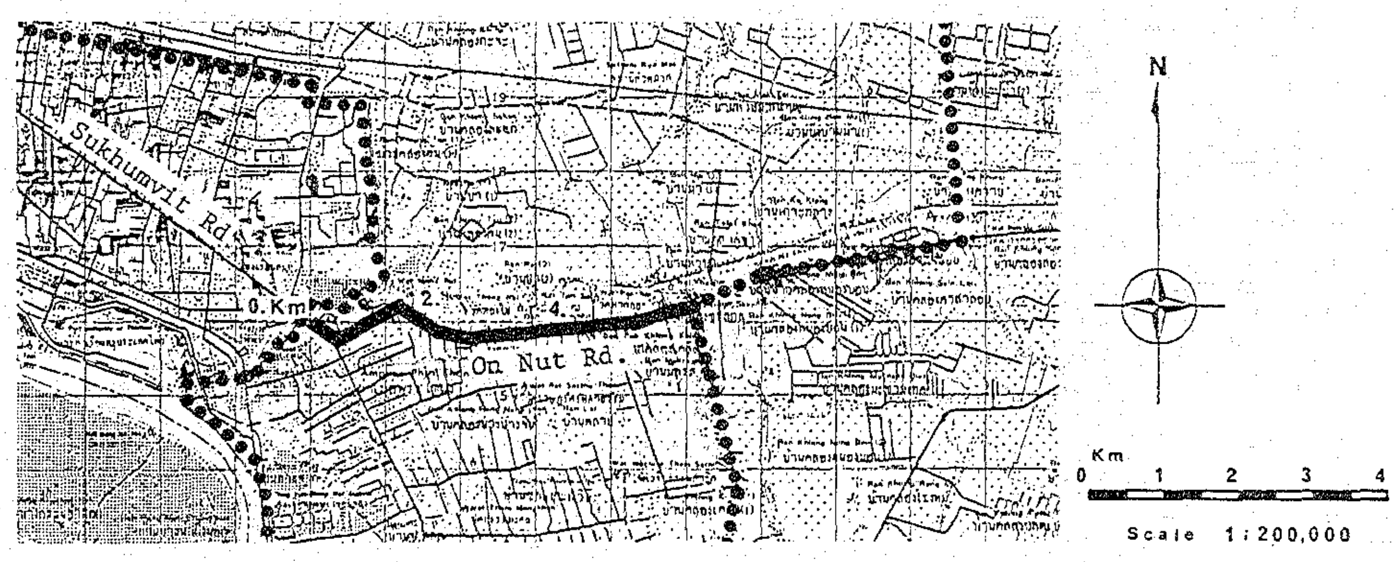


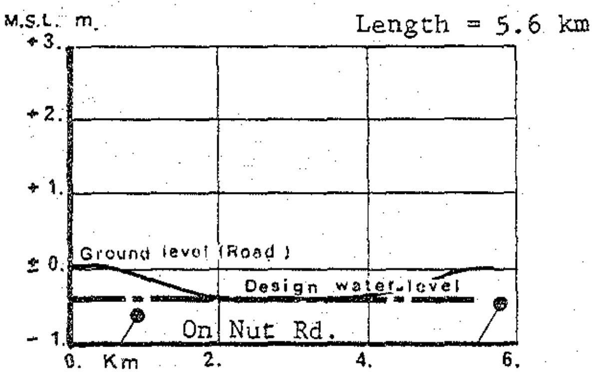
Ground level (Road)	0.02	0.20	-0.86	-0.19	-0.10	0.66	0.57	0.95
Required crest level		-0.05						
Design water level				-0.15				
Land subsidence				1.0				

Section VI

Fig. G.8 ALIGNMENT AND PROFILE OF FLOOD PROTECTION BARRIER-6 (BANG SUE DRAINAGE AREA)

MASTER PLAN ON FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK





Ground level (Road)	-0.04	-0.40	-0.35	+0.03
Required crest level		-0.30		
Design water level		-0.40		
Land subsidence		1.00		

Section VII

Fig. G.9 ALIGNMENT AND PROFILE OF FLOOD PROTECTION BARRIER-7 (BANG NA DRAINAGE AREA)

MASTER PLAN ON FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK

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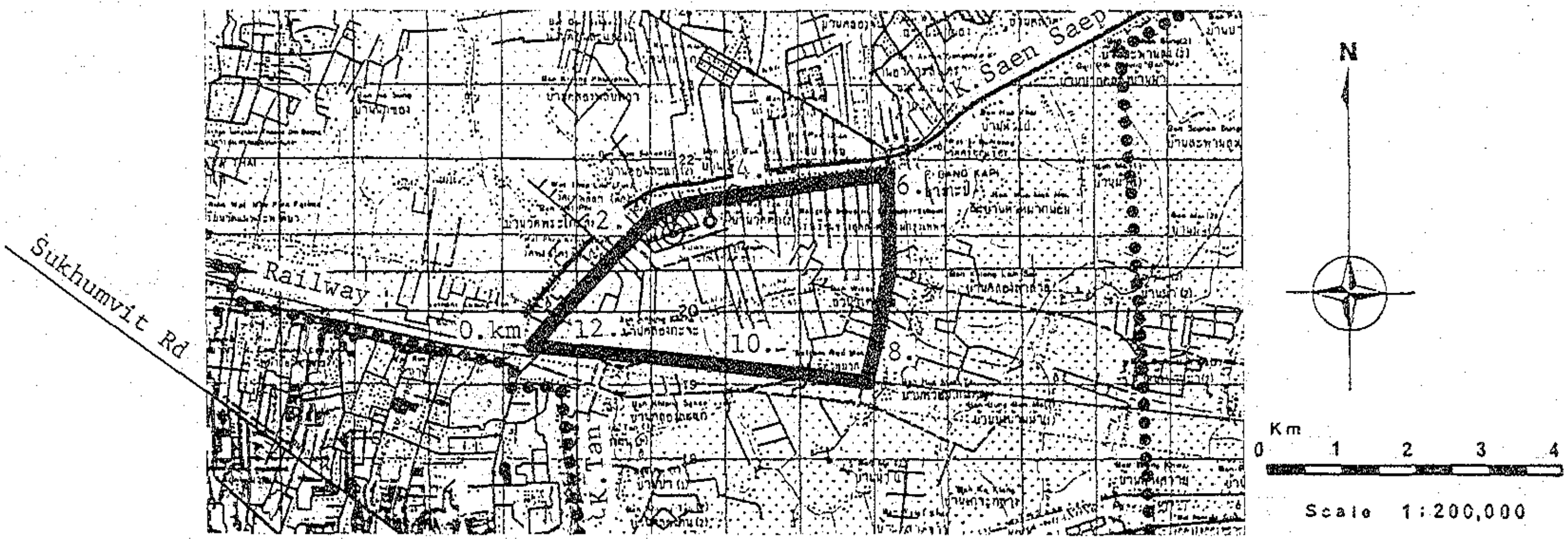

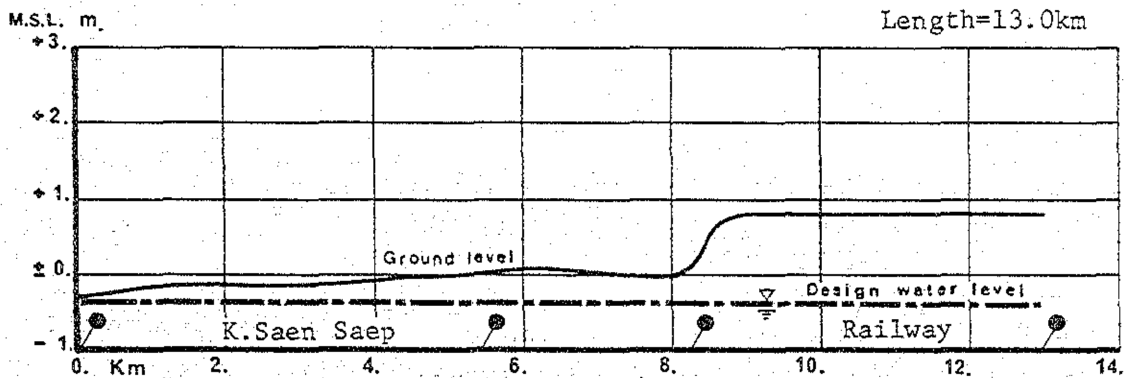

Ground level (Road)	-0.30 -0.16	-0.11	+0.04	-0.05 +0.80		+0.80
Required crest level			-0.30			
Design water level			-0.40			
Land subsidence			1.0			

Section VIII

Fig. G.10 ALIGNMENT AND PROFILE OF FLOOD PROTECTION BARRIER-8 (INNER POLDER AT RAMKHAMHAENG UNIVERSITY)

MASTER PLAN ON FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK

APPENDIX H

HYDROLOGICAL AND HYDRAULIC ANALYSIS FOR DRAINAGE FACILITIES

Appendix H. HYDROLOGICAL AND HYDRAULIC ANALYSIS FOR DRAINAGE FACILITIES

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1. General Concept of Drainage Facilities in the Polder

The drainage facilities in the polder consist of run-off control measures, drainage canal (klong network) measures and pumping discharge measures.

1.1 Run-off Control Measures

1.1.1 Effect of Run-off Control

Run-off control means mainly to reduce peak discharge of klong by utilizing the storage function in the catchment area.
In the master planning two kinds of run-off control measures i.e. establishment of rainwater retention area and the use of storage of klongs are considered. The retention area are sellected according to the concept of flood plain management (Non-Structural Measures).

(1) The location should be low flat swampy area or open space according to the future land use plan.

(2) Existing klongs are preferable to be connected to retention area.

The retention area are suggested to be used by following land use

1) Agriculture
2) Fish pond
3) Land for recreations and sports (during dry season)
4) Land for sewerage treatment plant or public use

The effect of storage capacity of klongs and retention area are recognized as follows from the result of sample water balance calculation in the Bang Khen-Bang Sue polder as shown in Fig. H.1.

1) When the maintenance water level in klongs is set up as low level, effective storage capacity increase and pump capacity can be reduced clearly.

For instance, effective storage capacity of 32 mm requires pump capacity of 30 CMS and effective storage capacity of 18 mm requires 70 CMS.

2) However, the large storage capacity needs long pump operation time to recover the maintenance water level after heavy rainfall.
For instance, case A shows more than 24 hours and case B shows 20 hours of pump operation time.

Therefore, the planning of run-off control measures should be studied based on required storage capacity which is influenced by allowable high water level, maintenance water level, pump capacity and pump operation time.

Table H.1 shows the total storage capacities of proposed klong network and retention area in the master planning.

The effective storage capacity of klong is the storage volume between allowable high water level and maintenance water level.

Table H.1 Estimated Total Storage Capacity in 2000

Polder	Klong: Lengths of Klongs(L)	Klong: Klong Pensity L/A	Retention Area: Area (km^2)	Total Storage Capacity (V max) unit: 10^6 m^3: Za(max)	Klongs	Reten-tion Area	Total
Bang Khen-Bang sue A = 93 km^2	39 km	0.41 km/km^2	2.5km^2	+0.4	2.79 (32 mm)	3.60 (7 mm)	6.39 (39 mm)
Phrakhanong A = 165 km^2	124 km	0.75 km/	39.8 km^2	-0.5	5.30 (32 mm)	5.95 (36 mm)	11.25 (68 mm)
Bang Na A = 31 km^2	31 km	1.8 km/	1.7km^2	-0.4	0.97 (32 mm)	0.18 (6 mm)	1.15 (37 mm)
Total	194 km	0.67 km/km^2	44.0km^2		9.06 (31 mm)	9.73 (34 mm)	18.79 (65 mm)

Note: Za(max) is allowable average highest water leverl V max is estimated volume below Za(max.)

1.1.2 Maintenance Water Level

The maintenance water level is very important for the determination of klong and pump capacity.
The maintenance water level in klongs should be maintained during rainy season for utilizing storage capacity. The following conditions are considered for the determination of maintenance water level.

(1) Rainwater storage for mitigation of peak discharge
(2) Recovering maintenance water level for 2nd incumbent rainfall
(3) Stability of revetment of klongs
(4) Use for navigation
(5) Daily use of resident (washing, suction of water supply for sprinking etc.)

Detailed explanation on the Pha Khanong Polder is given in Subsection 6.2. Referring to the Phra Khanong Polder, maintenance water levels in Bang Khen, Bang Sue and Bang Na Polder are decided as follow.

Bang Khen, Bang Sue Polder	:	-1.5 m MSL
Phra Khanong Polder	:	-1.8 m MSL
Bang Na Polder	:	-1.8 m MSL

As described in Subsection 6.2, a hydraulic effect of storage capacity of klong is very large. Recovering time for maintenance water level for 2nd incumbent rainfall is calculated for a preparation against 2nd rainfall although an occurance of continuous heavy rainfall is very seldom. According to the result of calculation, in all polders, the maintenance water level is found to be recovered within about 24 hours from starting of first rainfall.

A least depth for navigation is assume as one metres below maintenance water level.

For the determination of bank height and maintenance water level, stability analysis is carried out by circular slip method. The result is shown in Fig. H.2.

1.1.3 Klong Networks

1) Functions

The klong networks has three functions as follows:

(1) Conveying the stormwater
(2) Connection with subdrainage area and retention area
(3) Rainwater storage

2) Cross Section of Klong Shape

The cross section of klong were determined based on followings:

(1) Planned klong width shall be not exceeded from existing width between bank.

(2) Flow capacity of klongs, especially near the pumping station was studied to avoide excessive velocity considering allowable velocity for scoring.

Fig. H.40 shows the proposed klong network in the Master Plan Area.

2. Procedure of Hydrological-Hydraulic Analysis

2.1 Procedure of Hydrological-Hydraulic Analysis

Procedures for the hydrological-hydraulic analysis are shown in Fig. H.3.

2.1.1 Step I. Analysis

The step I provides an approximate flooding status for several different capacities of trunk drainage facilities. The analysis is made by the storage basin model. The study area is divided into 9 basins.

2.1.2 Step II Analysis

The step II analysis aims to identify the poor drainage areas in the Master Plan Area. In this analysis, the capacities of trunk drainage facilities analyzed in step I is adopted and the study area is divided into 19 basins to identify the flooding status in small areas.

2.1.3 Step III Analysis

The of drainage facilities such as klongs, and pumps in each drainage area were studied and determined based on peak flow discharge obtained by the unsteady flow formula.

2.1.4 Step IV Analysis

In the step IV analysis, the capacities of trunk drainage facilities (Phra Khanong Pumping Station, Klong Phra Khanong, Saen Saep and Tan) were obtained by the unsteady flow model of the Klong. And finally, the total drainage facilities including the drainage facility in each drainage area obtained at step III were checked and confirmed for whole area of Phra Khanong Plder.

2.2 Hydrological-Hydraulic Models

2.2.1 Storage Basin Model (Bi-Dimensional Model)

The phenomenon of flooding is treated macroscopically using a storage basin model in which whole drainage area is divided into several basins. Each basin is enclosed by roads, railway or other special topographical conditions. Each basin is connected by klongs, cofferdam, gate and pumps in bi-dimensional expression.

1) Basic Equations

The basic equations are introduced from unsteady flow formula, and consists of Momentum and Continuity equations as follows.

$$\frac{dQx}{dt} + \frac{d}{dx}\left(\frac{Qx^2}{Ax}\right) + gAx\frac{dZ}{dx} + g\frac{n^2|Qx|Qx}{Ax(Rx)^{4/3}} = 0 \quad \text{------ (1)}$$

$$\frac{dQy}{dt} + \frac{d}{dy}\left(\frac{Qy^2}{Ay}\right) + gAy\frac{dZ}{dy} + g\frac{n^2|Qy|Qy}{Ay(Ry)^{4/3}} = 0 \quad \text{------ (2)}$$

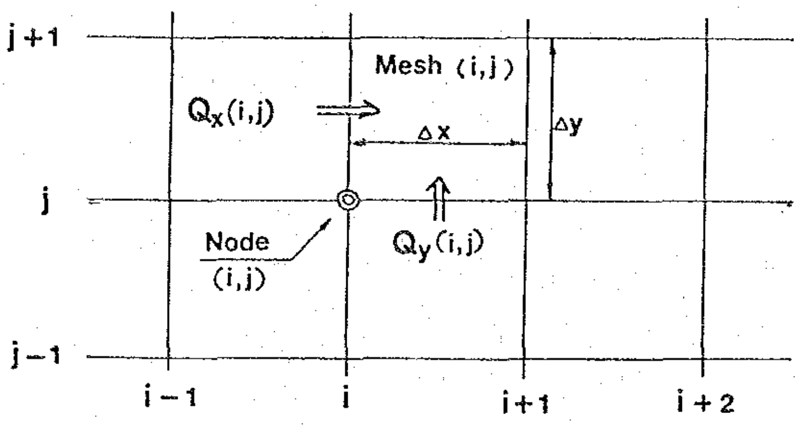
$$\frac{dZ}{dt} + \frac{dQx}{dx} + \frac{dQy}{dy} = R - E \quad \text{------------------ (3)}$$

where;

t	:	Time
X,Y	:	Direction of coordination
Qx,Qy	:	Flow of X and Y Direction
Ax,Ay	:	Sectional flow area of X and Y Direction
Z	:	Water level
g	:	Gravity acceleration
Rx,Ry	:	Hydraulic radius of X and Y Direction
R	:	Rainfall
E	:	Evapotranspiration

2) Mesh Components for Bi-Dimensional Model

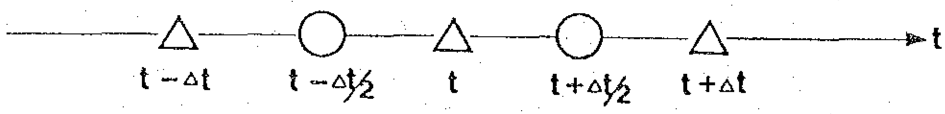
For the analysis, the study area is divided by meshes from consideration of topography, land-use pattern, road and railway network, klong network, and past flooded area. Each mesh can be identified by a mesh node number (i,j) and this node has the value of water level(Z), water depth(D), storage volume (Vol), and water surface area (S). The section of X, and Y have the value of discharge (Qx, Qy), velocity (Ux, Uy), section flow area (Ax, Ay) and coefficient of roughness.



