Sector B

Meteorology and Hydrology

THE STUDY ON
DRAINAGE IMPROVEMENT AND FLOOD CONTROL
IN THE MUNICIPALITY OF PHNOM PENH

SECTOR B: METEOROLOGY AND HYDROLOGY

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B1. Introduction

This Supporting Report, Sector B "Meteorology and Hydrology" describes the study results on meteorology and hydrology in the Study Area for the Study on Drainage Improvement and Flood Control in the Municipality of Phnom Penh. The study was in reality carried out stepwise: the Master Plan stage, and the Feasibility Study stage. However, all the results are compiled in one context, meaning that review, new findings and detailed discussions/ analyses for the feasibility study areas, given in the latter stage, are integrated with the Master Plan study results as a part.

This Sector consists of the following chapters:

(a) B1. Introduction: this chapter;

(b) B2. Present Conditions: explains on the present conditions of the Study Area, relevant rivers, watersheds, meteorology, water levels, and flood and inundation condition;

(c) B3. Analyses on Rainfall and Water Levels: deals with the analyses on rainfall and water levels relevant to the succeeding runoff and inundation analysis; and

(d) B4. Runoff and Inundation Analysis: is the conclusion of the study on meteorology and hydrology, compiling the methodologies of Two-dimensional Unsteady Flow Method and Rational Formula Method, modeling of the Study Area, calculation conditions and cases, and the results of runoff and inundation analysis.

B2. Present Conditions

2.1 Study Area, Relevant Rivers and Watersheds

2.1.1 Study Area and Relevant Rivers

The Study Area, with an area of 195.71 km^2, shares a greater part of Municipality of Phnom Penh, the capital of the Kingdom of Cambodia. The area is within longitude 105°45' E to 105°55' E and latitude 12°27' N to 12°40' N, and is in the delta plain of the Mekong river system with low altitudes ranging from 4 to 14 m above the mean sea level.

The Study Area is located on the right bank of three large rivers, Tonle Mekong, Tonle Sap and Tonle Bassac, and moreover it is sandwiched by two rather small rivers which flow from west to east joining to the Mekong river system. One is the Prek Phnov River with a catchment area of approximately 640 km^2, discharging to the Tonle Sap River. The other is the Prek Thnot River with approximately 5,200 km^2 of catchment, flowing into the Tonle Bassac River. Major features of these rivers are tabulated as below:

Major Features of Relevant Rivers

River Name	Catchment Area (km^2)	Stream Length (km)	Average Flow Rate (m^3/sec)
Tonle Mekong	660,000*	4,500*	11,830**
Tonle Sap	84,400*	400*	1,570**
Tonle Bassac	-	300***	
Prek Phnov	640	50	
Prek Thnot	5,200	110	

* Upstream of Phnom Penh.
** At Phnom Penh
*** From Phnom Penh to the sea.

On the other hand, Figure B2-1 shows a three-dimensional view of the Study Area. As can be seen in the figure, the Study Area is obviously classified into three zones. The first is Phnom Penh City Core and an adjoining riverine strip along the Tonle Sap River on a natural levee formed by the Mekong river system. The elevations range from EL. 8 to 11.5 m. The second is a low land in the middle, where the Prek Phnov River probably had flowed from north to south in ancient time, extending with several lakes as its remnants. The elevations are mostly lower than EL. 8 m. The third is the west area, where Pochentong Airport is located, spreading on a little higher flat land sloping down from west to east with elevations from 8 to 14 m. Such hydro-topographic features are clearly presented in Figure B2-2 as profiles across the Study Area.

2.1.2 Watersheds

The Study Area (195.71 km^2) is, as mentioned in the above Subsection 2.1.1, limited by the Tonle Sap and Bassac rivers on the east, by the Prek Phnov floodplain to the north, by the Prek Thnot floodplain to the south, and by a hilly area to the west. In view of the topography, hydraulic characteristics and land use, the Study Area can be divided into the following five major watersheds anti-clockwise from the City Core. These five are further partitioned into basins as below (refer to Figure B2-3):

- City Core : C1 to C10 Basins (25.29 km²)
- Northeast Area : E1 to E4 Basins (40.23 km²)
- Northwest Area : No subdivision (50.79 km²)
- Middle Area : M1 to M4 Basins (38.80 km²)
- South Area : S1 and S2 basins (40.60 km²)

The land use, topography and hydraulic characteristics of each basin, along with its catchment area, are enumerated in Table B2-1.

