2.3 Hydraulic Model

2.3.1 Drainage Network

Drainage network is schematically shown in Fig. C.12. In this network, klongs are organically connected with retention areas taking into account of land use in future and, the study area is divided into sub-drainage areas according to ground elevation, roads, railway and other topographic conditions.

The drainage network contains following elements;

- Number of klong's section (Block) ---------------- 240
- Number of connective section of block (Section) --- 330
- Number of sub-drainage area ----------------------- 243
- Number of retention area -------------------------- 14

Dimensions of klongs, sub-drainage area and retention area are shown in Tables C.5 to C.7.

2.3.2 Model for Hydraulic Study

The hydraulic models used consist of run-off model in sub-drainage areas, unsteady flow model in klongs and storage model in retention areas.

(1) Run-off Model

The Rational Method, as explained below are used as run-off model in sub-drainage areas.

$$q = \frac{1}{3.6} \cdot ft.r.A$$

where, q : Run-off Discharge (m^3/s)

ft: Run-off Ratio

r : Effective Rainfall (mm/hr)

A : Sub-drainage Area (km^2)

Calculated run-off discharge is an input to klong of unsteady flow model.

Table C.5 Dimension of Klongs (Existing)

(1)

Name of Klong or closed conduit	Block	LengthxWidth (Km) (m)	Name of Klong or closed conduit	Block	LengthxWidth (Km) (m)
K.Song	1	3.2 x 38.0		31	0.2 x 8.0
	2	1.6 x 40.0		32	0.5 x 12.0
	3	2.1 x 36.0		33	0.9 x 8.0 x 2
	4	2.0 x 33.0		34	0.9 x 8.0 x 2
	5	1.5 x 35.0		35	0.7 x 8.0 x 2
	6	2.0 x 34.5		36	0.5 x 8.0 x 2
K.Wang Hin	7	1.5 x 31.5		37	0.5 x 8.0 x 2
	8	1.3 x 31.0	C.C.Phahonvothin Rd.	38	2.5 x 2.3
	9	1.9 x 31.0		39	0.8 x 3.0
	10	1.8 x 26.0		40	0.8 x 3.0
K.Bang Sue	11	2.34x 22.0		41	0.7 x 3.0
	12	0.6 x 18.0		42	0.5 x 3.0
	13	0.6 x 14.0		43	0.6 x 3.0
	14	0.6 x 17.0		44	2.1 x 2.6
	15	1.2 x 20.0	K.Kasesart	45	1.75x 6.0
	16	2.1 x 21.3		46	0.25x 6.0
	17	(Boundary)	C.C.Sena Nichon Rd.	47	1.935x 1.9
K.Bang Khen	18	2.0 x 22.3	K.Lat Yao	48	0.5 x 3.0
	19	1.9 x 15.5		49	1.65x 3.0
	20	2.0 x 12.8		50	0.25x 3.0
	21	1.8 x 15.3	K.Middle Ring	51	0.8 x 4.0
	22	3.3 x 19.0		52	0.55x 4.0
	23	(Boundary)		53	0.3 x 4.0
K.Prem Prachakon	24	0.9 x 24.0		54	0.35x 4.0
	25	2.0 x 24.0		55	3.1 x 4.0
	26	0.9 x 24.0	K.Huay Kwang	56	0.6 x 8.0
	27	1.6 x 24.0	K.Phya Wake	57	1.0 x 7.0
	28	1.8 x 24.0		58	1.0 x 7.0
Highway side-ditch	29	1.8 x 8.0	C.C.Lat Phrao Rd.	59	1.2 x 2.0
	30	0.4 x 8.0	K.Nam Kaem	60	0.9 x 9.0

Width: Average Width

Continued to (2)

Legend

K. : Klong

C.C.: Closed Conduit

Table C.5 Dimension of Klongs (Existing)

Continued from (1) (2)

Name of Klong or closed conduit	Block	LengthxWidth (Km) (m)	Name of Klong or closed conduit	Block	LengthxWidth (Km) (m)
	61	1.5 x 9.5		91	0.5 x 13.0
K.Toong	62	1.35x 6.0		92	0.5 x 12.0
K.Saen Saep	63	1.5 x 32.5		93	0.5 x 11.0
	64	1.5 x 30.0		94	1.0 x 17.0
	65	1.0 x 26.0		95	1.2 x 18.0
	66	1.0 x 26.0		96	1.3 x 15.3
	67	0.8 x 28.0	K.Sam Wa	97	2.0 x 8.0
	68	1.2 x 29.0	K.Bang Chan	98	2.0 x 8.0
	69	1.0 x 33.0	K.Land Chala	99	2.0 x 12.0
	70	1.0 x 32.0		100	2.0 x 12.0
	71	0.8 x 30.0		101	2.0 x 12.0
	72	0.5 x 30.0	K.Lam Cheak	102	1.5 x 12.0
	73	0.7 x 30.0		103	2.5 x 12.0
	74	0.7 x 30.0	K.Ta Nang	104	1.5 x 9.5
	75	0.5 x 30.0		105	2.5 x 8.0
K.Tan	76	2.4 x 31.8		106	2.0 x 8.3
	77	2.0 x 30.8	K.Lum Phai	107	1.5 x 5.5
K.Phra Khanong	78	2.7 x 31.0	K.Lad Plakao	108	1.5 x 7.0
	79	1.3 x 31.8		109	2.0 x 9.0
	80	2.0 x 30.8	K.Chan	110	2.0 x 13.5
	81	1.0 x 31.0		111	1.5 x 7.0
	82	1.5 x 31.0		112	1.5 x 7.5
	83	1.5 x 30.3		113	1.5 x 10.0
	84	1.5 x 35.0		114	2.0 x 11.5
	85	2.0 x 33.5	K.Sua Noi	115	2.0 x 8.0
	86	(Boundary)	K.Kla Tiam	116	2.0 x 11.0
K.Lat Phrao	87	1.8 x 14.0		117	2.0 x 9.0
	88	0.5 x 16.0	K.Chao Khun Sing	118	0.6 x 12.9
	89	1.7 x 18.0		119	1.0 x 12.9
K.San Sen	90	1.2 x 7.6		120	1.0 x 23.0