3) Solution of Basic Equation

For the solution of the basic equation, the explicit difference scheme method was applied.

The concept of this scheme is shown in following figure.



where;

△ : Calculation point of flow

○ : Calculation point of water level

Δt : Calculation time interval

4) Based on the difference scheme mentioned above, the momentum equation (1) can be changed to following equation (4).

$$Q_{x\,ij}^{t+\Delta t/2} = Q_{x\,ij}^{t-\Delta t/2} - \Delta t \frac{d}{dx}\left(\frac{Q_x^2}{A_{x\,ij}}\right) - \Delta t g A_{x\,ij} \frac{2(Z_{ij} - Z_{i-1\,j})}{\Delta X_{ij} + \Delta X_{i-1\,j}}$$

$$- \Delta t g n^2 \frac{|U_{x\,ij}^{t-\Delta t/2}|\,Q_{x\,ij}^{t-\Delta t/2}}{(H_{x\,ij}^{t-\Delta t/2})^{4/3}} \quad \text{------------------} \quad (4)$$

where;

$$U_{x\,ij} = \frac{Q_{x\,ij}}{A_{x\,ij}}$$

$$H_{x\,ij} \doteqdot R_{x\,ij}$$

Similarly, the continuity equation (3) can be changed to following equation (5).

$$Z_{ij}^{t+\Delta t} = Z_{ij}^{t} + \frac{\Delta t}{B_{ij}^{t}}\left(Q_{x\,i+1,j} - Q_{x\,i,j} + Q_{y\,i,j+1} - Q_{y\,i,j} + R - E\right) \quad \text{----} \quad (5)$$

In the equation (5), Bij is the water surface area which is calculated from input data of the relationship of water level (Z) and surface area (B).

4) Numerical Stability

On the solution of the basic equation by explicit difference method the numerical stability shall be kept under the following condition.

$$\Delta t < \frac{\Delta S}{\sqrt{2gh} + U_{max}}$$

where;

Δt	:	Calculation time interval
Δs	:	Length of ΔX or ΔY
g	:	gravity acceleration
h	:	Water depth
Umax	:	Maximum Velocity

2.2.2 Simulation Model of Drainage Area

The simulation model consisting of a run-off model at subdrainage area, klong flow model and trunk klong model as shown in Fig. H.10.

1) Run-off Model

Fig. H.11 shows the run-off model using a rational method for design hyetograph at sub-drainage area, which is applied to the step III analysis.

2) Subklong Flow Model (Unsteady Flow Model)

Basic equations of the klong flow model consist of momentum and continuity equation, the same as the storage basin model. However the momentum equation is applied to uni-dimensional flow direction.

3) Trunk Klong Model

The trunk klongs, klong Phra Khanong, Tan and Saen Saep are analyzed by unsteady flow formula using the storage capacities of the klongs.

3. Hydrological Design Criteria and Drainage Criteria

3.1 Hydrological Design Criteria

The hydraulic design criteria and the drainage criteria are shown in Table H.2 and H.3 with comparison of CDM's and BFCD's criteria.

3.1.1 Design Rainfall

The design of the drainage facilities has been made on the basis of an appropriate scale of rainfall occurrence with due consideration for a reasonable investment for implementation. Hence, the design rainfall is considered in comparison for other relevant project such as CDM's and BFCD's reports as shown in Table H.2.

1) Design Rainfall

The adopted design rainfall:

Inside drainage area .... 2 years frequency $I_2 = \frac{5690}{t+37}$

Main Klong (K. Saen Saep / K. Phra Khanong)... 5 years frequency $I_5 = \frac{7600}{t+40}$

where I: Rainfall intensity (mm/hr)
t: Time of concentratioin (minute)

2) *Duration and Pattern of Design Rainfall*

According to the result of step I and step II analysis, the flood duration period will be reduced within one day by an improved capacity of the drainage facilities. Hence, a daily design rainfall can be adopted. Fig. I-11 shows the observed rainfall distribution patterns at Bangkok Metorological Observatory, and according to this figure, the duration and pattern of design rainfall were adopted as follows.

Duration .... 6 hours
Pattern .... Front concentration type

3) Areal Reducation Factor

Areal reduction factor is used to transfer point rainfall to areal average rainfall.
Design areal reduction factor is shown in Fig. H.12.

4) Run-off Coefficient and Run-off Ratio

Run-off coefficient (fp) means as follows.

$$f_p = \frac{3.6\ Qp}{I_p \cdot A}$$

QP: Peak discharge (m^3/sec)

I_p: Average rainfall intensity during time of concentration (mm/hr)

A : Catchment area (Km^2)

The same design run-off coeficient as BFCD's value was adopted as shown in Fig. H.14.

$$f_T = \frac{QT}{R_T}$$

Q_T: Total discharge in height (mm)

R_T: Total rainfall in height (mm)

In Eastern Suburban-Bangkok, rainfall will occur frequnetly, therefore, the storaged rainwater for a continuous rainfall should be discharged.

5) Time of Concentration (T_c)

T_c means as follows.

$$T_c = T_i + \frac{L}{V}$$

T_i: Time of inflow from ground surface to condit or small klongs (minute)

L : Length of subklong or main klong (m)

V : Average velocity in subklong or mainklong (m/s)

(T_i) is 10 minutes, the same as the CDM and BFCD reports.
(V) is 0.35 m/sec based on the result of the step II analysis and the flow measurement in the klongs in 1983.

3.1.2 Water Level of the Chao Phraya River

1) Scale
100-year frequency water level same as the city core project.

2) Pattern
a. For Phra Khanong and Bang Na polder: recorded pattern of 1980 at Bangkok Port
b. For Bang Khen, Bang Sue Polder: Hydrographic Dept. of RID.

3.1.3 Evapotranspiration

The following evapotranspiration figures are used for the step I, II and III and step IV analysis evapotranspiration is ignored.

July	106 mm/month
August	106
September	98
October	102
November	76
December	52

Table H.2 Hydrological Design Criteria

Item	Reference Report	CDM Report	BFCD Report	JICA Master Plan Report			
				Step I Analysis	Step II Analysis	Strp III Analysis	Step IV Analysis
Design Rainfall	Scale	1/N = 1/5	1/N = 1/2	1/N = 1/5	1/N = 1/5	1/N = 2	1/N = 1/5 & 1/2
	Duration	12 hours	3 hours	3 Month (Aug.- Oct.)	3 days (Sept.28-30)	6 hours	6 hours
	Pattern	Front Concentration Type	Front Concentration Type	24 hours average	6 hours average	Front Concentration Type	Front Concentration Type
	Point Rainfall Scale	67 mm/hr	61.5 mm/hr (95 mm/day)	872.4mm/3month	150.4mm/3days	58.7 mm/hr (91.0 mm/day)	76.0 mm/hr (1/5) (120.2 mm/day)(1
	Area Reduction Factor	A.R.F.=0.55-1.00	A.R.F. = 0.75-0.95	Above Values are areal average rainfall		A.R.F = 0.83-1.00	A.R.F. = 0.68-0.
Run-off Model for Sub Water Shed	Model	Rational Formula	Rational Formula	-	-	Rational Formula	Rational Formula + Linear Reservoir Model
	Run-off Coefficient	C = 0.55-0.60	C = 0.15-0.75	-	-	C = 0.15 - 0.75	C = 0.15 - 0.75
	Time of Concentration (minute)	$Tc=10+\frac{L}{(0.6-0.9)\times 60}$ L=Klong Length (m)	$Tc=10+\frac{L}{0.75 \times 60}$	-	-	$Tc = 10 + \frac{L}{0.35 \times 60}$	$Tc = 10 + \frac{L}{0.35\times 60}$
	Run-off Simulation	3.5 hrs	3.0 hrs	-	-	24 hrs	34 hrs
	Topography	A.D. 1990	A.D. 1994	A.D. 2000	A.D. 2000	A.D. 2000	A.D. 2000
	Land Use	A.D. 1990	A.D. 1994	A.D. 2000	A.D. 2000	A.D. 2000	A.D. 2000
Water Levels in Chao Phraya R. and Main Klong	Scale	1/N = 1/100	1/N = 1/100	1/N = 1/100	1/N = 1/100	1/N = 1/100	1/N = 1/100
	Pattern	Const. Water Level	Const. Water Level	Observed in 1980(Aug-Oct)	Observed in 1980(Oct28-30)	-	Observed in 1980 (Oct 28 - 30)
	Scale	-	1/N=1/10 (Out side of polder)	-	-	1/N = 1/5	1/N = 5
	Pattern	-	Const. Water Level	-	-	Based on the result of step II Analysis	-

Table H.3 Drainage Criteria

	Reference Report	CDM Report	BFCD Report	JICA Master Plan Report			
				Step I Analysis	Step II Analysis	Step III Analysis	Step IV Analysis
Flow Condition of Klong	Sub Klong Model	Unsteady Flow Model	Unsteady Flow Model	-	-	Unsteady Flow Model	Unsteady Flow Model
	Main Klong Model	-	-	Unsteady Flow Model	Unsteady Flow Model	"	"
	Coefficient of roughness	n=0.03-0.035	n=0.3-0.035	n_1 = 0.035 n_2 = 0.15 - 0.05	n_1 = 0.035 n_2 = 0.15 - 0.05	n = 0.02 - 0.035	n = 0.02 - 0.035
	Maximum Velocity	Vmax≦0.6m/sec	Vmax≦1.0m/sec	Vmax ≦ 1.0 m/sec	Vmax ≦ 1.0 m/sec	Vmax ≦ 1.0 m/sec	Vmax ≦ 1.0 m/sec
	Minimum Velocity	Vmin=0.75m/sec	Vmin=0.75-0.95 m/sec	-	-	-	-
	Minimum Water Depth	-	Dmin≦0.75-1.0 m/sec	-	-	Dmin ≦ 0.75 - 1.0 m	Dmin ≦ 0.75- 1.0 m
	Range of HWL-LWL	Ds = 1.5 m	Ds = 1.5 m	-	-	Ds = 1.5 m	Ds = 1.5 m
Inundation Condition	Allowable Depth	Dha ≦ 0	Dha ≦ 0	-	-	Dha ≦ 0 (In Principle)	Dha ≦ 0 (In Principle)
	Allowable Duration Time	Dta ≦ 0	Dta ≦ 0	-	-	Dta ≦ 0 (In Principle)	Dta ≦ 0 (In Principle)
Maximum Drainage period		-	-	-	-	Within 24 hrs	Within 24 hrs

4. Evaluation of Urgent Flood Protection/Drainage Measures

4.1 General

In order to evaluate the hydraulic effect of the Urgent Flood Protection Measures executed in coping with the 1983 flood, hydraulic analysis was carried out by means of bi-dimensional basin model. The calculated areas covers the Preliminary Study Area of 501 km^2 plus parts of the rainfall catchment area of Klong Sam Rong of 104 km^2 by considering the existing topographical conditions. The total area of 605 km^2 is divided into 9 basins and flooding status of each basin are analysed.

From the result of the analysis, it is found that the executed urgent measures is very effective to lower water levels of the main klongs and will mitigate the past prolonged and large area flooding.

4.2 Caliburation and Verification of Storage Basin Model

Prior to the study of urgent measures, the basin model was calibrated using 1983 flooding data and verified for the 1980 flood.

4.2.1 Inflow from Outer Area

In order to find out the inflow from the outer areas a water balance study was carried out prior to calibration study of the model. The water balance is shown in following equation.

$$V = Qi + R - (E - Q) \text{ ----- } (Eq - 1)$$

V = Accumulated Storage Volume

Qi = Accumulated Inflow Amount from Outer Area

R = Accumulated Rainfall Amount

E = Accumulated Evaporanspiration Amount

Q = Accumulated Discharge Amount through the Drainage Facilities

Each term except (Qi), were obtained from Table H.4.

Table H.4 Data Source for Water Balance Study

Term	Source
V	Topography map and observed water level
R	Observed area average rainfall
E	The report "Investigation of Land Subsidence caused by deep well pumping in the Bangkok Area" AIT, May 1981
Q_0	Pump and gate operation record

Qi, an unknown, can be calculated from equation (1) using the other known terms. The result of the water balance calculations are shown Fig. H.15.

4.2.2 Coefficient of Roughness (n)

The flow status is influenced strongly by the coefficient of roughness in both channel and flood plain. Table H.6 shows the coefficients of roughness which were used for previous typical studies of flood modelling.

1) Open Channel (n1)

Based on the observed water levels and flow discharge in Klong Phra Khanong and Klong Saen Saep, an open channel's coefficient of roughness was estimated as n1=0.03 to 0.04 as shown in Fig. H.16. Based on this estimation, three values of n1, namely, 0.025, 0.035 and 0.045 were used for the calibration.

2) Flood Plain (n2)

Coefficient of roughness (n2) in the flood plain is studied and estimated considering the following 3-stages, i.e., (1) low flow, (2) intermediate, (3) high flow, as shown in Table H.5.

Table H.5 Cofficient of Roughness (n_2) of Flood Plain Flow

	Case 1	Case 2	Case 3
Dh $\leqq$ 0.1	n_2 = 0.10	n_2 = 0.15	n_2 = 0.20
Dh = 0.4	n_2 = 0.05	n_2 = 0.05	n_2 = 0.05
Dh > 0.4	n_2 = 0.05	n_2 = 0.05	n_2 = 0.05

Dh: Depth of flood plain flow above average elevation of flood plain in meter.

Table H.6 Reference Data for Cofficient of Roughness

Flow Type		Source		Coefficient of Roughness
Flood Plain Flow	1	Tomoe River Flood Simulation	Japan	Paddy Field .. n_2 = 0.15 Urbanized Area .. n_2 = 0.30
	2	Flood Simulation in Polder fpr Isewan Typhoon	Japan	h = 0.1 m n_2 = 0.40 h = 0.3 m n_2 = 0.15 h = 0.5 m n_2 = 0.05
	3	Sirakawa Flood Simulation	Japan	Urbanized Area.. n_2 = 0.10 Other Area.. n_2 = 0.30
	4	Nakagawa Flood Simulation	Japan	n_2 = 0.20
	5	Flood Simulation on Bangkok Eastern Suburban Area by Lanti (AIT)	Thailand	n_2 = 0.05
Open Channel Flow	6	Flood Simulationoon Bangkok Suburban Area by Lani (AIT)	Thailand	n_1 = 0.035
	7	"Open Channel Hydraulics" Ven Te Choi p120-p1-1	USA	n_1 = 0.03 - 0.04
	8	Estimation based on observed flow condition in K. Phra Khanong & K. Saen Saep by JICA	Thailand	n_1 = 0.027 - 0.043 ≒ 0.03 - 0.04

4.2.3 Model Calibratioin for 1983 Flood

Fig. H.17 shows the result of calibration for the 1983 flood. Based on these figures, the following coefficient of roughness were selected.

$$n1 = 0.035$$

$$n2 = 0.15 - 0.05$$

Fig. H.18 shows the water level variation in each basin using above-mentioned values.

4.2.4 Model Verification for 1980 Flood

The results of verification for 1980 are shown in Fig. H.19 and H.20. It can be said that the verified storage volume and water levels are almost equivalent to the observed data.