2.2 Meteorology and Water Levels

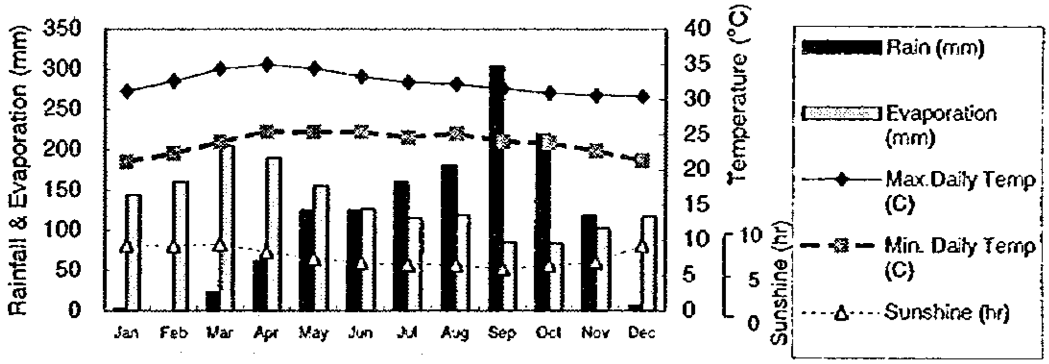
2.2.1 Location of Observation Stations and Available Data

In and around the Study Area exist one meteorological station named Pochentong near Pochentong Airport, two rainfall gauging stations named Bassac and Changvar, and three water level gauging stations at Chaktomuk, Phnom Penh Port and Changvar. All these stations are managed by General Directorate of Irrigation, Meteorology and Hydrology (GDIMH) of Ministry of Agriculture, Forestry and Fisheries (MAFF) as of 1998. The location of the stations is indicated in Figure B2-4 and the inventory of available data is given in Table B2-2.

2.2.2 Meteorology

The Study Area is situated on a part of the Continental Southeast Asia, so that the weather is strongly influenced by the monsoon and a year is clearly divided into the rainy and dry seasons. The rainy season usually lasts from May to November with wet winds from the Siam Gulf (from the south and west), bringing quite large amount of rainfall on the area. The dry season from December to April, on the other hand, is dominated by dry winds blowing from the Continental Shelf (from the north and east). The monthly means of general meteorological items observed at Pochentong Station are given in Table B2-3, which is summarized in the following graph:

General Meteorology at Pochentong Station



Rainfall

There are three stations measuring rainfall in and around the Study Area, however most reliable data, with the longest observation period, are obtained from Pochentong Meteorological Station. Records in the other two stations are said to include unreliable data with shorter observation periods (refer to Table B2-4). In this case, it is decided that the rainfall data recorded at Pochentong Meteorological Station only be applied to the further hydrological study.

The annual rainfall amounts recorded at Pochentong Meteorological Station from 1981 to 1997 range between 1,092 mm and 1,639 mm and the average is 1,327 mm as presented in Table B2-4. About 93 % of the annual rainfall occurs in the rainy season (May to November), 57 % of which concentrates in three months from August to October. On the other hand, the maximum daily rainfall in a year is mostly observed in the three months, ranging from 63 to 137 mm. Together with high water stage of the Tonle Mekong river system appearing in the period, this local rainfall often brings about serious inundation in the Study Area.

As for the rainfall type, the following two are identified:

(a) One is typical tropical showers. The humid wind comes from the Siam Gulf, heated by strong sunshine on the ground, forming cumulonimbus in the air, and results in rainfall that continues in a short period but having a significant intensity. The duration is usually 1 to 6 hours. Rainfall, in many cases, starts at the night and stops before coming sunrise. This type of rainfall is a main cause of inundation in the Study Area.