Width: Average Width

Continued to (3)

Legend

K. : Klong

C.C.: Closed Conduit

Table C.5 Dimension of Klongs (Existing)

Continued from (2) (3)

Name of Klong or closed conduit	Block	LengthxWidth (Km) (m)	Name of Klong or closed conduit	Block	LengthxWidth (Km) (m)
	121	2.0 x 8.0	Railway side-ditch	151	2.0 x 10.0
K.Wat Tuk	122	2.0 x 10.0		152	1.0 x 10.0
K.Huay Kwang	123	1.05x 9.0		153	1.0 x 10.0
	124	1.3 x 6.5	K.Saen Sab	154	2.0 x 5.0
	125	2.0 x 6.5	K.Sakae	155	2.0 x 8.0
K.Sam Saen Noi	126	2.0 x 6.0	K.Saen Sab	156	2.0 x 6.5
K.Chuad.Yai	127	2.0 x 10.0	K.Sakae	157	2.0 x 8.0
C.C.Suthisan Rd.	128	1.0 x 1.0	K.Bang Ma	158	2.0 x 5.0
Highway side-ditch	129	2.7 x 5.6		159	2.0 x 5.0
	130	0.9 x 5.1	K.Hua Mark	160	2.0 x 14.0
C.C.Suthisan-Huay Khwang Rd.	131	1.0 x 1.0		161	2.0 x 10.0
K.Na Song	132	1.1 x 4.0	K.Khon Sohon	162	1.0 x 9.5
	133	1.0 x 5.0		163	1.0 x 12.0
	134	1.4 x 6.8		164	1.1 x 5.0
C.C.Phachasong Kro Rd.	135	2.0 x 5.3	K.Klet	165	1.0 x 8.0
C.C.Asok-Din Daeng	136	1.0 x 0.6		166	0.7 x 9.5
K.Ku Nam	137	0.4 x 6.5		167	0.6 x 11.0
C.C.Soi Technic Wittaya School	138	0.8 x 1.2		168	0.7 x 9.0
K.Yai Soon	139	1.6 x 7.0		169	1.0 x 6.5
K.Bang Kapi	140	0.9 x 8.0		170	1.0 x 5.5
K.Bang Ma	141	2.0 x 5.0		171	1.2 x 6.5
	142	1.5 x 5.0	K.Bang Na	172	1.0 x 8.0
K.Hua Mark	143	2.0 x 5.0		173	1.0 x 9.0
K.Chit	144	1.3 x 9.0		174	1.1 x 11.0
K.Gig	145	1.54x 8.0		175	1.1 x 16.0
C.C.Ramkhamhaeng	146	2.0 x 1.5		176	1.0 x 12.5
	147	1.2 x 1.5		177	1.0 x 13.5
K.Kacha	148	3.1 x 8.7	Route 34	178	1.1 x 35.0
	149	1.0 x 14.5		179	0.7 x 35.0
	150	1.0 x 15.0		180	0.6 x 35.0

Width: Average Width
Legend
K. : Klong
C.C.: Closed Conduit

Continued to (4)

Table C.5 Dimension of Klongs (Existing)

Continued from (3) (4)