4.3 Calculation Conditions for Urgent Measures

- Case A : Before execution of Urgent Measures
- Case B : Before execution of Urgent Measures, but Green Belt Barrier is executed.
- Case C : Case B, with a total pump capacity of 159 CMS installed along the Chao Phraya River in the abovementioned area of 605 km^2.
- Case D : It is assumed that existing cofferdams located at Klong Phra Khanong and Saen Saep near the border of the Master Plan Area are removed.
- Case E : Case C, plus the inner barrier constructed between the Master Plan Area and Retention Area.
- Case F : Case C, 5-year frequency rainfall.
- Case G : Case F, with an inner barrier added.
- Case H : Case G, when the future topography in 2000 is applied.

Each case is calculated under the condition of Table H.7.

Table H. 7 Conditions of Calculation with 9 Storage Basin Model

		A	B	C	D	E	F	G	H
Rainfall		Areal Average Rainfall in 1983 ΣR = 1078 mm/3M					Design Rainfall 1/N=1/5 ΣR=872mm/3M		
Topography		Existing (1983)							Future (2000)
Green Belt Level		×	○	○	○	○	○	○	○
Urgent Pump		×	×	○	○	○	○	○	○
Inner Barrier		△	△	△	×	○	△	○	○
Total Pump Capacity		CMS 21	CMS 21	CMS 159	CMS 159	CMS 159	CMS 159	CMS 159	CMS 159
Pump Condition									
Capacity	Basin 9	3.0 CMS	45.0 CMS						
	Basin 3	16.0 CMS	84.0 CMS						
	Basin 1	1.5 CMS	30.0 CMS						
ON-OFF Water Level	Basin 9	+0.5 MSL	-0.4 CMS						
	Basin 3	+0.5 MSL	-C.1 CMS						
	Basin 1	+0.8 MSL	-0.4 CMS						
Gate Condition									
Span	Basin 9	6 M	16 M						12 M
	Basin 3	26 M	59 M						30 M
	Basin 1	6 M	18 M						12 M
Bottom Elev.	Basin 9	-2.8	-2.5						-2.5
	Basin 3	-3.2	-3.2						-5.5
	Basin 1	-2.8	-2.8						-4.0
Minimum ΔH for Gate Opening		ΔH = 0.3 Gate will be opened fully when difference of water level exceeds 0.3 M							
Water Level in Chao Phraya R.		Observed Water Level in 1983							1/N=1/100 Design WL
Inflow from City		Not considered							
Klong Condition		Existing Condition (same deta of Calibration of 9 Basin storage model)							Modified bottom Elev.

note: 1 × : Not considered

○ : Considered

△ : Existing Cofferdam in Klong Saen Saep and Klong Phrakhanong cosidered

2 Gate will be opened when difference water level between up stream and down stream increases more than minum ΔH (0.1 meter).

4.4 The Effect of Urgent Measures

The results of hydraulic analysis for urgent measures are shown in Fig. H.21 and H.22 and the variation of simulated water lavels in each basin are showin in from Fig. H.23 to H31.

As can be seen in Fig. H.21, that the maximum flood depth and total flood duration above mean lowest residential land are reduce:

	Max. Flood Depth	Flood Duration days
Case A : Before Urgent Measures	70	90
Case B : Green Belt	30	60
Case C : Green Belt + Pump	0	0

Figs. H.21 and H.22 shows the effect of Urgent Measures over the whole area. Especially the effect on the Master Plan Area is quite large. In the year 2000 AD, however, the effect of the Urgent Measures will be lost or will be more serious than before the execution of the Urgent Measures due to land subsidence in the Area. Therefore, the execution of the permanent flood protection and drainage measures are indispensable elimination of flood problems in the Master Plan Area.

5. Preparatory Study for Trunk Drainage Facilities

5.1 Step I Analysis

Step I analysis has been done to obtain a rough inundation status for a long period rainfall. The results of this analysis which was obtained by the 9 storage basin model ae shown in Fig. H.32, H.33 and H.34. Fig. H.32 show the inundation status vs. the size of the trunk drainage facility in the Master Plan Area. Based on this figure, the following can be pointed out.

(1) Required Capaicty of Main Pump are as follows:

Bangkhen - Bang Sue Area .... Qp = 50 CMS

Phrakhanong - Bang Na Area .... Qp = 70 CMS

(2) Duration period will be reduced to less than one to two days with these main pump capacities.

(3) Klong sizes were assumed to be the same as the existing klong's width and the future bottom elevation assuming a future land subsidence of 1.0 metre.

From the result of this analysis, it is understood that an inundation for a short duration even part of the area will be anticipated.

On the other hand, inundatiion status vs. size of trunk drainage facility in the retarding area are shown in Fig. H.33 and H.34. From these figures, it is found that the existing klongs located from north to south direction (upstream of Klong Sam Rong) should be widened to about twice the existing size.

5.2 Step II Analysis

In the step II analysis, the Master Plan Area is divided into 19 storage basins.
The conditions for step II analysis are decribed in Table H.2 and Fig. H.3.

The main pumping station of the Phrakhanong Polder is the Prakhanong Pumping Station.
As simulated inundation status using 45 CMS pump capacity at Phrakhanong are shown in Fig. H.35 and Fig. H.36 and with 70 CMS Capacity are shown in Fig. H.37 and Fig. H.38.
Even after improvement by increasing to 70 CMS Capacity some poor drainage areas remain as shown in Fig. H.39.
Based on a comparison between Fig. H.38 and Fig. H.39, Ramkamhaeng Area (Basin 16) is selected as the inner polder.

6. Planning of Drainage Facilities

The drainage facilities inside each drainage area is explained in sub-section 6.1.

The trunk drainage facilities consisiting of Phrakanong Pumping Station and Klong Phra Khanong, Saen Saep and Tan are described in sub-section 6.2 and the final hydrological-hydraulic confirmation of the whole drainage facilities is made in sub-section 6.3.

6.1 Drainage Facilities for inside drainage area

6.1.1 Basic Condition

1) Rainfall

(1) Design Raifall

Drainage facilities had better be designed to discharge all the rainwater expected for a given location. However, the actual design of the drainage facilities should be made with due consideration of the economy and investment for the project.
One to 10-year frequency rainfall is generally adopted world-wide, depending n the regional characteristics. Although 5-year frequency was recommended in the Preliminary Study, a 2-year frequency is adopted in the Master Plan to conform with that planned for central Bangkok. The adopted rainfall of hourly rainfall of 58.7 mm is expressed as follows:

$$I = \frac{5,690}{t + 37}$$

where

I : Rainfall intensity (mm/hr)

t : Time of concentration (min.)

2) Rainfall Pattern and Time of Concentration

The patterns of the short term rainfall above 60 mm per day recorded at head office of the Meteorological Department at Bangkok are shown in Fig. H.11. Out of 52 samples, the rainfall lasting from 4 to 9 hours accounts for 52 percent. In addition, 45 percent occur during the flood season, i.e., Septebmer to November.

It is also found out from Fig. H.11 that more than 90 percent of the rainfall with a duration of less than six hours falls within two hours. Consequently, a front concentration type rainfall with a duration of six hours is adopted for the design.

3) Areal Reduction Factor

Areal reduction factor is used to transfer point rainfall to areal rainfall. The areal reduction factor used for the drainage facilities inside the drainage area is shown in Table H.8.

Table H.8 Areal Reduction Factor
(6-hours rainfall)

Area (km^2)	Areal Reduction Factor
5	1.00
10	0.97
20	0.95
30	0.89
40	0.86
50	0.84
60	0.80

2) Runoff

(1) Hydrograph in Sub-Drainage Area

The rainfall in the sub-drainage area runs off from the previous and impervious land surfaces, roofs, streets, etc. to the klongs via the drainage facilities of street gutters, conduits and sewers. This process is simulated by means of the Rational Method which is expressed as follows:

$$Q = CiA/3.6$$

where

Q = Peak runoff (m^3/sec)

C = Runoff coefficient

i = Average rainfall intensity for the time of concentration (mm/hr)

A = Catchment area (km^2)

Time of concentration is a summation of an inlet time of run-off flow over the ground surface to the nearest conduit or sewer and the time of flow in the conduit or sewer from the most remote inlet to the point under consideration. The former is assumed to be 10 minutes. For the estimation of the latter, an average velocity of 0.35 m/sec is considered. Then the time of concentratin expressed in minutes is:

$$t = 10 + L / 21$$

where

L : Length of conduit or sewer from the most remote inlet to the point of consideration (m)

L is assumed for each sub-drainage areas, average size of which is 1.6 km^2.

Runoff coefficients (Table H.9) are determined for the various land-use types based on Fig. H.14.

Table H.9 Run-off coefficients for various land-use types

Land-use type	Runoff coefficient(c)
1. Residential (medium density)	0.50
2. Residential (low density)	0.40
3. Commercial	0.75
4. Indutrial	0.70
5. Institutional	0.40
6. Park/Agricultural	0.15
7. Pond	(1.00)

(2) Layout of Sub-drainage Area

The subdrainage area are determined based on the future land use plan, klong network and road network.

Fig. H.41 shows the proposed sub-drainage area in the Master Plan Area.
The proposed subdrainage areas are applied in step III and IV analyses.

3) Water Level

(1) Chao Phraya River

1.9 metre above mean sea level (MSL) at Bangkok Port (100-year return period) is used while 2.3 m MSL is used for Bang Khen and Bang Sue drainage areas.

(2) Maintenance Water Level at Pumping Station in Drainage Area

The recommended maintenance levels at each Pumping Station in drainage area are indicated in Table H.10. These levels are defined as the level to be maintained just upstream of the pumping stations during normal dry weather times. Under design rainfall, waterlevels in the sub-klongs would rise some 1.5 m above maintenance water levels, reaching land level elevations.

Table H.10 Maintenance Water Levels

Polder Area	Maintenance Water Level (m MSL)	
	Present	Future (in 2000)
Bang Khen	-0.50	-1.50
Bang Sue	-0.50	-1.50
Phra Khanong	-0.80	-1.80
Bang Na	-0.80	-1.80

The klong initial water level at the beginning of rainfall for calculation is a maintenance water level.

4) Land Subsidence

Land subsidence up to the year 2000 of 0.7 m (in Bang Khen and Bang Sue drainage areas) and 1.0 m (in other 6 drainage areas) is considered. These are are obtained in the Preliminary Study. The ground elevations in 2000 are used for the analysis.

5) Retention Area within Drainage Area

Retention area for temporary water storage is planned in this plan in order to reduce the scale of the drainage facility.

6) Klongs

Existing klongs are planned to be incorporated into the proposed drainage system.

(1) Velocity

In view of klong maintenance, the velocity of a klong is preferable lower than 1.00 m/sec.

(2) Roughness coefficient

Roughness coefficient (n) used in the Manning formula is assumed to be 0.03.

7) Computations

The drainage system for the designated 8 drainage areas and the proposed inner polders are analysed by run-off model, unsteady model.

6.1.2 Drainage Facilities inside the Drainage Area

1) Bang Khen Drainage Area (29 km^2)

Bang Khen Drainage Area is situated in the north-west part of the Master Plan Area. The ground elevation is rather high and rainwater will flow through the Klong Bang Khen.

Don Muan Air Port is located to the north of the Area and Highways No. 1 and No. 3 constitute main parts of the boundary of the Area.

The analysis is made for the layout of the drainage facilities as shown in Fig. H.42 on the condition that a pump capacity of 15 m^3/sec is installed and that the klongs are of rectangular shape widened. From the result of the analysis, a variation of water level are shown in Fig. H.43, and no flooding anticipated.

2) Bang Sue Drainage Area (35 km^2).

Bang Sue Drainage Area is adjacent to Bang Khen Drainage area and is also rather high and rainwater will flow out through Klong Bang Sue.
At present, some rainwater in the Area flows down into Phra Khanong-Saen Saep Area through Klong Lat Phrao. Due to the very small capacity of Klong Phra Khanong, the existing RID control gate located at Klong Lat Phrao is to be closed during the flood season. An inflow of 12 m^3/sec from the Core Area is also taken into account in this system. Capacities considered in the first analysis with a pump capacity of 30 m^3/sec, (larger than that of the urgent measures of 24 m^3/sec) and that the Klongs ae widened in a rectangular shape, up to the width of the right of way. However, as a large inundation is expected in this pump capacity, the diversion of some water into Bang Khen Area is considered as a next step in order to utilize the relatively large Klong Lat Phrao, which connects Bang Khen Area and Bang Sue Area. Nevertheless, water level does not change much, that is, flooding will still occur.

Finally, in order to relieve storm water downsteam of Bang Sue Area (under flood conditions), the capacity of Bang Sue pumping station is changed to be 50 m^3/sec. In this case, connection of Bang Sue Area and Bang Khen Area is taken into account.

3) Phra Khanong-Saen Saep Pllder (165 km^2)
This polder is divided into five drainage areas as follows:

(1) Klong Chan (24 km^2)
(2) Lat Phrao (59 km^2)
(3) Huay Kwnag (35 km^2)
(4) Patterna Karn (24 km^2)
(5) Hua Mark (23 km^2)

These drainage facilities inside each drainage area are described:

3.1) Klong Chan Drainage Area (24 km^2)

Klong Chan Drainage Area is located on the north-east side of the Master Plan Area. The rainwater flows mainly in a southernly direction through Klong Lam Chala, Paenang Phua and Phya Suren etc. to Klong Saen Saep. Boundaries are found by National Highway No.304 in the northeast, Bang Kapi-Bang Chan road in the west and Klong Saen Saep in the south.

Retention area is planned in the north as shown in Fig. H.44. With this area, water is transported by gravity to Klong Saen Saep if the klongs are improved.

3.2) Lat Phrao Drainage Area (59 km^2)

Lat Phrao Drainage Area is located in the north of the catchment area of Phra Khanong-Saen Saep Area. The boundaries are found by National Highway No.304 in the north, Klong Lat Phrao in the west and Lat Phrao Road in the north.

Owing to the large retention area in the north (Fig. H.46) storm water is drained southward to Klong Saen Saep through Klongs Chan, Ta Nang etc. without inundation in the Area (Fig. H.47 to H.48) if improvements are made to the klongs.

3.3) Huay Kwang Drainage Area (35 km^2)

Huay Kwang Drainage Area, adjacent to the Core Area of Bangkok Metropolis is expected to be developed rapidly in the near future. The area is enclosed by the Klong Saen Saep in the east, Klong Bang Sue and Lat Phrao Road in the north, a super highway in the west and the east-bound railway in the south. This area consists of two areas: East Huay Kwang (11 km^2) and West Huay Kwang (24 km^2), bordered by a future road along the east of Klong Lat Phrao.

Rain water in the East will flow out by Klong Wat Tuk and in the West by Klongs Lat Phrao and Sam Sen. Retention area is planned in the East Huay Kwang Area.

(1) East Huay Kwang (11 km^2)

The layout of drainage system is shown in Fig. H.49. From the flood simulation, although some small flooding is expected upstreatm (Fig. H.50), rainwater is transported by gravity to Klong Saen Saep. Improvement of the existing klongs is necessary.

(1) West Huay Kwang (24 km^2)

It is found from the result of the flood simulation, rainwater will be transported by gravity to Klong Saen Saep (Fig. H.52). Improvement of the existing klong is needed. The layout of the drainage system is shown in Fig. H.51.

3.4) Patterna Karn Drainage Area (24 km^2)

Patterna Karn Drainage Area is bordered by Klong Saen Saep in the north, Bang Kapi-Bang Na Road in the west and Klong Phra Khanong in the south. The population in this area is rather low and is currently not much urbanized.

Owing to the small flow capacity of Klong Tan, rainwater is planned to flow mainly into Klong Phra Khanong and not into Klong Saen Saep.
Retention area is planned in the middle of the Area. From the result of the flood simulation, storm water is transported by gravity to Klong Phra Khanong if the klongs are improved. Fig. H.53 and H.54 shows the layout of the drainage system and water levels respectively.

3.5) Hua Mark Drainage Area

Hua Mark Drainage Area is enclosed by Klongs Saen Saep, Tan, Phra Khanong and the Bang Kapi-Bang Na road. This Area has the lowest elevation in the Master Plan Area and is expected to experience severe land subsidence.
Coping with these circumstance, North Hua Mark (Ramkhamhaeng) Area has been already formed by the small polder and some rainwater is discharged by pumping. From the preliminary analysis of Phra Khanong-Saen Saep Area

by use of a 31-basin model, North Hua Mark area is found to be flooded if an inner polder is not provided. Consequently North Hua Mark Area is planned as an inner polder area. The border of the polder area is determined by the Ramkhamhaeng road in the northwest and Bang Kapi-Bang Na road in the east. The southern border is a railway. Accordingly, the Hua Mark Area is divided into North Hua Mark (inner polder area) and South Hua Mark.