(b) The other type of rainfall is a long spell of rains by the influence of a typhoon coming up north from the China Sea. The duration of rainfall depends on the course and speed of the typhoon, but in general lasts for 2 to 3 days. This type of rainfall produces flooding in rivers surrounding the Study Area. For instance, the Prek Thnot River was flooded in 1991, 1993 and 1994 with such rainfall, inflicting heavy damage on its floodplains. This type of rainfall, however, does not directly make the Study Area inundated.

<u>Evaporation</u>

The annual evaporation depths recorded from 1981 to 1997 vary between 1,224 mm and 2,145 mm, with a mean of 1,623 mm as shown in Table B2-5. These values are larger than the annual rainfall amount. This is because open pan evaporation measurements during the dry season, commonly, give much larger values than those in actual fields. The seasonal variation of evaporation, increasing in the dry season (205 mm in March at maximum) and decreasing in the rainy season (84 mm in September at minimum), is contrary to the rainfall pattern.

<u>Other Meteorological Items</u>

(1) Temperature

The maximum and minimum daily temperatures are 32.4 °C and 23.8 °C on the average from year 1985 to 1997 (refer to Table B2-6). The temperature is highest at the end of the dry season and lowest at the beginning of the dry season. (In terms of maximum and minimum daily temperatures, about 35 °C and 25 °C in April whilst about 30 °C and 21 °C in December.) The all time daily maximum and minimum were recorded at 40.4 °C in April, 1990 and 15.0 °C in December, 1993.

(2) Humidity

The monthly mean relative humidity, on the average from 1985 to 1997, ranges between 68.2 % in March and 85.8 % in September as shown in Table B2-7. The relative humidity, naturally, increases in the rainy season and decreases in the dry season.

(3) Sunshine

The daily sunshine hours range from 9.4 hours in March (the dry season) to 5.9 hours in September (the rainy season). For the details, refer to Table B2-8.

(4) Atmospheric Pressure

The monthly mean atmospheric pressure record from 1981 to 1897 is shown in Table B2-9. The monthly mean atmospheric pressure hits the peak at December in the dry season and reaches the bottom at June and July in the rainy season.

(5) Wind

The monthly maximum wind velocity and its direction are presented in Table B2-10. Strong winds, whose velocities exceed 10 m/sec, tend to appear in the first half of the rainy season with directions of south, southwest and west mostly.

2.2.3 Water Levels

On the Mekong river system, three water level gauging stations are provided by Department of Hydrology of GDIMH, MAFF. The water level is observed twice a day (7:00 and 19:00). Observations have continued since 1960, except between January, 1975 and June, 1980, at Chaktomuk Water Level Gauging Station. At Phnom Penh Port and Changvar stations, on the other hand, complete records are available from 1993 only. Hence, applied to the further analysis are the data recorded at Chaktomuk Station.

Figure B2-5 depicts seasonal variation of the water level at Chaktomuk Station since 1960. Moreover, Table B2-11 shows the annual highest, mean and lowest water levels at the station, which are EL. 8.83 m, EL. 4.07 m and EL. 0.66 m on average. The all time high water level is EL. 9.96 m in October, 1961, followed by EL. 9.92 m in October, 1996. In addition, noted in the table is that the highest water level in year 1998 is the lowest record since observation started.

In Figure B2-6, the yearly water level variations in the last decade are superimposed by the daily rainfall measured at Pochentong Meteorological Station. The figure suggests high probability of synchronization between high water level of the Mekong river system and strong local storms in the Study Area. In fact, such synchronization has often resulted in serious inundation over the Study Area.

There is no water level record in the Prek Phnov and Prek Thnot rivers. However, records in the 1995 and 1996 rainy seasons at several points in the Study Area are compiled in a French report "Bilam des Inondations Octobre 1996"(see Subsection 2.3.1).

2.3 Flood and Inundation Condition

2.3.1 Hydraulics during Flood and Inundation

To clarify the flood and inundation conditions in the recent major flood years, i.e. 1995 and 1996, an interview survey over the Study Area was carried out on sub-contract basis. (A Thai consulting firm undertook this task and submitted two reports in July and November, 1998.) The survey was conducted at 609 points in City Core and 291 points in the other suburban area, totaling 900 points, by using the 1:2,000 map and a questionnaire form (prepared by the consulting firm and approved by the Study Team). Each of the interview comprises the following items:

- Location of sample point;
- Name of informant;
- Maximum flood/inundation depth in the year;
- Duration of the flood/inundation;
- Direction of inflow and outflow;
- Cause of the flood/inundation, and
- Suggestion from the informant for mitigation measure.