Name of Klong or closed conduit	Block	LengthxWidth (Km) (m)	Name of Klong or closed conduit	Block	LenghxWidth (Km) (m)
	181	0.75x 35.0		211	0.6 x 10.5
	182	0.9 x 20.0		212	0.56x 7.5
C.C.Route 3102	183	0.9 x 5.0	K.Bang Oa	213	0.7 x 9.0
	184	1.0 x 5.0		214	0.8 x 10.0
K.Bang Na Trad K3	185	0.6 x 4.0		215	0.8 x 10.0
K.Bang Na Trad K2	186	0.6 x 4.0	K.N.N.	216	0.7 x 3.0
K.Bang Na Trad K1	187	0.7 x 4.0	C.C.Soi50-Soi79	217	0.7 x 1.9
	188	0.65x 4.0	K.Soi50	218	0.9 x 4.0
C.C.Sukhumvit Rd.	189	0.5 x 1.9	K.Bang Jek	219	1.0 x 5.0
K.Bang Lai	190	1.0 x 8.0	K.N.N.	220	0.45 x 3.0
	191	0.7 x 9.5	C.C.Sukhmvit Rd.	221	0.7 x 1.9
	192	0.53x 10.5		222	0.7 x 1.9
	193	1.1 x 8.25		223	0.7 x 1.9
K.Bang Bon	194	0.8 x 6.75		224	0.9 x 4.95
	195	0.8 x 6.25		225	0.6 x 2.45
	196	0.67x 10.0	K.Jek	226	0.58x 6.5
	197	0.6 x 8.0		227	1.0 x 7.5
C.C.Soi 101/1	198	1.0 x 1.9	K.Bang Chak 1	228	0.55x 6.0
	199	1.5 x 1.9		229	0.8 x 8.5
	200	1.0 x 1.9		230	1.0 x 9.5
C.C.Soi 103	201	1.0 x 1.2	K.Bang Chak 2	231	0.9 x 7.0
	202	1.5 x 1.2		232	0.85x 7.0
	203	1.0 x 1.2		233	(Boundary)
C.C.Soi 66/1	204	0.5 x 1.9		234	(Boundary)
C.C.Sukhmvit Rd.	205	0.75x 1.9		235	(Boundary)
K.Suan Aoi	206	0.6 x 5.0		236	(Boundary)
K.Kwang Lai	207	1.0 x 5.0		237	(Boundary)
K.Bang Na Chine	208	1.0 x 8.0		238	(Boundary)
	209	0.8 x 9.0		239	(Boundary)
	210	0.6 x 12.0		240	(Boundary)

Width: Average Width

Legend

K. : Klong

C.C.: Closed Conduit

Table C.6 Size of Sub-drainage Area (Future) - (1)

Sub-drainage Area	Land Use Type	Area (Km^2)	Sub-drainage Area	Land Use Type	Area (Km^2)	Sub-drainage Area	Land Use Type	Area (Km^2)
1	RM	4.50	31	RL	1.40	61	RL	2.70
2	RL	2.40	32	RM	0.63	62	RL	2.20
3	INS	8.20	33	RM	0.43	63	RL	0.80
4	RL	0.90	34	RM	0.18	64	RL	1.10
5	RM	1.80	35	RM	0.77	65	RL	1.40
6	INS	1.33	36	RM	0.58	66	RL	0.70
7	RL	1.00	37	RM	0.40	67	RL	1.70
8	RM	2.20	38	RM	1.16	68	RL	1.80
9	RM	1.71	39	COM	0.26	69	RL	1.50
10	RM	0.44	40	COM	0.18	70	RL	3.70
11	RM	1.11	41	COM	0.27	71	RL	2.10
12	RM	0.94	42	COM	0.56	72	RL	1.70
13	RM	0.75	43	RM	0.39	73	RL	4.40
14	RM	0.81	44	RM	0.30	74	RL	0.70
15	RM	0.37	45	RM	0.83	75	RL	1.50
16	RM	0.94	46	RM	0.42	76	RL	0.60
17	RM	0.16	47	RM	0.80	77	RL	0.80
18	INS	1.95	48	RL	2.71	78	RL	1.30
19	RL	2.70	49	COM	0.31	79	RL	0.90
20	RL	3.00	50	RL	0.31	80	RL	0.70
21	RL	4.40	51	RM	0.38	81	RL	1.50
22	RM	1.30	52	RM	0.56	82	RL	0.90
23	INS	1.80	53	RL	0.17	83	RL	1.40
24	RL	1.00	54	RM	0.41	84	RL	2.60
25	RL	4.50	55	RM	0.66	85	RL	2.10
26	RL	2.30	56	RM	0.52	86	RL	1.10
27	RL	3.40	57	RL	0.80	87	RL	1.50
28	RL	1.80	58	RL	0.80	88	RL	1.50
29	RL	1.40	59	RL	2.20	89	RL	1.10
30	RL	1.40	60	RL	0.70	90	RL	4.30

Table C.6 Size of Sub-drainage Area (Future)-(2)