(1) North Hua Mark (9 km^2)

Retention area is planned in the southeast. First, an analysis is made asuuming that the klong is improved within the existing right-of-way and that a pump of 6 m^3/sec is installed at the end of Klong Kacha. This layout is shown in Case 1 of Fig. H.55. In this case, although no flooding is expected in the urbanized area, the duration of flooding in the retention area is rather long (Case 1 of Fig. H.56).
Therefore, an additional pump of 3 m^3/sec is planned at the end of Klong Gig (Case 2 of Fig. H.55). In this case, the water in the retention area will subside within one day (case 2 of Fig. H.56).
It is noted that Ramkhamhaeng Campus is lower topographically by 10 cm, than the planned retention area.

Therefore, the University must take self-supporting drainage measures.

(2) South Hua Mark (14 km^2)

From the result of the flood simulation for the drainage system of Fig. H.57, rainwaters flow by gravity to Klongs Tan and Phra Khanong by improvements to the existing klongs (Fig. H.58). A large retention area is planned near Klong Phra Khanong.

3.6) Bang Na Drainage Area (31 km^2)

Bang Na Drainage Area is situated in the south of the Master Plan Area and is bordered by the boundary to Samut Phrakang Province in the south, Chao Phraya River in the west, Klong Phra Khanong in the north and Band Kapi-Bang Na Road in the east.

This area is rather highly urbanized low lying land and is expected to surffer severe flood damage. Rainwater is planned to flow out through Klongs Bang Na, Bang Oa, Bang Jek etc. mainly into the Chao Phraya River due to the limited capacity of the Klong Phra Khanong.

It is found, however, that some storm water near Klong Phra Khanong is better drained to the Klong Phra Khanong.

For the hydraulic study in the Bang Na Drainage Area, the following four alternatives as shown in Fig.H-59 were studied.

Altinative I

All storm water is planned to be drained directly to the Chao Phraya River as shown in Fig.H.59. In this alternative, the same pump capacities are assumed as the one installed by the urgent measures, i.e., 15 m^3/sec in Klong Bang Na, 18 m^3/sec in Klong Bang Oa and 6 m^3/sec in Klong Jek. These pumps will be effective under the conditions of klongs improvement within the right-of-way with exception of new klongs (sections 1 and 14 of Fig.H.59) connecting Klong Bang Na Chine (in the east of Sukumvit Road) with Klongs Bang Oa and Jek (in the west of Sukumvit Road). As can be seen in Fig. H.60, flooding will occur in the middle-stream and upstream, i.e., in the eastern area. The following three alternatives are considered in order to solve the floodings remained in the Alternative I.

Alternative II

Installation of two new pumping stations at Klongs Bang Na Chine and Khlet.

Alternative III

Installation of a new pumping station at Klong Bang Na Chine and capacity increase at Bang Na pumping station from 15 m^3/sec to 21 m^3/sec.

Alternative IV

Installation of new pumping station at Klong Bang Na Chine and diversion of storm water in the east of Sukumvit Road to Klong Bang Na.

The main difference among these alternatives are summarized below.

As can be seen in Fig.H.60, Alternatives II, III and IV are more effective in alleviating floods from a hydrological viewpoint. Alternatives III and IV are preferable to alternative II because the latter alternative will divert more large water to Klong Phra Khanong, which has limited drainage capacity. In order to utilize existing pumping stations at Klongs Jek and Bang Oa in Alternative III, new klongs (sec.1 and sec.14) are necessary which requires land aquisition in the density populated area.

On the other hand, in alternative IV, replacement of pumps, and new klongs sec.13 are required. Between alternatives III and IV, the required total pump capacities and klong improvement works (including new klong) are almost the same. Therefore, both alternatives are equally preferable, however, in this Master Plan, alternative III is adopted by considering the pumping capacities already executed in the urgent measures.

6.1.3 Flow Amount and Drainage Improvement Works

Based on the hydrological analysis developed in 6.1.2, Peak discharge in to the klongs are presented in Figs. H.61 and H.62, and the ncessary klong improvement works are presented in Figs. H.63 and H.64 by type of work as follows:

<u>Klongs</u>

- Category I : New Drain
- Category II : Widening + Deepening + Construction of Retaining Walls
- Category III : Deepening + Construction of Retaining Walls
- Category IV : No Works Required

Table H.11 Alternatives of Drainage Facilities in Bang Na Polder

Item / Case	Pump Capacity (m^3/sec)						New Klong (section number)			
	Jek	Bang Oa	Bang Na	Bang Na Chine	Khlet	Total	1	14	13	25
Existing	6	18	15	-	-	39	-	-	-	-
Alternative I	6	18	15	-	-	39			-	-
Alternative II	6	18	15	9	6	54			-	
Alternarive III	6	18	21	9	-	54			-	
Alternative IV	6	9	30	9	-	54		-		

Note: The new klongs sec.1 and sec.14 aims at draining storm water from east to west, the Chao Phraya River.
The new klong sec.13 aims at diverting storm water in the north to Klong Bang Na.
The new klong sec.25 aims at lowering water level in the middle area.

Required pumps are as follows:

Bang Khen and Bang Sue Drainage Areas

- Klong Bang Khen; 15 m^3/sec
- Klong Bang Sue ; 50 m^3/sec

  total : 65 m^3/sec

Hua Mark Drainage Area

- Klong Gig; 3 m^3/sec
- Klong Kacha; 6 m^3/sec

Bang Na Drainage Area

- Klong Bang Na Chine; 9 m^3/sec
- Klong Bang Jek; 6 m^3/sec
- Klong Bang Oa; 18 m^3/sec
- Klong Bang Na; 21 m^3sec

  total : 54 m^3/sec

Besides, 90 m^3/sec pumps are required at Klong Phra Khanong which are described in trunk drainage facilities.

6.2 Trunk Drainage Facilities in Phra Khanong Polder

6.2.1 General

This sub-section describes the hydraulic study on the trunk drainage facilities in Phra Khanong Polder which consist of the Klongs Saen Saep, Tan, Phra Khanong and the Phra Khanong Pumping Station.

Firstly, the required capacities of klongs (K. Saen Saep and K. Phrakhanong) and Phrakhanong pumping station is studied by the unsteady flow model of a klong based on the outflow hydrograph down stream of the klongs inside the designated drainage area.

In this study the alternatives of pump capacity variation and the maintenance water levels are studied.

Fianlly, based on the obtained capacity of trunk drainage facilities, a total check of the combination of trunk drainage and inland drainage of drainage area is checked.

6.2.2 Conditions for Hydraulic Analysis

1) Design Rainfall

Daily rainfall of 5-year return period (80.0 mm/day) is adopted.

6.2.3 Standard Cross Section and Profile of Trunk Klong

The standard width and depth of the trunk klongs is decided as follows:

For Klong Tan and Saen Saep	:	22 meters wide 4.5 - 4.8 meters deep
For Upstream of Klong Phra Khanong	:	25 meters wide 4.3 - 4.5 meters deep
For Downstream of Klong Khanong	:	35 meters wide 5 meters deep

The width of the klongs is decided within the existing right of way.

The depth of the klongs is determined by structural stability of the bank due to the weak subsoil charactaristics in the Area.

Fig. H.3 shows the result of stability analysis using the circular slip failure method under the assumption of cohesion of soil (2 t/m^2) and unit weight of soil (1.5 t/m^3).

According to this figure, the bank height and maintenance water level are decided as follows:

At critical point of Klong Tan, in the year 2000.

Future Bank Elevation (highest)	-0.3 m MSL
Future Bottom of Klong	-5.0 m MSL
Future Maintenance Water Level	-1.8 m MSL
Future height of bank	-4.7 m
Free Board (difference between (ground elevation and mainteance water level).	1.5 m

6.2.4 Maintenance Water Level at Phra Khanong Pumping Station

Maintenance Water level at the Phra Khanong Pumping Station is adopted as -1.8 metre MSL. This level is the planned water level at which the pump will start to operate in case of rainfall. This value is obtained by consideration of not only flood discharge but also convenience for navigation and water supply etc.

The mean lowest land level in the vicinity in the year 2000 is estimated to be about -0.9 meters MSL. The difference between -0.9 meters MSL and -1.8 meters MSL in the klongs is available for rainwater storage. This enables the required capaicty of the Phra Khanong Pumping Station to be reduced. The lower the maintenance level, the smaller the pump capacity. However, due to the weakness of the subsoil of the klong banks and the difficultry of land acquisition for klong improvements, a lower maintenance water level than -1.8 meters MSL is judged to be impossible.
The alternative study on maintenance water level is described in following section.

6.2.5 Alternative Study

For the hydraulic study of the trunk drainage facilities, the following alternatives for pump capacities are studied.

Case 1 : Phra Khanong P.S. - 90 m^3/sec
Case 2 : Phra Khanong P.S. -130 m^3/sec
Case 3 : Phra Khanong P.S. - 60 m^3/sec
Min Buri P.S. - 30 m^3/sec (Discharged to the retention area)

In case 1 and 2, the capacities of Phra Khanong Pumping Station are 90 and 130 CMS respectively.

For case 3, two Pumping Stations are planned. One is Phra Khanong of 60 CMS and the other is Min Buri of 30 CMS which is located at the east end of the Master Plan Area. In this case, 30 CMS will be discharged into the Retention Area.

Fig. H.66 shows the calculated water levels of the trunk klongs. In all cases, the calculated high water levels are lower than the minimum residential land levels along the klongs except for Block 11, Ramkarmhaeng Site which will be an inner polder.

In Case 1, the highest water level in Block 11 reaches almost the riverside elevation (RSE) therefore almost no allowance exists. In Case 2, the highest water level at Block 11 is about 30 cm below RSE.

It means that Case 2 has an allowance of 30 cm, therefore in Case 2, the maintenance water level at Phra Khanong Pumping Station can be raised to -1.5 m MSL from the calculated maintenance water level of -1.8 m MSL. This is beneficial for both navigation and environmental conditions. However, due to small required pump capacity of case 1 and under the consideration of future allowance for urban development but Case 1, the installation of the 90 CMS pump is justified.

In Case 3, the high water level at Block 11 is almost the same as Case 2. The highest water level is about 30 cm below RSE. Therefore, the maintenance water level at the Phra Khanong Pumping Station will be -1.5 m MSL. However the adoption of the discharge of 30 CMS into the retention area is considered to be difficult. From these comparisons, Case 1, the installation of 90 CMS at the Phra Khanong Pumping Station, is recommended.

At the beginning of the study, the Klong Tan was thought to be a bottle-neck of drainage in the Phra Khanong Polder. From the result of this study, however, it is found that land acquistiion at Klong Tan is not needed except for temporary construction because of the planned width of 22 m. An alternative study for a diversion tunnel between Ramkarmhang Site and Phra Khanong Pumping Station Site is not necessary due to the enhanced capacity of an improved Klong Tan. Further an alternative study to discharge into the Green Belt Area is not necessary at this time. In future, after 2000, it will be necessary to be considered to cope with the expanded urban development of the Study Area.
The proposed improvement works of klong Saen Saep and Phra Khanong are shown in Fig. H.60 and Fig. H.61.

6.2.6 Final Check of Whole Drainage System of Phra Khanong Polder

1) Outline of Whole Drainage System and Gates

The Drainage facilities (klongs, pumps and gates) examined in previous subsections are checked for the whole system combined by the trunk klongs and subklongs.
Fig. H.70 shows the schematic klong network and the locations of pumping station.

The pump capacities and initial water level (maintenance water level) conditions are in Table H.11.

Table H.12 Pump Capacity and Initial Water Level for Final Check of Whole Drainage System of Phra Khanong Polder

Pumping Station	Capacity	Initial Walter level
Phrakhanong	90 CMS	-1.8 m above MSL.
Hua Mark (K. Gig)	3 CMS	-2.0 m above MSL.
Hua Mark (K. Kacha)	6 CMS	-2.0 m above MSL.

2) Result of Calculations

Fig. H.71 to H.75 shows the inundation status and the variations of water level in a typical stretch of a klong of Phra Khanong Plder. From these figures, the inundation status are acceptable.

From these figures, also the maintenance water level of -1.8 m is found to be recovered in about 32 hours.

3) Gate Discharge

The water level in up-steam of the gates is not higher than the water level in Chao Phraya River in the year 2000. Therefore a discharge through the gate can not be made.

6.3 Proposed Drainage Facilities

1) Capacity of Pumping Station

According to the result of hydrological-hydraulic analysis the pump capacities, maintenance water levels and main gates are proposed in Table H.12. The locations of proposed pumping station are shown in Fig. H.76.

Table H.13 Proposed Scale of Pumping Stations

	Polder	Area (km^2)	PUMPING STATION: Name of Pumping Station	PUMP: Capacity (m^3/sec)	PUMP: Maintenance Water Level above (M.S.L)	PUMP: Specific Discharge ($m^3/s/km^2$)	GATE: Total Span (m)	GATE: Gate Bottom Elev. above (M.S.L)
MAIN POLDER	BANG KHEN & BANG SUE	64+29* = 93	Bang Khen	15	-1.50		15+10 = 25	-4.00
			Bang Sue	50	-1.50		25	-4.50
			Sub-Total	65		0.70		
	PHRAKHANONG	165	Phra Khanong	90	-1.80	0.55	35	-5.30
	BANG NA	31	Bang Jek	6	-1.80		8	-4.50
			Bang Oa	18	-1.80		8	-4.50
			Bang Na	21	-1.80		15	-4.50
			Bang Na Chin	9	-1.80		6	-3.00
			Sub-Total	54		1.74		
	Total	260+29 = 289		209		0.72		
INNER POLDER	NORTH HUA MARK	9	Gig	3	-2.00		6	-4.70
			Kacha	6	-2.00		6	-4.80
			Sub-Total	9		1.00		

2) Storage Capacity of Klongs and Retention Area

The storage capacity of klongs and retention area are listed in Table H.13.

Table H.14 Proposed Stroage Capacity

(Unit: $10^6 m^3$)

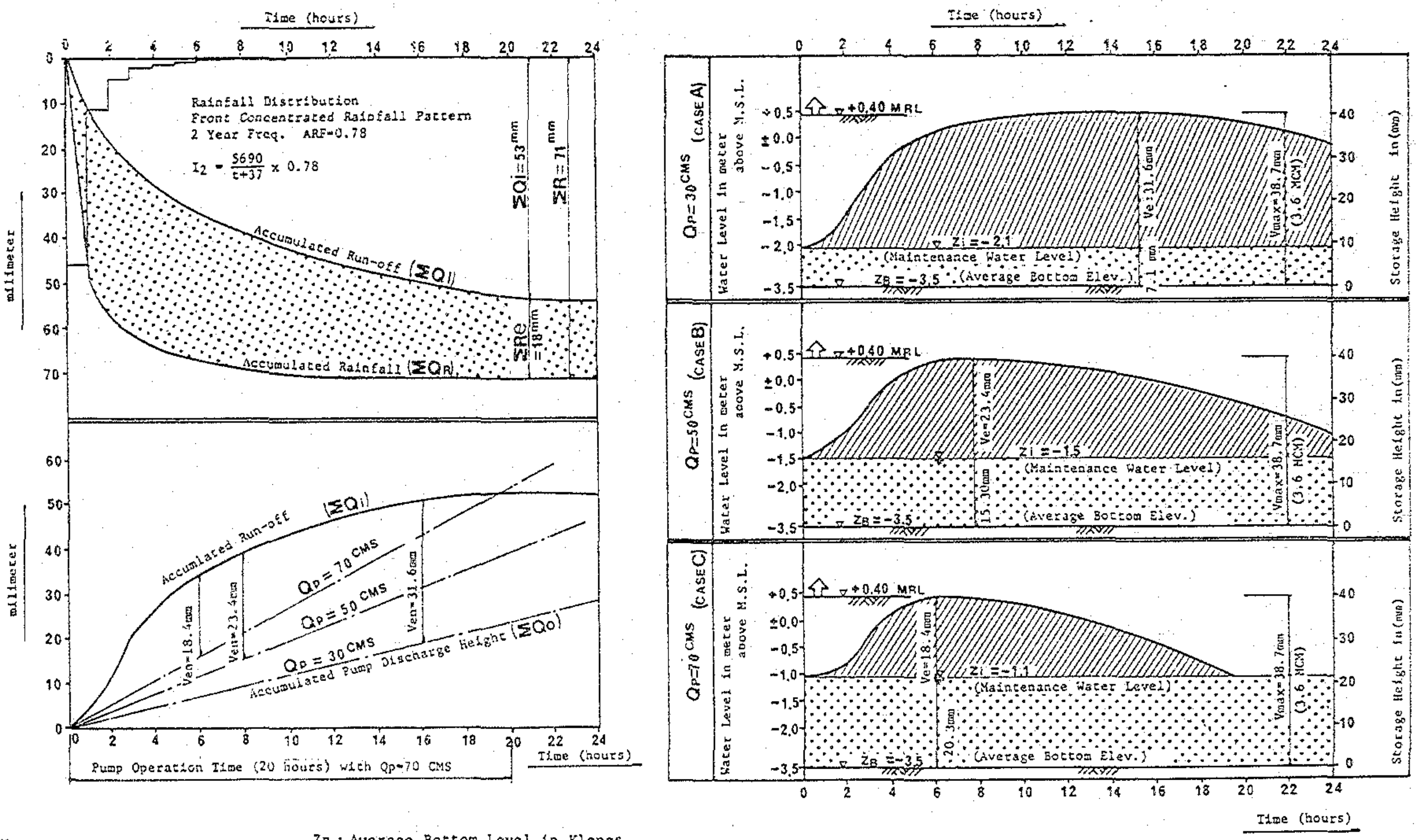
Polder	Retention Area	Effective Storage Capacity		
		Klong	Retention Area	Total
Bang Khen & Bang Sue (A=64+29* = 93 km ^{2})	2.5 km^2	1.79 (19 mm)	0.38 (4 mm)	2.17 (23 mm)
Phrakhanong (A=165km^2)	39.8 km^2	3.74 (23 mm)	4.19 (25 mm)	7.93 (48 mm)
Bang Na (A=31km^2)	1.7km^2	0.49 (16 mm)	0.17 (5 mm)	0.66 (21 mm)
Total (A=289 km^2)	44.0km^2	6.02 (21 mm)	4.74 (16 mm)	10.76 (37 mm)

Note: Effective Required Storage Capacity (Za - Zi)
Maximum Storage Capacity (Za - ZB)
Za : Allowable high water level
Zi : Mainteance water level
ZB : Bottom elevation of Klong
( ) show equivalent storage height in milimeter
* additional area between Chao Phraya R. and Super High Way is 29 km^2

The effect of proposed drainage facilities is described in Fig. H.77.