These interview survey results are compiled in a Separate Volume to delineate a flood and inundation map and to identify the hydraulic characteristics during flood and inundation in each location of the Study Area. Major findings obtained are:

(a) No overtopping happened along the Outer Ring Dike in both flood years thanks to the flood defense activity by governmental agencies concerned (refer to Table B2-12). So, all the inundation identified through the interview survey was rated as ones caused by local rainfall, except in the South Area where floodwaters from the Mekong river system easily come in and out through openings provided along the Outer Ring Dike.

(b) There is no meaningful difference in the magnitude of inundation between the year 1995 and 1996 (refer to Table B2-13). In this case, the Thai consulting firm prepared a flood and inundation map for year 1996 only that is higher in the water level of the Tonle Mekong by 0.8 m and is a bit larger in the annual rainfall in the Study Area by 226 mm. The map is briefed in Figure B2-7. (For the original map, see the Separate Volume.)

(c) At any location, interviews cannot specify exact dates when flood or inundation took place in the year. This infers that the surveyed flood/inundation depths and duration may correspond to the maximal ones occurring some day in the year.

Water levels in the 1995 and 1996 rainy seasons observed at several points in and around the Study Area are delineated in Figures B2-8 and B2-9, respectively where the daily rainfall at Pochentong Station is superimposed. These records include some unreliable data, but they are quite valuable in realizing relative correlation among high water levels at necessary locations.

2.3.2 Flood and Inundation Damage

A survey entitled "Asset and Flood Damage Survey" was conducted by the same Thai consulting firm as in Subsection 2.3.1. The survey was to collect data on the damage caused by past flood and inundation events, and present assets belonging to households, business enterprises and social organizations. The following table displays the number of samples surveyed by type of interviewees:

Number of Samples Surveyed

Category	Number		
	City Core	Suburban Area	Total
Household	312	104	416
Shop	89	32	121
Factory, warehouse, office	37	0	37
School	16	1	17
Hospital	9	0	9
Farm	30	72	102
Livestock operator	0	30	30
Fishpond operator	0	20	20
Total	493	259	752

A number of findings derived from the survey are used as the basic data for estimating inundation damage and expected economic benefit by projects suggested in the Master Plan and feasibility studies as Sector Reports D and F explain. Table B2-14 summarizes major findings through the survey.

2.3.3 Field Observation in 1998 Rainy Season

In order to identify actual flood and inundation conditions in the Study Area, a field observation work was realized by the Study Team from Oct. 11 to Oct. 28, 1998. Following are data, information and observation collected during the work specifically pertinent to this rainy season:

(a) Tonle Sap River's water level at Chaktomuk Station managed by GDIMH (refer to Figure B2-5);

(b) Water levels at 17 stations measured by DPWT in accordance with the Study Team's request (see Table B2-15 and Figures B2-10 and B2-11);

(c) Rainfall in the City Core;

(d) Conditions of Kop Srov and Tompun Dikes;

(e) Operation conditions of existing pump facilities; and

(f) Clogging conditions of drainage channels and sewers.

First, it should be mentioned that the highest water level of the Tonle Sap River in 1998 rainy season is as low as EL. 6.90 m. This annual maximum water level is the lowest since 1960 compared to the second lowest EL. 7.30 m occurring in 1988. In this case, floodwater barely comes up on the outside slopes of Kop Srov and Tompun dikes, bringing about little damage to the dikes. Through the field investigation of the Study Team, only found as dike deformation are holes on the dike road surfaces which were however observed even in the dry season. Such holes are judged to result from local rainfall on the dikes in previous rainy seasons. No flood defense activity has been taken uncommonly with other years.