Sub-drainage Area	Land Use Type	Area (Km2)	Sub-drainage Area	Land Use Type	Area (Km2)	Sub-drainage Area	Land Use Type	Area (Km2)
91	RL	2.90	121	RL	0.70	151	RL	1.30
92	RL	1.60	122	COM	0.54	152	COM	1.70
93	RL	1.10	123	RL	1.60	153	RL	0.70
94	RL	1.00	124	RL	1.70	154	RL	0.50
95	RL	1.50	125	RL	1.60	155	RL	1.70
96	RL	1.00	126	RL	2.10	156	RL	0.40
97	RL	1.70	127	RL	0.30	157	RL	1.20
98	RL	2.20	128	RL	0.47	158	RL	0.67
99	RL	0.80	129	RL	0.53	159	RL	1.09
100	RL	1.20	130	RL	0.33	160	RL	0.74
101	RL	0.50	131	RL	0.15	161	RL	0.26
102	RL	2.40	132	RL	0.51	162	RL	0.14
103	RL	1.10	133	RL	0.20	163	RL	0.20
104	RL	0.80	134	COM	0.25	164	RL	0.30
105	RL	1.10	135	COM	0.25	165	RL	0.38
106	RL	2.00	136	INS	0.93	166	RL	0.51
107	RM	0.41	137	COM	0.33	167	RL	0.39
108	RM	0.31	138	COM	0.32	168	RL	0.43
109	RM	0.33	139	RL	0.65	169	RL	0.29
110	RM	0.25	140	RL	1.10	170	RL	0.23
111	RM	0.46	141	RL	0.65	171	RL	0.30
112	RM	0.20	142	RL	0.58	172	RL	0.25
113	RM	0.42	143	RL	0.34	173	COM	0.28
114	RM	0.65	144	RL	0.68	174	RM	0.45
115	RM	0.69	145	COM	0.52	175	RM	0.52
116	RM	0.54	146	RL	0.60	176	RM	0.31
117	RM	1.42	147	RL	2.90	177	RM	0.14
118	COM	0.60	147	RL	1.20	178	RM	0.14
119	COM	0.12	149	RL	2.10	179	RM	0.25
120	RL	0.80	150	RL	1.40	180	RM	0.25

Table C.6 Size of Sub-drainage Area (Future)-(3)

Sub-drainage Area	Land Use Type	Area (Km2)	Sub-drainage Area	Land Use Type	Area (Km2)	Sub-drainage Area	Land Use Type	Area (Km2)
181	RL	0.24	211	COM	0.13	241	RL	0.92
182	RL	0.31	212	COM	0.10	242	RL	0.99
183	RL	0.24	213	COM	0.04	243	RM	0.27
184	RL	0.32	214	COM	0.29			
185	RL	0.47	215	COM	0.09			
186	RL	0.34	216	RM	0.36			
187	RM	0.35	217	RM	0.57			
188	COM	0.06	218	RM	0.49			
189	COM	0.05	219	COM	0.15			
190	RL	0.49	220	IND	0.20			
191	RL	0.28	221	RM	0.34			
192	COM	0.12	222	IND	1.12			
193	RL	0.25	223	RM	0.18			
194	RL	0.85	224	RL	0.35			
195	RM	0.43	225	RM	0.20			
196	COM	0.26	226	RL	0.27			
197	RL	0.41	227	IND	0.23			
198	RL	0.87	228	RL	0.43			
199	RL	0.44	229	IND	0.15			
200	COM	0.09	230	RL	0.42			
201	COM	0.09	231	RL	0.16			
202	COM	0.18	232	RL	0.11			
203	COM	0.18	233	RL	0.77			
204	COM	0.13	234	RL	0.77			
205	COM	0.14	235	RL	0.54			
206	COM	0.14	236	RL	0.42			
207	COM	0.16	237	RL	0.67			
208	COM	0.30	238	RL	0.54			
209	COM	0.21	239	RL	0.40			
210	COM	0.17	240	RL	0.32			

Legend

Land Use Type

- RM Residential Area (Medium Density)
- RL Residential Area (Low Density)
- COM Commercial Area
- IND Industrial Area
- INS Institutional Area

Table C.7 Size of Retention Area

(Unit:Km^2)

No.	Existing	Future	Remark
1	2.04	1.37	Bang Sue D.A.
2	2.50	2.50	Bang Sue D.A.
3	12.13	7.00	Lat Phrao D.A.
4	13.72	8.00	K.Chan D.A.
5	12.80	9.80	Lat Phrao D.A.
6	10.20	2.30	Lat Phrao D.A.
7	6.08	1.30	East-Huay Kwang D.A.
8	11.75	2.00	East-Huay Kwang D.A.
9	17.01	8.80	Patterna Karn D.A.
10	4.31	1.10	Ramkhamhaeng D.A.
11	9.44	3.70	South-Hua Mark D.A.
12	0.38	0.38	West-Huay Kwang D.A.
13	0.50	0.50	Bang Na D.A.
14	4.82	0.50	Bang Na D.A
Total	107.68	49.25	

a. Run-off ratio (ft)

Run-off ratio as shown in Table C.8 are adopted according to land use types.

Table C.8 Run-off Ratio

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

b. Effective Rainfall (r)

Effective rainfall is calculated using hyetograph as shown in Fig. C.13 based on rainfall intensity-duration curve.

c. Time of Concentration (tc)

Time of concentration is used for calculation of hyetograph. This was estimated in the Master Plan as follows:

$$tc = to + L/V$$

where, to : inlet time of run-off flow over the ground surface to the nearest drain, 10 minutes

L : length of drain from the most remote inlet to the point of consideration (m)

V : average velocity of drain, 0.35 m/s

This is reviewed and estimated based on kinematic wave method.

$$h = k.q^p$$

$$k = (ne/\sqrt{i})\quad p$$

where, h : water depth

q : run-off discharge per unit width

p : constant, 0.6

ne : equivalent roughness, 0.07

i : gradient of ground surface, 0.0001

$$r = \frac{\partial h}{\partial t} + \frac{\partial q}{\partial x}$$

where, r : rainfall

t : time interval

x : Length of ground surface

As a result, calculated time of concentration is presented in Fig. C.13.