Fig. H.77 shows the relationship between storage and pump discharge in three polders.

Fig. H.78 shows the simulated maximum discharge in klongs.



Legend

Qp : Pump Capacity
Zi : Required Maintenance WAter Level
Ven : Required Maximum Effective Storage Capacity
Ve : Effect Storage Capacity (Ve=ΣQi−ΣQo)
0+0.4 M.R.L. : Average Minimum Residential Level (Allowable High Water Level)

Z_R : Average Bottom Level in Klongs
Σfl : Loss Rainfall Height (18mm)

Calculation Condition

Rainfall : 2 Year Freq.	$I_2 = \frac{5690}{t+37}$
Area Reduction FActor	ARF=0.78
Catchment Area	A=93 Km^2 (64+29)
Run-off Coefficient	fp=0.5
Run-off Ratio	ft=0.7

Fig. H.1 EFFECT OF STORAGE IN THE BANG KHEN-BANG SUE POLDER (RELATIONSHIP BETWEEN STORAGE AND PUMPING DISCHARGE)

MASTER PLAN ON FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK

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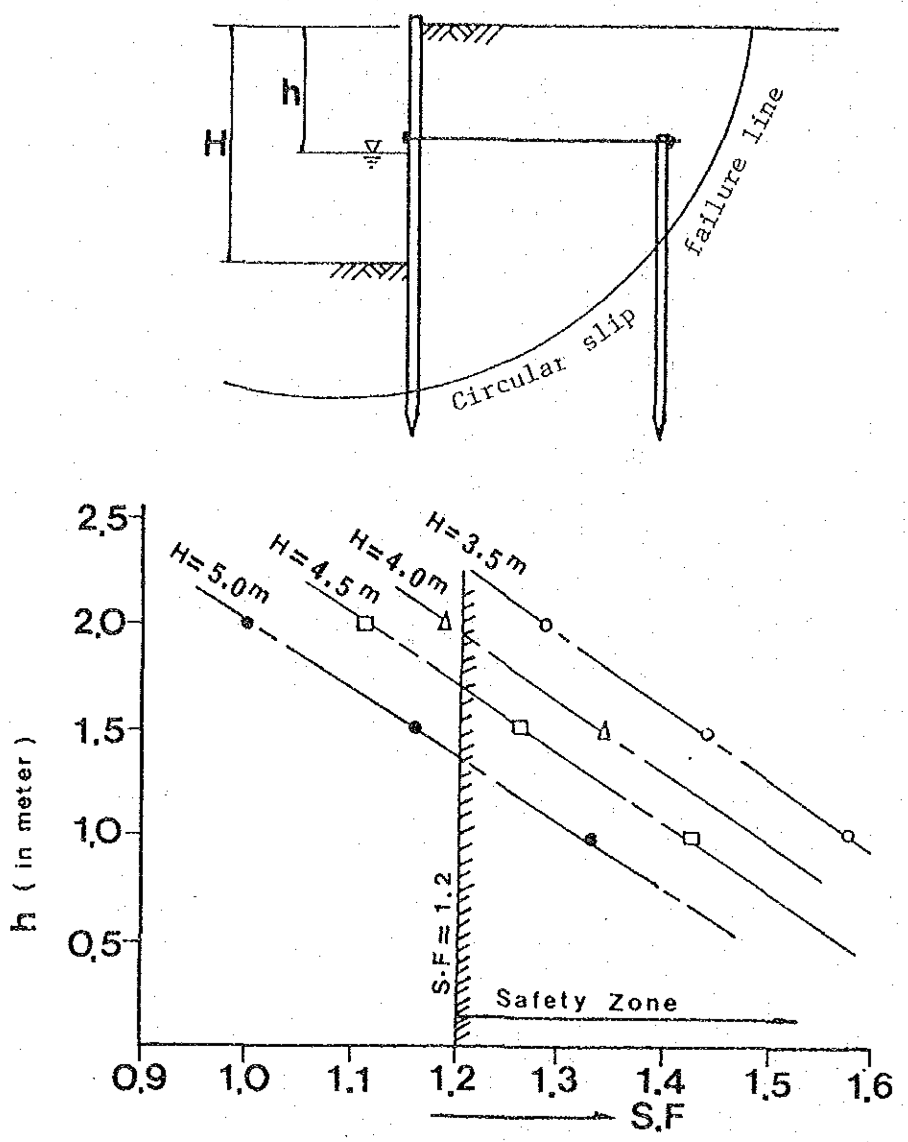
Safty Facter of Circular Sliding



γt : Unit weight of soil (1.6 t/m³)

C : Cohesion of soil (2.0 t/m²)

Fig. H.2 THE STABILITY OF REVETMENT

MASTER PLAN ON FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK

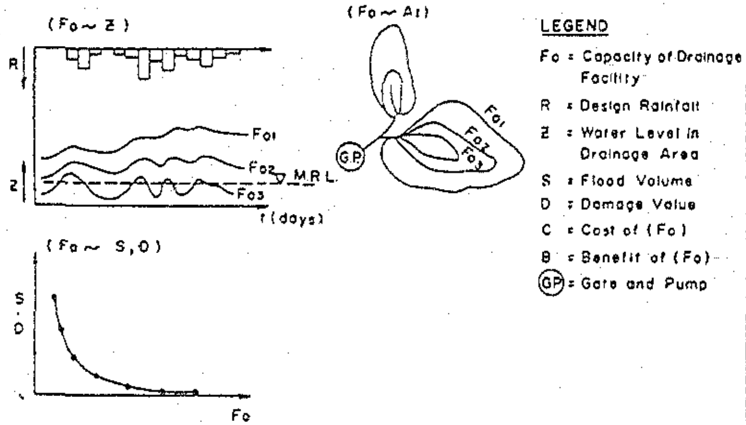
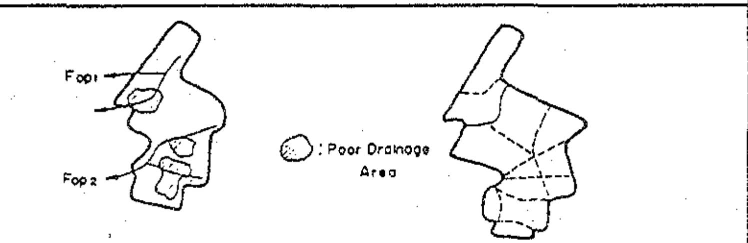
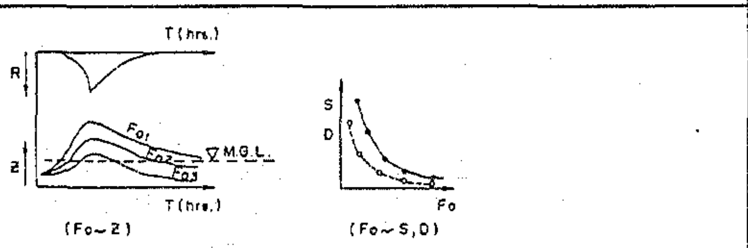
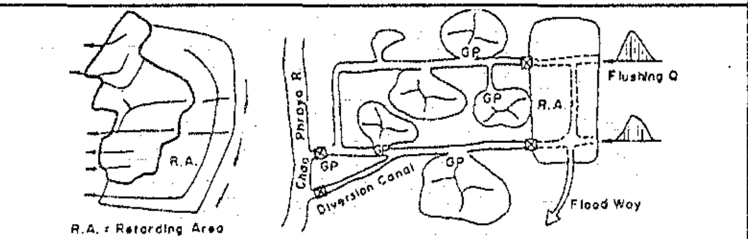
Step	Purpose of Analysis	Schematic Outline of Hydraulic and Hydrological Analysis	Conditions of Judgement	Conditions of Analysis	Applied Models
I	Preparatory Analysis of Trunk Drainage Facility		1. Allowable Depth of Inundation (Ha) 2. Allowable Duration of Inundation (Dta) 3. Physically Limited Capacity of Drainage Facility (Fo1) 4 Specific Discharge Capacities in Other Areas (Qo)	1. Topography (T.)......AD. 2000 2. Land Use (L.S)......A.D. 2000 3 Design Rainfall (D.R.) Scale.....5 year Frequency Pattern.....A.D. 1980 Distribution 3 Months (Ang.~Oct) 4 Design Water Level in Chao-phaya R. (D.W.) Scale.....100 year Frequency Pattern .....A.D. 1980	• Storage Basin (Bi-Dimensional) Model 9 Meshes. • Calculation Period 3 Months. • Time Step 120 Secs.
II	Selection of Poor Drainage Area Zoning of Drainage Area		1. Flooded Area Map 2. Topographic Map 3. Simulated Poor Drainage Area 4 Based on Step 1 5. Land use Map	1 T..........A.D. 2000 2. L.U.........A.D. 2000 3. D.R. Scale............5 year Freq Pattern..........A.D. 1980 Distribution......3 ~ 5 Days ΔT...............One Hour 4 D.W. Scale............100year Freq Pattern A.D. 1980	• Storage Basin Model (Bi-Dimensional) 31 Meshes • Calculation Period 3 ~ 5 Days • Time Step 120 Secs
III	Planning of Drainage Facility in the Drainage Area (Within Polder)		1. Ha 2. Dta 3 Fo1 4 Qo	1. T..........A.D. 2000 2. L.U.........A.D 2000 3. D.R. Scale............2 year Freq Pattern ....Front Concentration Type Distribution.......One Day ΔT...............20~60 Min 4. Design Water Level in Main Klongs ....Basin on the Result of Step①	• Run-off Model (Rational Method) • Klong Model (Unidimensional Unsteady Flow Model)
IV	Planning of Trunk Drainage Facilities		Allowable Velocity, High Water Level and Depth in the Klongs	Same as Step ②	Unsteady Flow Model

Fig. H.3 PROCEDURE OF HYDROLOGICAL-HYDRAULIC ANALYSIS ON FLOOD PROTECTION AND DRAINAGE SYSTEM

MASTER PLAN ON FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK

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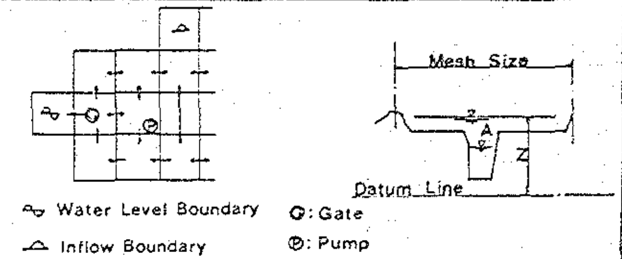
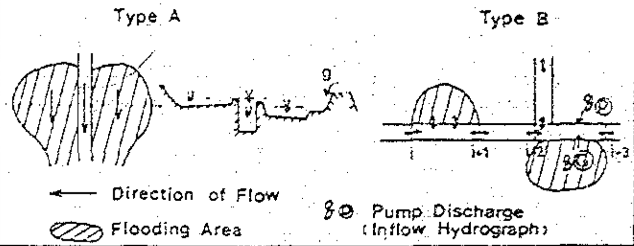
Preparatory Study	Storage Basin Model (Bidimensional Model)	$\frac{\partial Q_x}{\partial t} + \frac{\partial}{\partial X}\left(\frac{Q_x^2}{A_x}\right) + gA_x\frac{\partial Z}{\partial X} + g\frac{n^2\lvert Q\rvert Q}{A R^{4/3}} = 0$ Q : X Direction Flow $\frac{\partial Q}{\partial t} + \frac{\partial}{\partial y}\left(\frac{Q_y^2}{A_y}\right) + gA_y\frac{\partial Z}{\partial y} + g\frac{n^2\lvert Q\rvert Q}{A R^{4/3}} = 0$ R : Rainfall $\frac{\partial Z}{\partial t} + \frac{\partial Q_x}{\partial X} + \frac{\partial Q_y}{\partial y} = (R - E)$ E : Evapotranspiration	
Klong Flow Model	Unsteady Flow Model	$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial X} = g(t)$ g: Inflow Hydrograph $\frac{\partial Q}{\partial t} + \frac{\partial}{\partial X}\left(\frac{Q^2}{A}\right) + gA\frac{\partial h}{\partial X} + g\frac{n^2\lvert Q\rvert Q}{A \cdot R^{4/3}} = 0$ A: Flow Area n: Coefficient of roughness	
Sub-Drainage Area Model	Rational Method Model	$Q_p = \frac{1}{3.6} I.F_p.A$ I: Rainfall Intensity (mm/Hour) F_p: Run Off Coefficient A: Cachment Area (Km^2) Q_p; Peak Discharge (m^3/sec)	

[Estimated by Water Balance Model]

Fig. H.4 OUTLINE OF HYDROLOGICAL-HYDRAULIC MODELS

MASTER PLAN ON FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK

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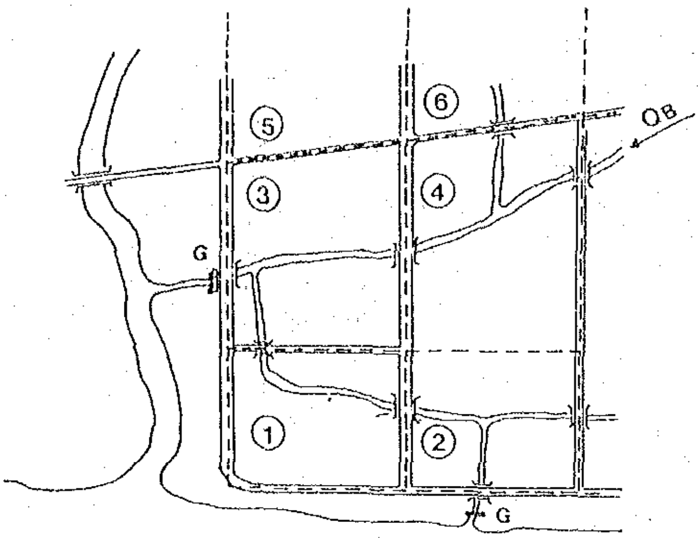
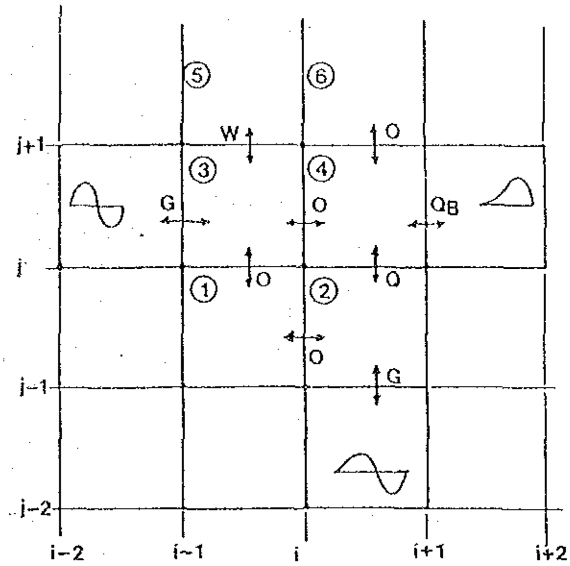
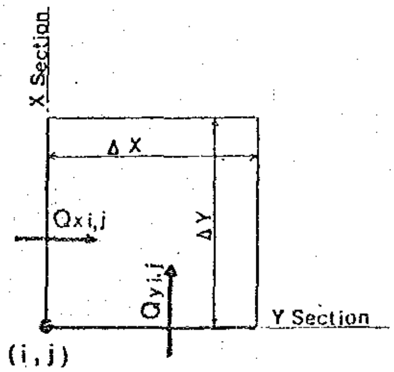
1. Overall Picture of Model Area