Second, with respect to inundation in the Study Area due to local storms, the Study Team experienced 8 times of rains in their stay (16 days in total). The rainfall amount in each rain is less than 20 mm, except a rain starting at midnight and terminating early in the morning on October 20 whose amount reached 63.5 mm. At 8 o'clock in the morning, the Study Team still observed many places of inundation with about 20 cm of depth. This condition was prolonged over the morning. Particularly around the DPWT office, inundation lasted until the evening. Pump facilities, Trabek and Tompun stations, etc., were fully operated, however the effects being limited in their lower reaches, and because of less capacity/clogging of drainage channels and especially sewer pipes, the upper reaches cannot be free from such longtime inundation.

B3. Analyses on Rainfall and Water Levels

3.1 Rainfall Analysis

3.1.1 Premises

Premises for the rainfall analysis are set as follows:

(1) Maximum Annual Rainfall

Rainfall data at Pochentong Meteorological Station, as mentioned in Clause "Rainfall" in Subsection 2.2.2, are used for the rainfall analysis in this study. Shown in Table B3-1 are the maximum annual rainfall for each duration (15 minutes to 4 days) between 1980 and 1997. This has been compiled by Pochentong Station itself using automatic gauging data at 15 minutes intervals. The present hydrological study will be based on the results.

(2) Area Reduction Factor

In the present study, the area reduction factor is not considered on the conservative side since there are no sufficient data to verify such factor.

(3) Rainfall Duration

Figure B3-1 shows the single rainfall patterns of recent heavy rains causing sever inundation in the Study Area. As can be seen in the figure, all rains terminated within 6 hours. It is hence concluded that the duration of the design rainfall can be 6 hours.

3.1.2 Rainfall Intensity Curves

Rainfall intensity curves have been developed as follows:

<u>Calculation of Probable Rainfalls</u>

The recurrence probability analysis for various times of duration was made by using two methods, Gumbel and Normal Distribution methods, based on the data in Table B3-1. The results are delineated in Figure B3-2. Gumbel Method gives higher accuracy and safer values for planning, hence its result is applied to the succeeding studies.

Table B3-2 shows the values of probable rainfalls, by Gumbel Method, for rainfall duration of 15 minutes to 4 days in the return periods of 2, 5, 10, 30 and 50 years, which are summarized as follows:

Probable Rainfall

Return Period (year)	Hourly Rainfall (mm/hr)	Daily Rainfall (mm/day)
2	44.8	87.8
5	63.2	112.3
10	75.4	128.4
30	93.8	152.9
50	102.2	164.0

Equations to Express Rainfall Intensity-Duration Relation

The following equations are commonly applied to express the relationship between rainfall intensity and its duration:

(a) Talbot Type : $I = a / (T + b)$
(b) Sherman Type : $I = a / T^n$
(c) Kuno Type : $I = a / (T^{0.5} + b)$
(d) Horner Type : $I = a \times (T + b)^n$

where,

I	: Rainfall Intensity (mm/hour)
T	: Rainfall Duration Time (min.)
a, b, n	: Constants

The constants of the foregoing equations were estimated by the least-square regression analysis on the relation between the probable rainfall intensity and its corresponding rainfall duration. The estimation was made individually for less than 6 hours and for more than 6 hours. The results are presented in Table B3-3.

The error of each equation is calculated in Table B3-4. This table shows the Horner Type equation is most in conformity with the actual relation between probable rainfall intensity and duration, so that it is selected for further studies. The rainfall intensity curves of Horner Type, along with their equations, are given in Figure B3-3.

The intensity curves, or the equations, will directly be used, through the Rational Formula, to determine the sizes of the sewer pipes (with a design scale of a 2-year return period as discussed in Sector Report D).

3.1.3 Design Hyetograph

Figure B3-4 shows three actual rainfall patterns attained from Pochentong Meteorological Station. These rainfall patterns are characterized by the facts that all rainfalls terminate within 6 hours and the peak of each rainfall appears nearly at the middle of its duration. In this case, the study is decided to apply so-called 'Centrally Concentrated Rainfall Pattern' shown on the bottom of Figure B3-4 to the design hyetograph for planning the major drainage facilities such as pumping stations, regulation ponds and drainage mains. (The magnitude of the hyetograph is a 5-year return period as stated in Sector Report D.)

This pattern of model hyetograph is commonly used in other practices when sufficient numbers of actual rainfall data are unavailable. Moreover, this type of rainfall gives the safe side baseline in the facility planning.