(2) Unsteady flow model

Unsteady flow model consists of momentun and continuity equations as follows;

. Momentun equation

$$\frac{dQ}{dt} + \frac{d}{dx}\left(\frac{Q^2}{A}\right) + gA\frac{dZ}{dx} + g\frac{n\ 1Q1.Q}{AR^{4/3}} = 0 \text{ ....(a)}$$

. Continuity equation

$$\frac{dZ}{dt} + \frac{dQ}{dx} = r + q \text{ ....(b)}$$

t : Time

u : Velocity

Q : Flow

A : Sectional flow area

Z : Water level

g : Gravity acceleration

R : Hydraulic radius

n : Coefficient of roughness

r : Rainfall

q : Side inflow

For the solution of above equations, the difference scheme method is applied and, the hydraulic situation of klongs is analysed.

(3) Storage Model

Storage model is applied to express hydrology in retention area. Firstly, water level in each retention area is calculated based on Height-Volume curve, which are obtained from the topographical condition, and run-off discharge in sub-drainage area. Discharge between retention area and klong are calculated by unsteady flow model, using the calculated water level in retention area as the boundary condition. In other words, change of storage volume in retention area is expressed as follows:

$$\frac{\Delta V}{\Delta t} = R + q \pm Q$$

where, ΔV : change of storage volue

Δt : time interval

R : rainfall

q : discharge from sub-drainage area

Q : outflow to or inflow from klong.

2.3.3 Calibration and Verification of Model

The above-mentioned models are calibrated and verificated in Ramkhamhaeng inner polder. This polder is characterized as shown in Fig. C.14 and is schematically shown in Fig. C.15 from the hydraulic point of view.

Using the results of run-off analysis on rainfall on Oct. 19, 1985 (31mm/day), equivalent roughness (ne) of run-off model and roughness coefficient (n) of unsteady flow model are calculated water levels generally coincide with the observed water levlels when the values as shown in Table C.9 are used.

These values are calibrated and verified as shown in Figs. C.16 to C.17 and therefore, these models are considered appropriate for the Feasibility Study.

Table C.9 Value of Roughness

Item	Value	Remark
Equivalent Roughness	ne = 0.07	Used for Calculation of tc
Coefficient of Roughness (Manning's)		Determined in M/P
. Open Channel		
Retaining wall	n = 0.020	
Mad Bed	n = 0.035	
. Pipe, Box	n = 0.015	

2.4 Proposed Drainage System

Particular attention is paid to existing klongs and side-ditches of road in order to increase retention capacity. Short-duration inundation is also considered in planned sparsely-populated areas (designated retentin areas) to protect densely-populated areas (urbanized areas) economically. The respective polders are described in the following subsections. In these subsections the works to be executed are divided into two categories.

- Category I : new works and major improvements
- Category II : existing works which require only slight adjustment or no improvement.

2.4.1 Basic Concept for System Planning

The small capacity of discharge or storage of klongs is thought to be one of the causes of floowing in the study area. Therefore, improvement works of klongs are required for alleviation of flood. If retention area/pond are remained in future, it is expected that improvement works will be fairly saved. Then, three cases about retention area as shown in Fig. C.18 and Table C.10 are studied. According to the results, flood damage evidently varys according to the size of retention area. Considering the reclamation of retention area, flood will be expected to occur more severely after reclaimed. As above mentioned, retention area is very effective for alleviation of flood, in other words, saving improvement works. Therefore, based on the land use plan, retention area/pond are planned as large as possible in the drainage system.

Table C.10 Area vs Ground Elevation in Model Cases

Ground Elevation (m)	Area (km^2)					
	CASE-1		CASE-2		CASE-3	
	A_1	A_1	A_2	A_2	A_3	A_3
R.A. (-0.5)	0.5	0.5	0.25	0.25	0	0
-0.4	0.5	1.0	0.75	1.0	1.0	1.0
-0.3	0.5	1.5	0.5	1.5	0.5	1.5
-0.2	3.5	5.0	3.5	5.0	3.5	5.0
-0.1	4.0	9.0	4.0	9.0	4.0	9.0
Total	9.0	-	9.0	-	9.0	-

2.4.2 Bang Na Polder (31 km^2)

Bang Na polder is divided into four sub-drainage areas as shown in Fig. C.19. Area A located between the Chao Phraya River and the Sukhumvit road has three klongs (Jek, Bang Chak and Bang Oa) running westward into the river. Klongs Bang Nang Chine and Bang Lai in area B run northward into Klong Phra Khanong. Klong Bang Nang Chine connects with area A crossing Sukumvit road and the expressway. Klong Klet in area C runs northward into Klong Phra Khanong, and Klong Bang Na in area D runs westward into the Chao Phraya River.

(1) Alternatives

Taking into account of the above conditions, three altenatives (see Fig. C.19 and Table C.11) are compared. These alternatives have the 1.0 km^2 retention areas which spread between Klongs Klet and Bang Lai.

Alternative BN-1 separates four areas while alternatives BN-2 and BN-3 combines two areas. In alternative BN-2 rainwater in the areas A and B, and in alternative BN-3 rainwater in the areas C and D are to be discharged respectively into the Chao Phraya river.