2. Mesh Arrangement



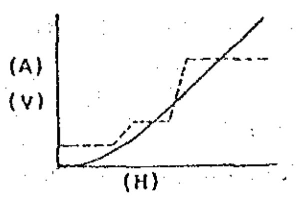
3. Unit of Mesh/Section



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
Z_B : Lowest Bottom Elevation
H – V : Water Depth — Mesh Volume
H – A : Water Depth — Water Surface Area



SECTION DATA

$Q_{x\,i,j}$: Discharge of X section
H – A · N : Sectional Water Depth — Flow Area, Coef. of Roughness
Z_{BS} : Lowest Bottom Elevation
Type : Open Canal, Gate, Weir, Pump

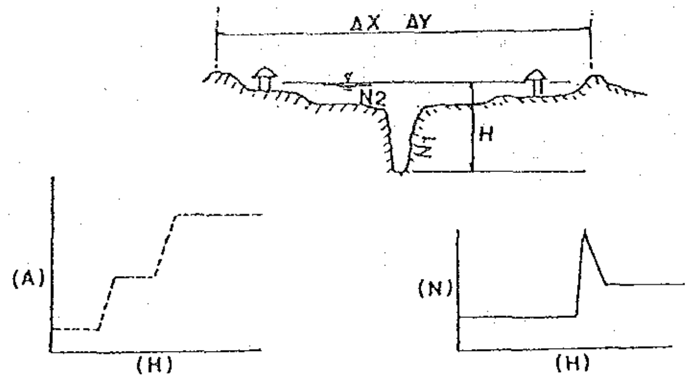


Fig. H.5 OUTLINE OF STORAGE BASIN MODEL (STEP I & II ANALYSIS)

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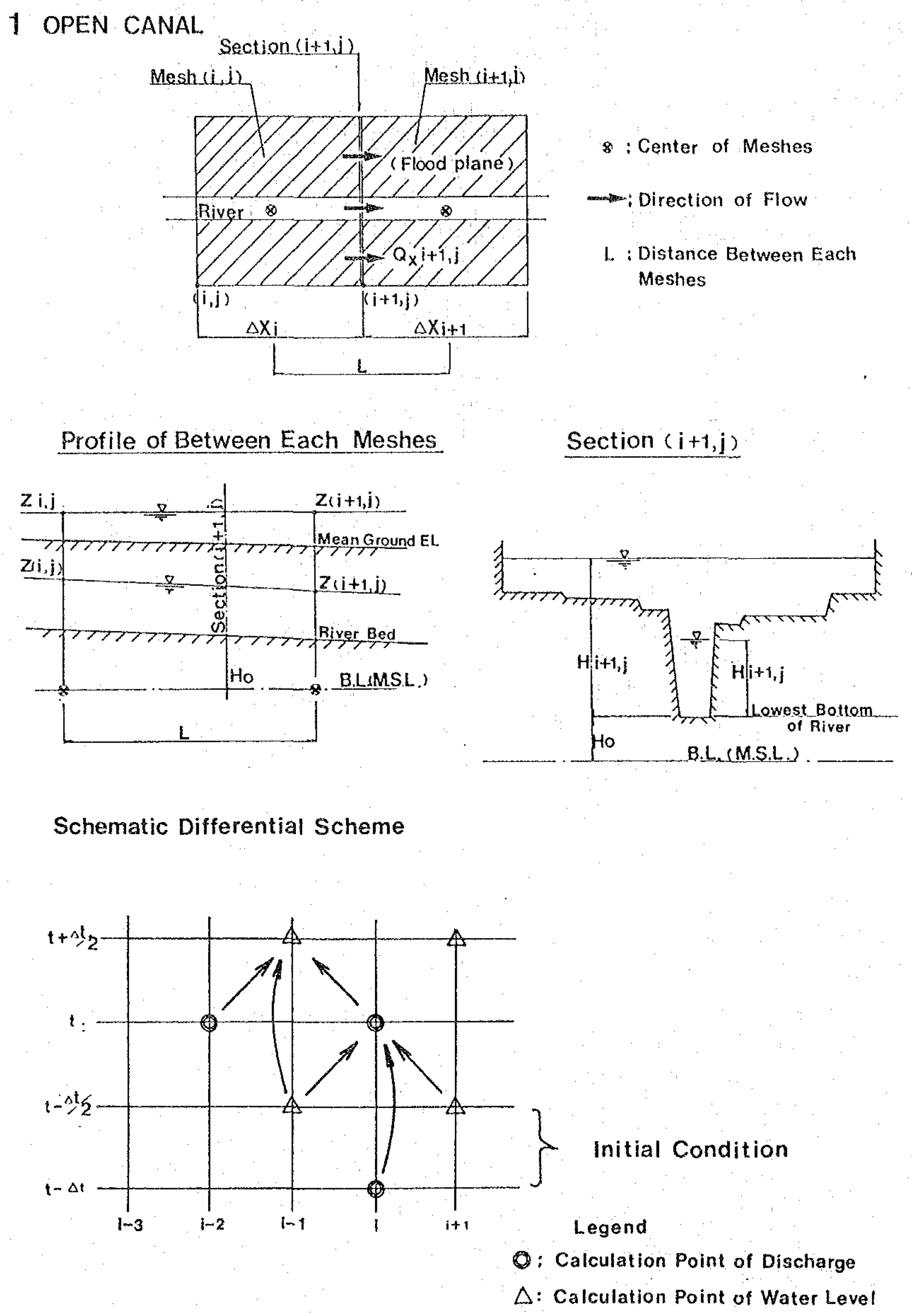
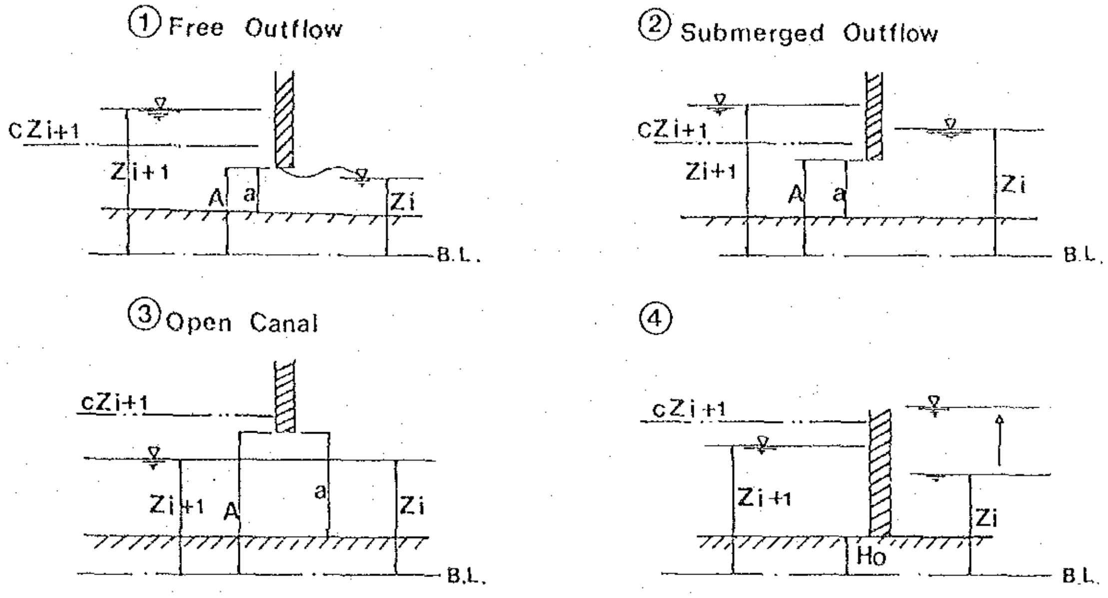


Fig. H.6 SCHEMATIC DESCRIPTION FOR OPEN CANAL FLOW (STEP I, II, III & IV ANALYSIS)

2 GATE



Zi+1 > Zi 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 $A \leqq H_o$

$Q_{i+1} = 0$

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

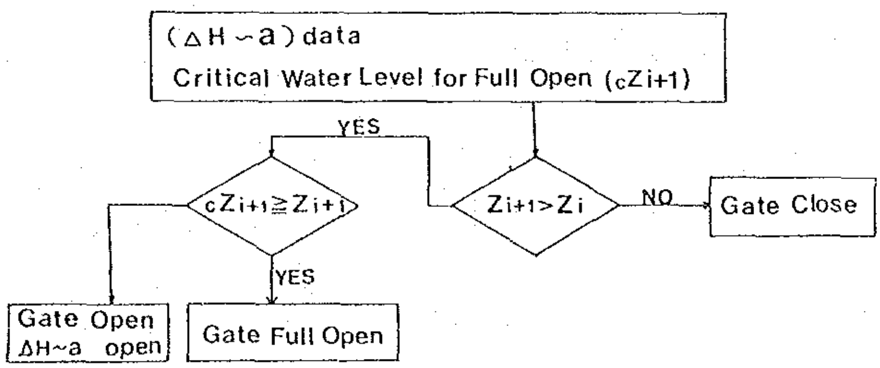
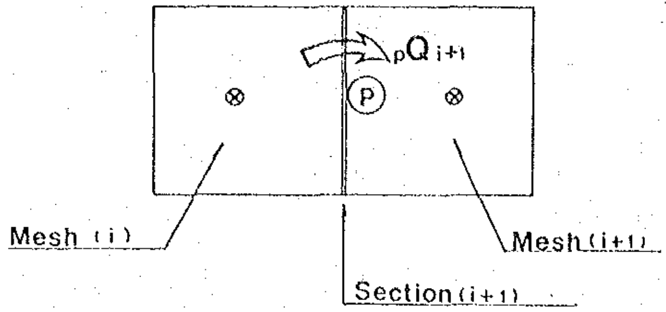
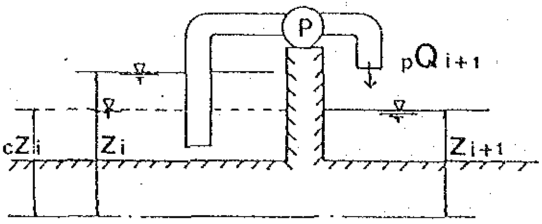


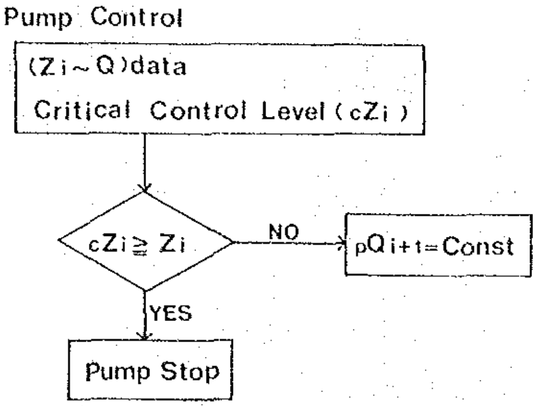
Fig. H.7 SCHEMATIC DESCRIPTION FOR GATE DISCHARGE (STEP I, II, III & IV ANALYSIS)

MASTER PLAN ON FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK

3 PUMP

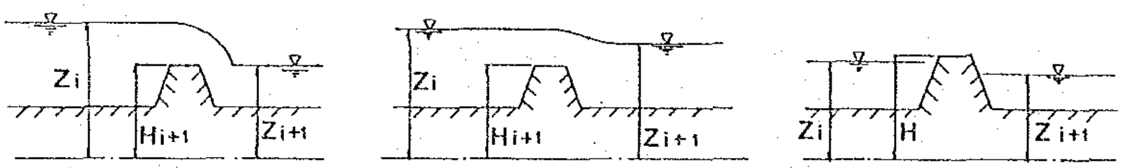






4 WEIR

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

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

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

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

③ $Z_i \leqq H$

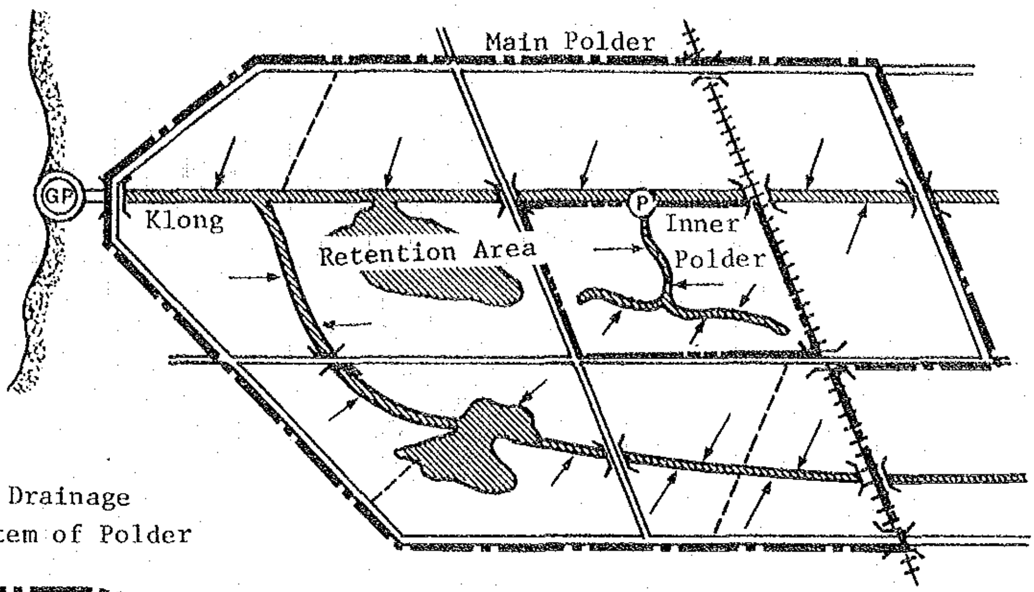
$$Q_{i+1} = 0$$

∴ μ: Coefficient of Overflow

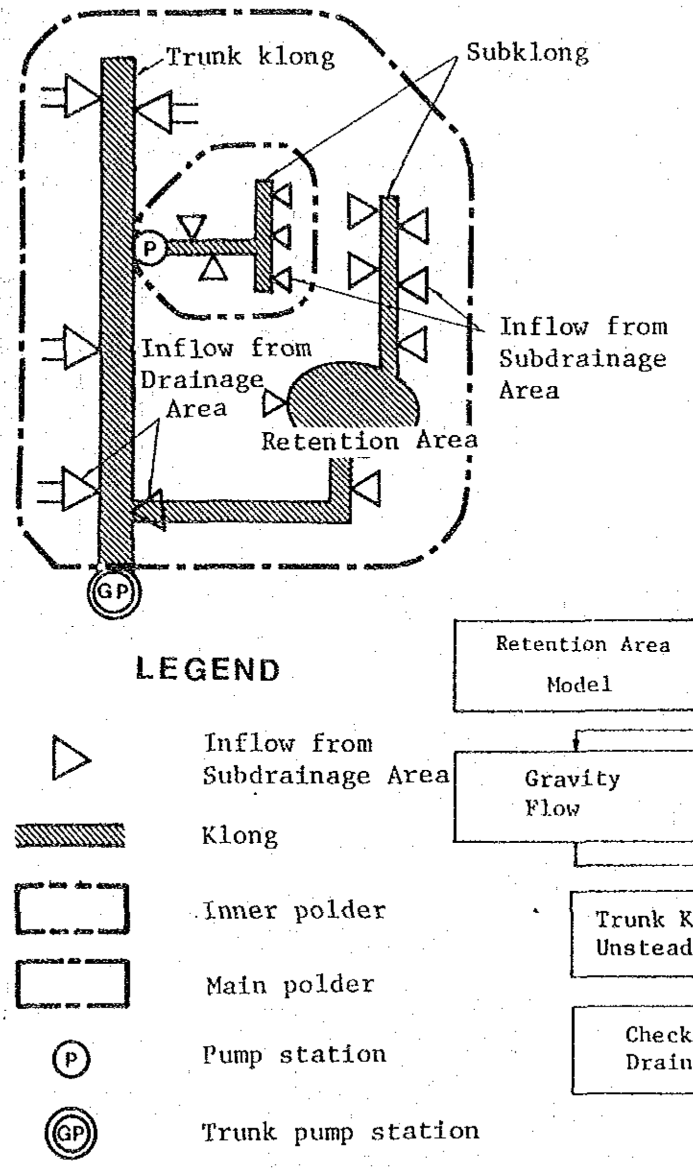
Fig. H.8 SCHEMATIC DESCRIPTION FOR PUMP AND WEIR DISCHARGE (STEP I, II, III & IV ANALYSIS)