3.2 Water Level Analysis

3.2.1 Flow Regime

Based on the water level observation data at Chaktomuk Station, the flow regime of the Mekong river system was analyzed to realize the general annual fluctuation of water level outside the Study Area. The results are shown in the following table:

Flow Regime at Chaktomuk Station

Water Level	Average since 1960 (EL. m)
Annual Highest	8.88
95th day in a year	6.59
185th day in a year	3.38
275th day in a year	1.36
355th day in a year	0.80

3.2.2 Probable High Water Levels

To determine the design high water level along the Tonle Sap and Tonle Bassac rivers, probable high water levels are analyzed by using the data in Table B2-11 that shows the annual highest water levels at Chaktomuk Station since 1960. The analysis results are shown in the table below:

Probable High Water Levels at Chaktomuk Station

Return Period (year)	High Water Level (EL. m)
2	8.9
5	9.4
10	9.7
20	9.9
30	10.0
50	10.1

Note: EL. 9.96 m is the all time high since 1960.

In addition, Figure B3-5 shows the trend of the annual maximum water levels with time based on the data from 1960 to 1997. However, no meaningful inclination can be read from the figure.

B4. Runoff and Inundation Analysis

4.1 Methodology

4.1.1 Principles

The Master Plan and feasibility studies require the following three sorts of runoff and inundation analyses:

(a) Analysis to estimate the design discharges and volumes of major drainage facilities such as pumping stations, regulation ponds and drainage mains (corresponding to a 5-year return period), where hydrographs in consideration of the retarding effect in the upper reaches are entailed;

(b) Analysis to clarify the inundation conditions, with and without projects, for various return periods of rainfall to estimate the benefits induced by the project implementation; and

(c) Analysis to determine the design size of each pipe in sewer networks (corresponding to a 2-year return period), where peak discharges only are necessitated;

For the third analysis, the Rational Formula will be applied according to common practices in the similar type of projects. On the contrary, the first and second analyses can be made in a single manner, but in such analysis there are several methods. Following are discussions to select a suitable method for the analysis.

The methods of runoff and inundation analysis to be applied to Items (1) and (2) above are generally classified into two types: the one-dimensional analysis and the two-dimensional analysis (usually with unsteady flow calculation). The former is simple, but cannot express the spread of flow in two dimensions on floodplains like the Study Area. For that end, the latter would be superior and could simulate the spreading and gathering flow condition, even if it is a little more sophisticated. It was hence concluded that the runoff and inundation analysis be made by the 'Two-dimensional Unsteady Flow Method' that is one of typical two-dimensional analyses.

4.1.2 Two-dimensional Unsteady Flow Method for Major Drainage Facilities

The idea of the two-dimensional unsteady flow runoff and inundation analysis is presented in Figure B4-1, and the basic equations of the method are as follows:

Basic Equations

(1) Equation of Continuity

$$\frac{\partial A}{\partial t} + \frac{\partial Q_x}{\partial x} + \frac{\partial Q_y}{\partial y} = 0$$

$$\frac{dV}{dt} = \sum_{n=1}^{m} Q_n$$

(2) Equation of Motion

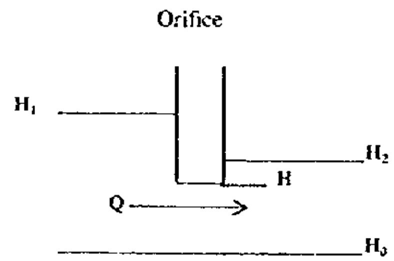
$$\frac{1}{gA}\frac{\partial Q}{\partial t}+\frac{2Q}{gA^2}\frac{\partial Q}{\partial x}-\frac{Q^2}{gA^3}\frac{\partial A}{\partial x}+\frac{\partial h}{\partial x}-i_b+\frac{n^2|Q|Q}{A^2R^{4/3}}=0$$

where,

Q_x, Q_y	: discharge of x and y directions
A	: current area
R	: hydraulic depth
g	: gravity acceleration (9.8 m/s^2)
n	: Manning's roughness coefficient
i	: water level
t	: water depth
V	: flow velocity (m/s)