Improvement works of klongs and drains are considered in each alternative in order that no flooding occurs generally in the whole area. All of klongs have only a small longitudinal gradient as the ground elevation of the middle area is the lowest in this polder.
According to this fact the influence of pump discharge is not effective to the upstream of klongs. Thus the latter two alternatives need widening klongs. Project cost in construction and land acquisition is as follows;

Alternative BN-1	1,080 million Baht
Alternative BN-2	1,190 million Baht
Alternative BN-3	1,340 million Baht

Alternative BN-1 is the lowest cost in three alternatives.

Table C.11 Sub-Drainage Areas and Their Primary Klongs and Pumping Station in Alternative of Bang Na Polder

(Unit: m^3/s)

Sub-drainage Area Alternative		Pumping Station A	B	C	D	Measures for alleviation of flooding in soi 103
BN-1	Base(1)	Jek ($3\ m^3/s$) Bang Oa (12)	Bang Nang Chine (9) Bang Lai (6)	Klet (9)	Bang Na (15)	Small Pipe
	(2)					By-pass Klong to Bang Na
	(3)					Large Pipe
BN-2		Jek (3) Bang Oa (18)		Klet (9)	Bang Na (15)	Same as alternative 1-1
BN-3		Jek (6) Bang Oa (12)	Bang Nang Chine (12)	Bang Na (24)		Same as alternative 1-1

In addition, increase of discharge into Klong Phra Khanong in BN-1 is found to bring no increase of klong improvement works and capacity of Phra Khanong Pumping Station as explained later. Therefore, alternative BN-1 is recommended.

(2) Improvement works

In the adopted alternative BN-1 (base), some flooding is expected in the middle of the polder, border area of areas B and D. This flooding is caused by a lack of drain capacity in Soi 103. Although the damage is little, in order to alleviate this floodings, construction of new klongs connecting with Klong Bang Na (alternative BN-1 (2)) and enlargement of drain along soi 103 (alternative BN-3)) are compared. As a result, alternative BN-1(3) is recommended.

Water levels and discharge of recommended alternative BN-1 (3) are shown in Fig. C.20. The improvement works are indicated in Table C.12.

Table C.12 Drainage Works in Bang Na Polder

	Category I	Category II
Pumping Station		
- Bang Na		248
- Bang Oa		299
- Jek		316
- Bang Na Chine	291	
- Bang Lai	269	
- Klet	235	
Klong		
- Bang Na	172,173,174,175,176,177	
- Bang Na Trad K1	187,188	
- " K2	186	
- " K3	185	
- Klet	165,166,167,168,169,170	
- Khon Sohon	162,163,164	
- New Klong	171	
- Bang Lai	190,191,192,193	
- Bang Bon	194,195,196,197	
- Bang Nang Chine	208,209,210,211,212, 213 (Part), 225	
- Suan Aoi	206	
- Kwang Lai	207	
- Bang Jek	219	
- Soi 50	218	
- N.N.	216,220	
- Jek	226,227	
- Bank Chak 1	228,229,230	
- Bang Chak 2	231,232	
- Bang Oa	213 (Part),214,215	
Drain		
- Sukhumvit Rd.		221,222,223, 224,205,189
- Soi 101/1		198,199,200
- Soi 103	201,202,203	
- Soi 50-Soi 79	217	
- Soi 66/1		204
- Route 3102	183,184	
- Route 34		178,179,180,181,182

Pumping Station ..... Section Number in Fig. C.12
Klong, Drain .... Block Number in Fig. C.12

2.4.3 Phra Khanong Polder (165 Km^2)

Phra Khanong polder contains 6 drainage areas and one inner polder (North Hua Mark). Main klongs, Klongs Saen Saeb, Tan and Phra Khanong, run in this polder.
Klong Saen Saeb runs westward connecting Klong Tan. Klong Tan runs southward into Klong Phra Khanong. Klong Phra Khanong runs westward into the Chao Phraya River and is the only outlet of this polder. In this paragraph, only main facilities are described under the design rainfall of 5-year frequency.

1) Proposed System

Drainage system in Phra Khanong Polder has been reviewed and modified. Rainwater is to be discharged into the Chao Phraya River by means of the Phra Khanong pumping station. In this situation inflow from the Core Area (15 m^3/s) and Bang Na Polder (24 m^3/s) as shown in Fig.C.21 is considered. The recommended (by the Master Plan) capacity for the Phra Khanong pumping station is 90 m^3/s. Hydraulic analysis has been executed under these conditions. The results are shown in Figs. C.22, C.23. Although improvement works of klongs are partially required, the recommended capacity (90 m^3/s) is sufficient for the Phra Khanong pumping station.

The recommended system, revised improvement works are indicated in Table C.13.

Table C.13 Drainage Works in Phra Khanong Polder

	Category I	Category II
Pumping Station		
Phra Khanong	-	106
Klong		
° Phra Khanong	80, 81, 82, 83	
° Tan	76, 77	
° Saen Saep	69,70,70,72,73,74,75	

Pumping Station ..... Section Number in Fig. C.12
Klong .... Block Number in Fig. C.12

2) Influence of Additional Inflow from the Core Area.