MASTER PLAN ON FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK

(1) Typycal Plan of Polder



(2) Schematic Drainage System of Polder



(3) Flow of Flood Routing Model

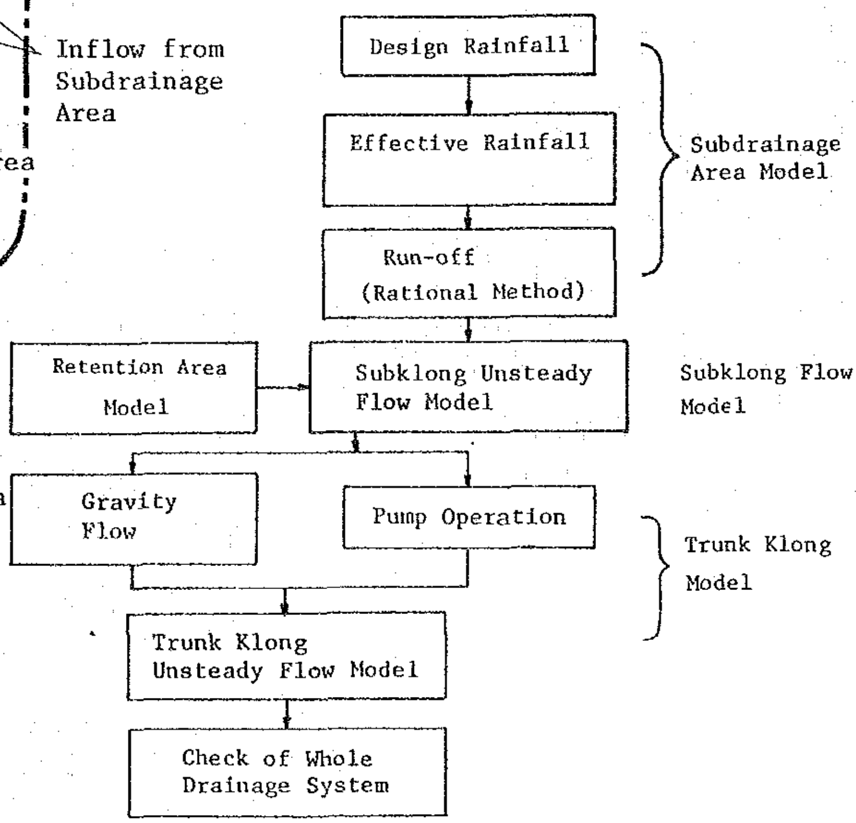


Fig. H.9 OUTLINE OF FLOOD ROUTING MODEL (STEP III & IV ANALYSIS)

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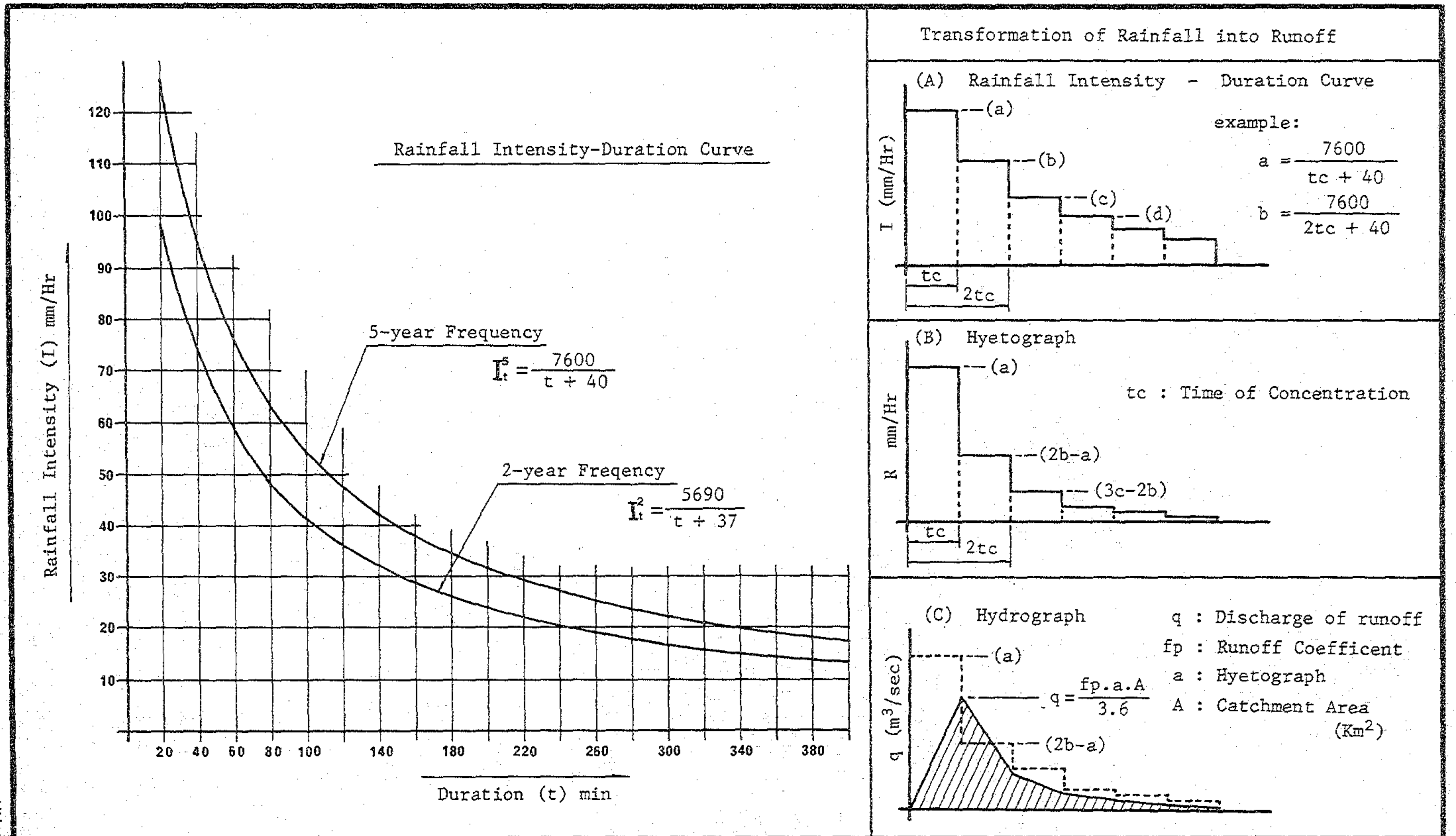

Fig. H.10 DESIGN HYETOGRAPH AND HYDROGRAPH FOR RUN-OFF MODEL IN SUB-DRAINAGE AREA

MASTER PLAN ON FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK

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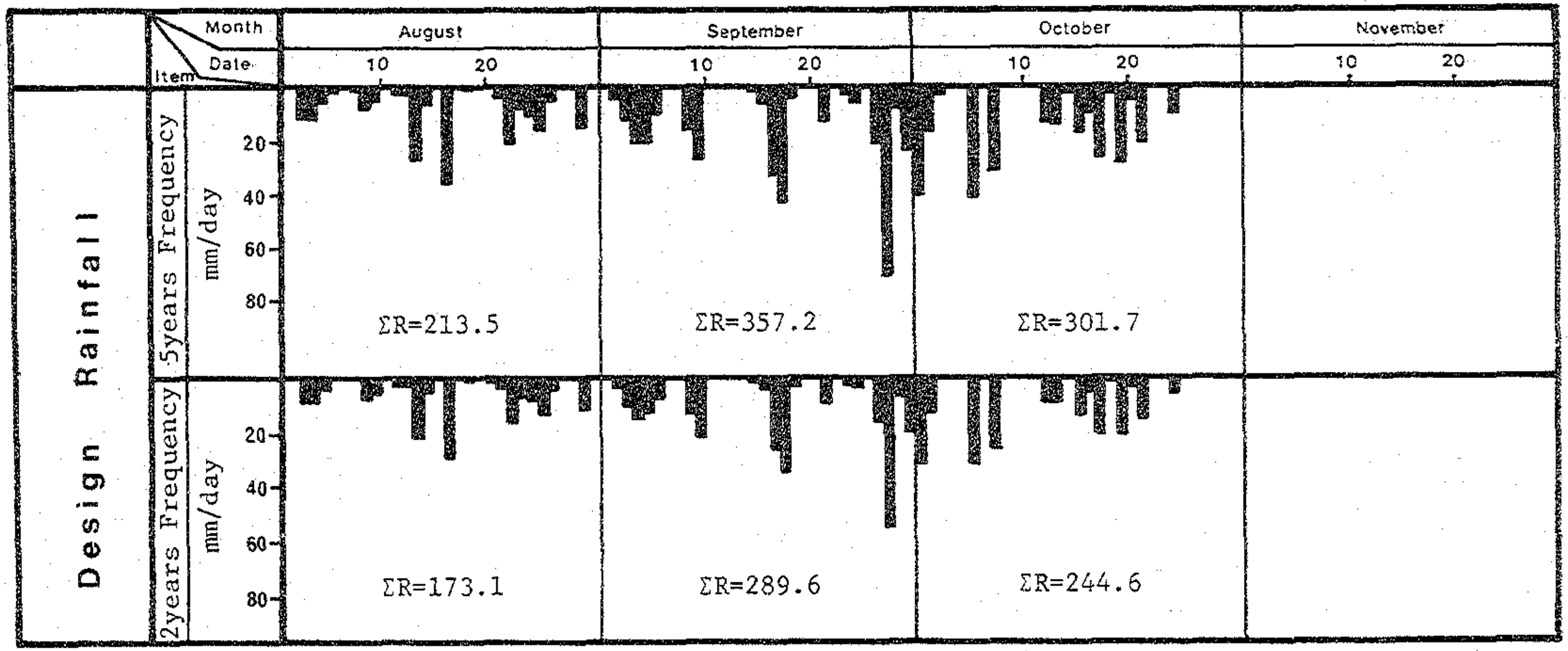

			Daily	3days	Month	3month	Remarks
Areal Average Rainfall ($A=605Km^2$)	Design Rainfall (R_A) (mm)	5 Years Frequency	80.8	150.4	417.3	872.4	
		2 Years Frequency	60.1	105.9	324.0	707.3	
	Observed Rainfall (mm)	Observed in 1980	62.4 (2.5)	93.6 (1.6)	325.0 (2.5)	796.0 (3.0)	( ) : Equivalent Scale of Probability
		Observed in 1983	87.1 (7.0)	114.0 (3.0)	461.5 (7.0)	1078.1 (25.0)	
Point Rainfall at Bangkok (R_P) (mm)		5 Years Frequency	120.2	184.2	468.9	976.8	Bangkok Weather Station
		2 Years Frequency	91.0	137.4	368.5	786.8	

Fig. H.11 THREE MONTHS RAINFALL FOR STEP I ANALYSIS

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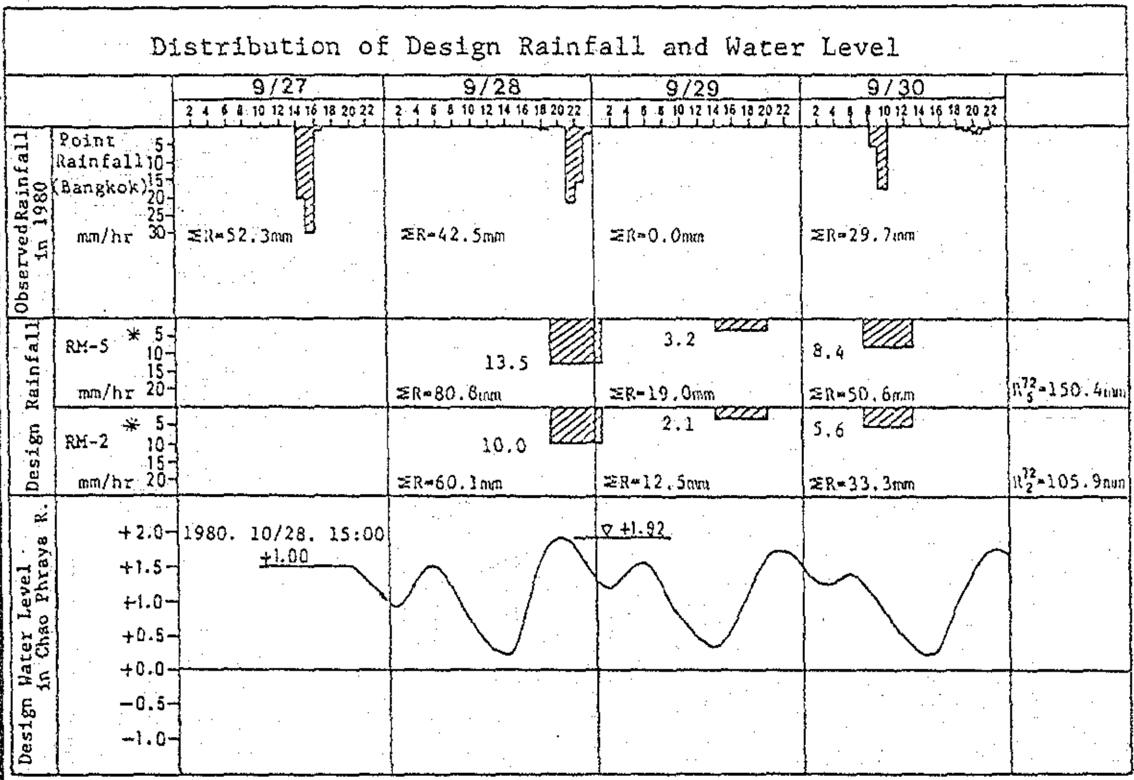