Flood Protection/Drainage project are also planning in the City Core Area. In that project, increase of discharge from 15 m^3/s to 35 m^3/s into the most upstream of Klong Tan from the east polder of Core Area is under consideration.

Therefore, in this report increase of inflow is analysed how flooding situation of Phra Khanong polder is affected. According to the analysis, flooding will occur near Ramkamhaeng in Klong Saen Saep and, further, highest water level will increase by about 20 cm (See Figs. C.24, C.25).

In order to alleviate this flooding, three measures have been considered as following,

- . Increase of Phra Khanong pumping station
- . Diversion channel
- . Widening of klong

(1) *Increase of Phra Khanong pumping station.*
Increase of pumping capacity from 90 m^3/s to 105 m^3/s has been analysed.

According to the result as shown in Fig. C.26, flooding will remain although highest water level will be reduced by about 10 cm. Consequently, improvement works of klongs are further required.

(2) Diversion Channel
Diversion channel connecting Klong Saen Saep with Klong Phra Khanong has been also analysed. Diversion channel will cause water level in Klong Phra Khanong to increase as shown in Fig. C.26. The reason is that rainwater in the east drainage area is to be discharged into Klong Phra Khanong much more easily. Therefore, water level in Klongs Tan, Saen Saeb will be affected by backwater from Klong Phra Khanong and, increase simultaneously. Consequently, this measure is not effective and not recomended.

(3) Widening of Klong

Klong Tan was thought to be a bottle-neck because of its scale. Therefore, in order to increase the sectional flow area, widening of Klong Tan is studied.

In this study, three cases in which the pump capacities at Phra Khanong pumping station are 90, 105 and 110 m^3/s are applied. The results are shown in Fig. C.27. The hydraulic situation which must be subjected is due to the same water level as obtained by proposed facilities in M/P.

In the case that pump capacity is 90 m^3/s, increasing of water level is only alleviated from 20 cm to 15 cm by means of 10m widening of Klong Tan.

On the other hand, in the case that pump capacity is increased from 90 m^3/s to 110 m^3/s and the widening of Klong Tan is 10 m, the widening measure of Klong Tan is effective and maximum water level in Klong Tan will almost reduce to the hydraulic situation obtained by the proposed system.

If land acquisition can be possible and pump capacity is 110 m^3/s, additional inflow of 20 m^3/s from the City Core Area is acceptable.

2.4.4 Ramkamhaeng (North Hua Mark) Polder (9 km^2)

Ramkhamhaeng area, bordered by Klong Saen Saep in the north, east-bound railway in the south and Bang Kapi - Bang Na Trad road in the east will form an inner polder within Phra Khanong polder. Klong Kacha runs in east-west direction in the middle of the area, branching off Klongs Gig, Saen Sab and Sakae.

(1) Alternatives

In alternative R-1 (See Fig. C.28), storm water is planned to be pumped out into Klong Saen Saeb through Klongs Kacha and Gig. Besides, storm water in the Ramkhamhaeng Campus and the area between Ramkhamhaeng road and Klong Saen Saeb is planned to be pumped into Klong Saen Saeb since they are lower topographically.

Alternative R-2 is considered to relieve overloaded Klong Tan, downstream of Klong Saen Saeb i.e., storm water is to be pumped out southward through Klong Lao connecting Klong Phra Khanong.

Table C.14 Pumping Stations in Alternatives

Alternative	Pumping station
R-1	Kacha (6 m^3/s), Chit (3 m^3/s), Campus (1 m^3/s)
R-2	Lao (9 m^3/s), Campus (1 m^3/s)

According to the future land use plan, relatively large retention areas (1.1 km^2) will remain as compared with other drainage areas.

Consequently, improvement works in both alternatives are the same in terms of klongs and pump capacity. However, influence of pump discharge in alternative R-2 is more effective than in alternative R-1 because rainwater is to be discharged at the middle of Klong kacha in alternative R-2.

(2) Improvement works

Alternative R-2 is adopted to reduce overloaded Klong Tan discharge capacity. The improvement works of revised drainage system are shown in Table C.15 and water levels and discharge of recommend alternative R-2 are shown in Fig. C.29.

Table C.15 Drainage Works in Ramkhamhaeng Polder

	Category I	Category II
Pumping Station		
- Lao	215	-
- Ramkhamhaeng		202
Klong		
- Kacha	148 (part), 149,150	-
- Gig	145	-
- Chit	144	-
- Sakae	-	153 (part)
- Railway sideditch	151,152,153 (part)	
Drain		
- Ramkhamhaeng road	-	147,146 (part)
- Soi 35	146 (part)	-

Pumping Station ..... Section Number in Fig. C.12
Klong, Drain .... Block Number in Fig. C.12

2.4.5 West Huay Khwang Drainage Area (24 km^2)

West Huay Kwang drainage area is enclosed by Klong Bang Sue in the north, super highway in the west, east-bound railway in the south and planned BMA road near Klong Lat Phrao in the east. Some storm water in this area used to be discharged westward into the Chao Phraya river through Klong Sam Sen until the construction of the polder for the City Core Area in later 1970s.

(1) Alternatives

Taking account of existing topographic conditions and klong network, three alternatives are compared as the ways of discharging rainwater. (see Fig. C.30, Table C.16). The discharge westward (alternative HK-3) is not practical because of an extensive amount of widening or tunnel construction in the congested City Core Area and the limited capacity of Klong Sam Sen as studied in the City Core Project. Further it is pointed out that ground elevation in the east will become lower than in the west due to land subsidence.

Therefore, the possible ways of discharging storm water are 1) through Klong Sam Sen eastward then Klongs Tan and Phra Khanong (alternative HK-1 of Fig. C.30) and 2) in addition of Klong Sam Sen, through Klong Bang Sue westward partly (alternative HK-2).

Comparison of both alternatives reveal that 1) drainage facilities are the same except Huay Kwang pumping station (3 m^3/s), discharging into Klong Bang Sue of alternative HK-2 and that 2) drainage condition of HK-2 is far better. Some discharge into Klong Bang Sue is found no adverse effect which is indicated in Bang Sue drainage area. Therefore, alternative HK-2 is recommended despite a little higher cost.

Table C.16 Pumping Station in Alternatives

Alternative	Pumping Station
HK - 1	-
HK - 2	Huay Khwang (3 m^3/s)
HK - 3	Sam Saen, Bang Kapi

(2) Improvement works

The recommended alternative HK-2 improvement works are shown in Table C.17 on the condition that about 0.4 km^2 retention areas where Makkasan pond is under construction are maintained. Besides highway side drain is incorporated in this drainage system. Water levels and discharge of recommend alternative HK-2 are shown in Fig. C.31.

Table C.17 Drainage Works in West Huay Khwang Drainage Area

	Category I	Category II
Pumping Station		
- Huay Kwang	162	-
Klong		
- Lat Phrao	87, 88, 89	
- Chao Khum Sing	118, 119, 120, 121	
- Wat Tott	122	
- Chuad Yai	127 (Part)	
- Sam Saen Noi	126	
- Huay Khwang	56,123,124,125,127 (Part)	
- Yai Soon	139	
- Na Song	132, 133, 134	
- Sam Saen	90,91,92,93,94,95,96	
- Ku Nam	137	
- Bang Kapi		140
- Highway sideditch	130	129
Drain		
- Suthisan Rd.		128
- Suthisan-Huay Khwang Rd.		131
- Phachasong Kro Rd.		135
- Soi Technic Wittaya School		138
- Asok-Dindaen		136

Pumping Station ..... Section Number in Fig. C.12
Klong, Drain .... Block Number in Fig. C.12

2.4.6 Bang Sue Drainage Area (35 km^2)

The ground elevation is relatively high, ranging from +0.9 to 1.5 meter above mean sea level at present. Hence flooding is not a long-duration one caused by overland flow as observed in other eastern suburbs but a short-duration one as experienced in the City Core Area. Flooding is presumably caused by inadequate drainage facilities, particularly small capacity of klongs and retention areas. Within this dranage area which are surrounded by Klongs Bang Khen, Lat Phrao and Bang Sue, there exist only small klongs. Most storm water is currently discharged through sparsely distributed box culverts into surrounded klongs with flooding along roads and streets.

(1) Alternatives

Klong Bang Sue is the only outlet of this polder.
Two alternatives (see Fig. C.32, Table C.18) are considered as pump capacity.

As a result of comparative study, scale of Bang Sue pumping station proposed in the Master Plan are reduced from 50 m^3/s to 36 m^3/s.

Table C.18 Alternatives in Bang Sue Drainage Area

Alternative	Pump Capacity (m^3/s)	
	Bang Khen	Bang Sue
1	15	50
2	15	36

Inflows to Klong Bang Sue from the City Core Area (12 m^3/s) and West Huay Kwang drainage area (3 m^3/s) are taken into account in Bang Sue drainage system.

The recommended drainage system as shown in Fig. C.32 intends to increase drainage and retention capacities.

For that purpose not only existing Klong Prem Prachakorn (which just runs outside of this area) and super-highway side drain but also new klongs along middle ring road and Ngam Wong Wan road near Kasetsart university are incorporated.

(2) Improvement works

The recommended improvement works of obtained drainage system are shown in Table C.19.

The retantion area (2.50 km^2) is planned around the railway yard. Fig. C.33 shows discharge and water level in Bong Ken-Bang Sue Polder.

Table C.19 Drainage Works in Bang Sue Drainage Area

	Category I	Category II
Pumping Station		
- Bang Sue		17
Klong		
- Wang Hin	7,8,9,10	
- Bang Sue	11,12,13,14,15,16	
- Nam Kaem	60,61	
- Rhya wake	57,58	
- Middle Ring	51,52,53,54,55	
- Highway side-ditch		29,30,31,32,33,34,35,36,37
- Kasesart	45	
- Lat Yao		48,49,50
- Toong		62
- Prem Prachakon		24,25,26,27,28
Drain		
- Lat Phrao Rd		59
- Phahonyothin Rd	38,39,40,41,42,43,44	
- Sena Nichon Rd	47	

Pumping Station ..... Section Number in Fig. C.12
Klong, Drain .... Block Number in Fig. C.12