Note * RM-5:5-Year Frequency
RM-2:2-Year Frequency

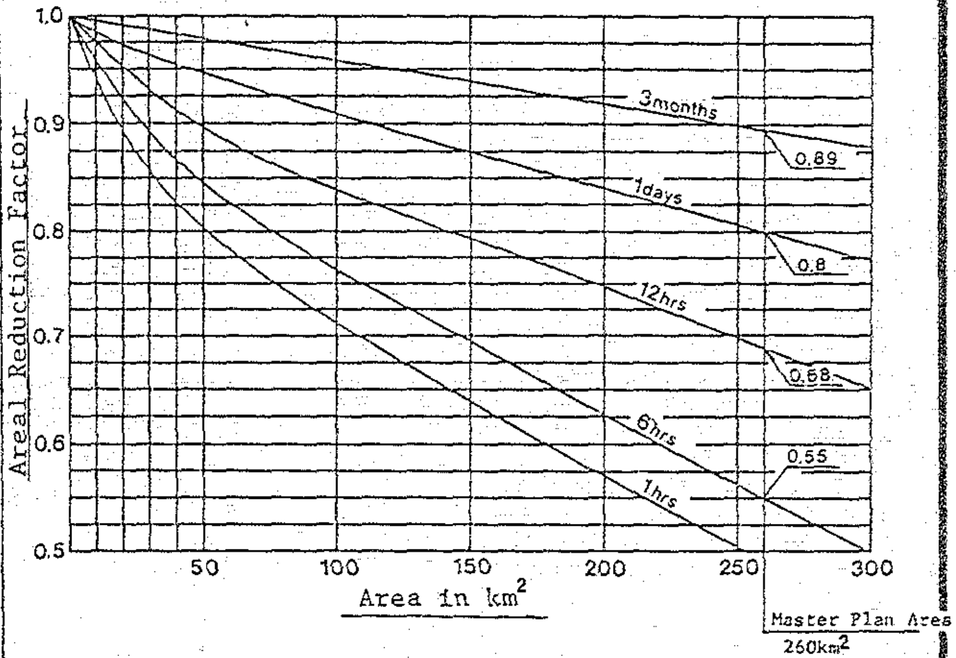

Fig. H.12	THREE DAYS RAINFALL FOR STEP II ANALYSIS
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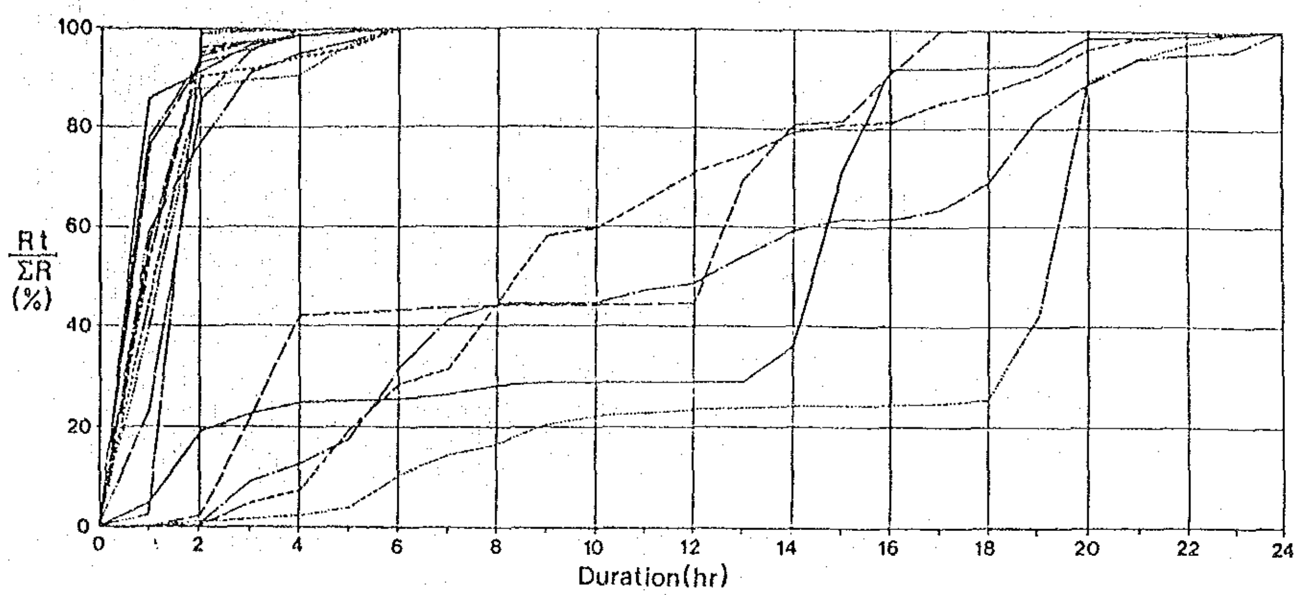
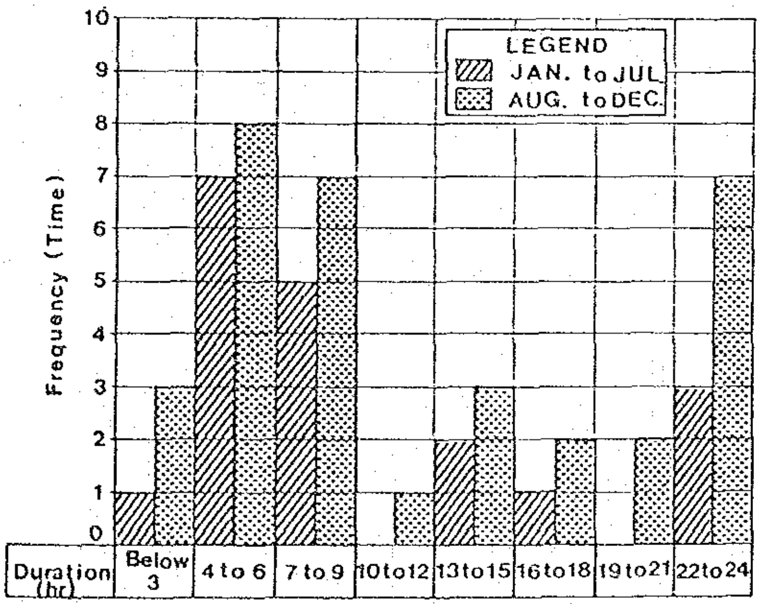


Time Distribution Diagram for Duration of Daily Rainfall above 90 mm/day

Note: Daily rainfall data (15 samples) above 90 mm/day recorded at the Bangkok Station between 1951 and 1982 were used.



Frequency Diagram for Duration of Daily Rainfall above 60 mm/day

Note ; Daily rainfall data (52 samples) above 60 mm/day recorded at the Bangkok Station between 1951 and 1982 were used.

Fig. H.13	OBSERVED RAINFALL DISTRIBUTION PATTERNS AT BANGKOK METEOROLOGICAL OBSERVATORY

MASTER PLAN ON FLOOD PROTECTION/DRAINAGE PROJECT IN EASTERN SUBURBAN-BANGKOK

Design . Run-off Coefficient (fp) and Ratio (ft)

Land Use Type	Run-off Coefficient (fp)	Run-off Ratio (ft)
1. Commercial/Residential High Density	0.75	0.75
2. Residential Medium Density	0.50	0.70
3. Residential Low Density	0.40	0.60
4. Institutional	0.40	0.60
5. Parks/Agriculture	0.15	0.50
6. Industrial	0.70	0.70
7. Railroad Yard	0.35	0.50

Reference Data

1) C D M's Master Plan Report

TABLE 10.1 RUNOFF COEFFICIENTS

Land Use Designation of Area	Average Runoff Coefficients "C" for Varying Drainage Areas, in square kilometers				
	0 to 0.2	0.2 to 0.5	0.5 to 1.0	1.0 to 5.0	5.0 to 20.0
Commercial	0.60	0.50	0.40	0.30	0.25
Residential, high density	0.55	0.45	0.35	0.30	0.25
Residential, medium density	0.50	0.40	0.35	0.30	0.25
Residential, low density	0.45	0.35	0.30	0.25	0.20
Institutional, Manufacturing and Utilities	0.40	0.35	0.25	0.20	0.20
Parks and Agricultural	0.30	0.25	0.20	0.15	0.15

The runoff coefficient ("C") is the variable of the Rational Method least susceptible to precise determination and calls for considerable judgement. The average runoff coefficients shown in Table 10.1 were used in Bangkok and Thonburi.

2) City Core Project Report by B F C D

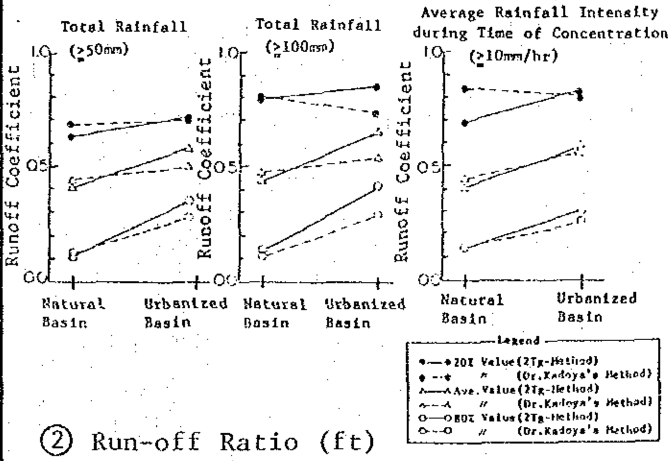
Table Runoff coefficients for various land-use types

Land-use type	Runoff coefficient C
1. Commercial/Residential high density	0.75
2. Residential medium density	0.50
3. Residential low density	0.40
4. Institutional	0.40
5. Parks/Agricultural	0.15
6. Industrial	0.70
7. Railroad Yard	0.35

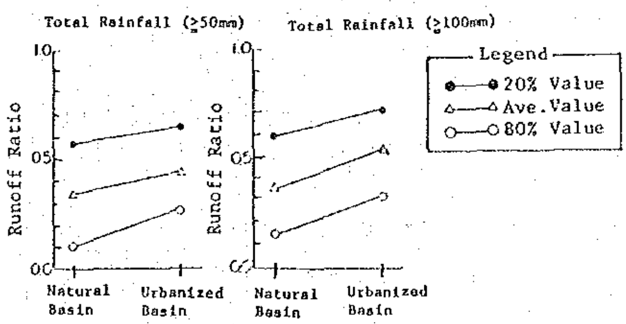
The land-use types for the present and future situation (see Annex H), were transferred to the sub-drainage basin map to determine the runoff coefficients. Weighted average C-values were assigned to the sub-basins, if more than one land-use type was present.

3) Data on Run-off Modeling Area by P W R I (JAPAN)

① Run-off Coefficient (fp)



② Run-off Ratio (ft)



P W R I : The Public Works Research Institute
Ministry of Construction JAPAN
(Dr.Kadoya's Method)

Fig. H.14 DESIGN RUN-OFF COEFFICIENT AND RATIO

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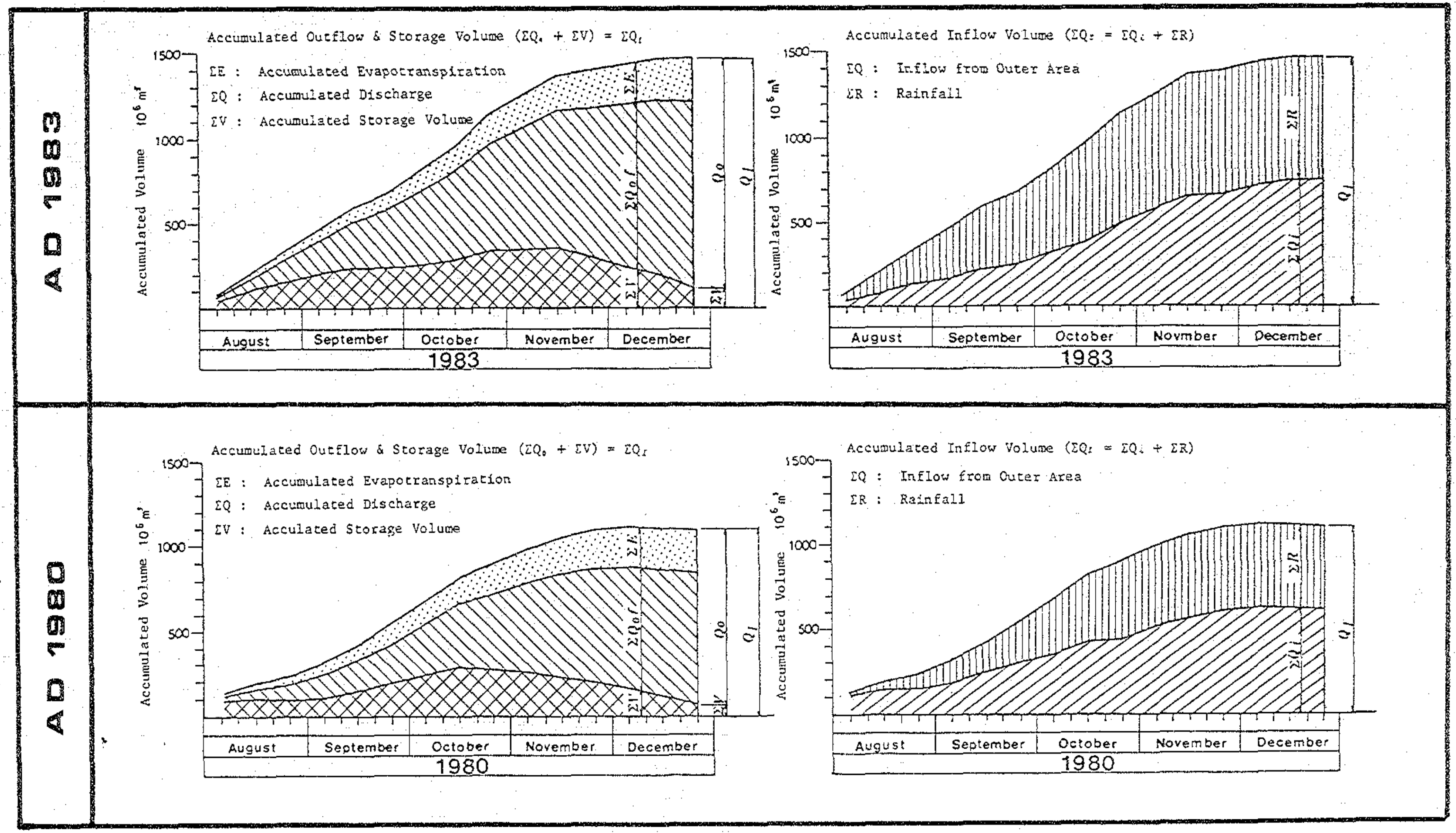

Fig. H.15 ESTIMATED INFLOW AMOUNT FROM OUTER AREA (FLOODING IN 1980 and 1983)

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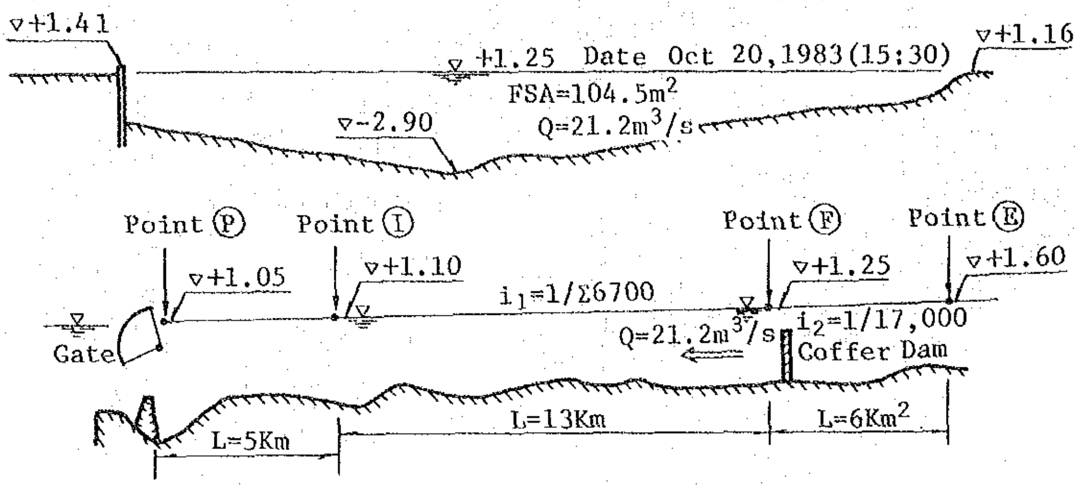
K. Saen Saep Point Ⓕ sta.20



$Q=21.2m^3/s$ $A=104.5m^2$ $P=38m$ $R=A/P=2.75m$

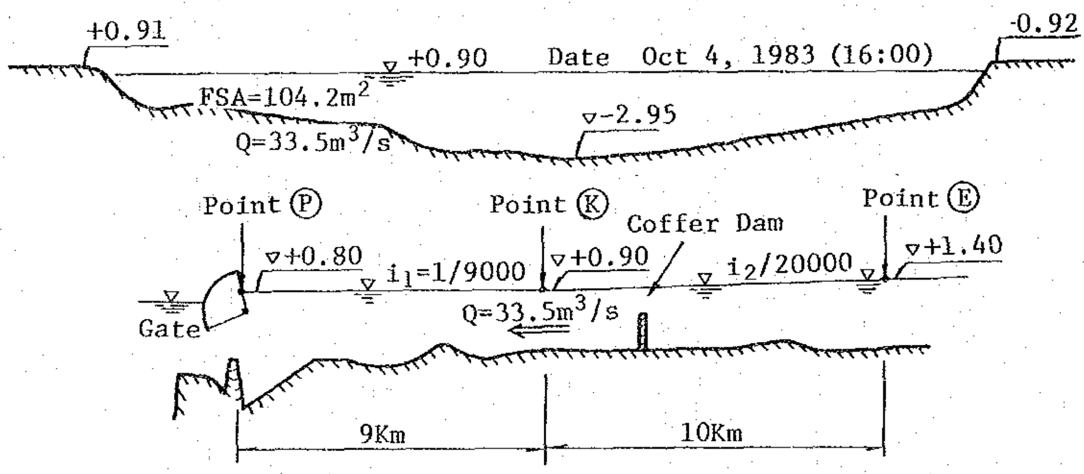
$v=Q/A=0.20m/sec$

$i_1=1/86700 \dashrightarrow n=\frac{1}{v}R^{2/3}i_1^{1/2}=0.033$

$i_2=1/17000 \dashrightarrow n=\frac{1}{v}R^{2/3}i_2^{1/2}=0.075$

$\tilde{i}=\frac{i_1+i_2}{2}=1/51900 \dashrightarrow n=\frac{1}{v}R^{2/3}(\tilde{i})^{2/2}=0.043$

K. Phrakanong Point Ⓚ Sta. 11



$Q=33.5m^3/s$ $A=104.2m^2$ $P=37m$ $R=A/P=2.82m$

$v=Q/A=0.32m/s$

$i_1=1/90,000 \dashrightarrow n=\frac{1}{v}R^{2/3}i^{1/2}=0.021$

$i_2=1/20,000 \dashrightarrow n=\frac{1}{v}R^{2/3}i^{1/2}=0.044$

$\tilde{i}=\frac{i_1+i_2}{2}=1/55,000 \dashrightarrow n=\frac{1}{v}R^{2/3}(\tilde{i})^{1/2}=0.027$

Fig. H.16 ESTIMATED COEFFICIENT OF ROUGHNESS IN MAIN KLONGS (OBSERVED IN 1983)

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