Equations to Express Boundary Condition between Blocks

(1) Discharge through Orifice



$when H_1 > H_2 > H$ (*Perfect*)

$$Q = CB(H - H_0)\sqrt{2g(H_1 - H_2)}$$

$when H_1 > H > H_2$ (*Unperfect*)

$$Q = Q_1 + Q_2$$

$$Q_1 = C\frac{2}{3}\sqrt{2g}B\{(H_1 - H_2)^{\frac{3}{2}} - (H - H)^{\frac{3}{2}}\}$$

$$Q_2 = CB(H_2 - H_0)\sqrt{2g(H_1 - H_2)}$$

$when H > H_1 > H_2$ (*Free*)

$$Q = Q_1 + Q_2$$

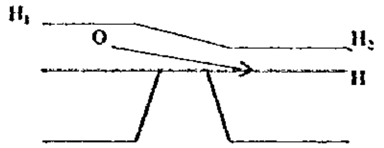
$$Q_1 = C\frac{2}{3}\sqrt{2g}\,B\,(H_1 - H_2)^{\frac{3}{2}}$$

$$Q_2 = CB(H_2 - H_0)\sqrt{2g(H_1 - H_2)}$$

where,

H_1, H_2, H	: Height as shown in the figure
B	: Width of orifice
α, μ, μ'	: Coefficients
g	: Gravity acceleration (9.8 m/s^2)

(2) Discharge over Weir



$$when\ H_1 < H\ and\ H_2 < H$$
$$Q = 0$$

$$when\ H_1 > H_2$$
$$when\ (H_1 - H)\cdot\alpha_1 \leqq (H_2 - H)\quad (Submerged\ Overflow)$$
$$Q = -B\mu'(H_2 - H)\sqrt{2g(H_1 - H_2)}$$
$$when\ (H_1 - H)\cdot\alpha_1 > (H_2 - H)\quad (Perfect\ Overflow)$$
$$Q = -B\mu(H_2 - H)\sqrt{2g(H_1 - H)}$$

$$when\ H_1 < H_2$$
$$when\ (H_2 - H)\cdot\alpha_2 \leqq (H_1 - H)\quad (Submerged\ Overflow)$$
$$when\ (H_2 - H)\cdot\alpha_2 > (H_1 - H)\quad (Perfect\ Overflow)$$

where,

H_1, H_2, H : Height as shown in the figure
B : Width of overflow
α, μ, μ' : Coefficients
g : gravity acceleration (9.8 m/s^2)

4.1.3 Rational Formula Method for Sewer System

The basic formula and constants involved in it are enumerated as follows.

Basic Formula

Q = 1/360 C I A

where,

Q : Design discharge (m^3/sec)

C : Runoff coefficient

I : Rainfall intensity within the concentration time (mm/hr)

A : Drainage area (ha)

Constants in the Formula

(1) Runoff Coefficient

The runoff coefficient of each land use type, on the year 2010 condition established in Sector Report A, is set forth in the table below. These values are delineated based on other practices in similar projects. The runoff coefficient in the above formula, C, is defined as an areally weighted average of the runoff coefficients by land use type within the drainage area.

Runoff Coefficient by Land Use Type

Land Use Type	Runoff Coefficient
Dense activities area, Dense urban center	0.80
Dense residential area	0.65
Loose residential area	0.50
Loose activities area	0.35
Agricultural land	0.05
Green spaces and parks	0.10
Fishponds, Lakes and ponds	1.00

(2) Concentration Time

T = Inlet time (T_1) + Travelling time (T_2)

$T_2 = L / V$

where,

T: Concentration time of floodwater (min.)

T_1: 10 min.

L: Sewer pipe length from its beginning to the point where the design discharge is to be calculated (m)

V: Flow velocity in the pipe (1.5 m/sec)

(3) Rainfall Intensity within the Concentration Time

The rainfall intensity within the concentration time, corresponding to the design magnitude of sewer systems (2-year return period), is calculated as follows:

$$I = 2{,}566.07\ (T + 25.48)^{-0.93}$$

where,

I: Rainfall intensity (mm/hr)

T: Concentration time (min.)

4.2 Modeling of Study Area

The sewer pipe design using the Rational Formula is involved in Sector Report D. In this case, this and following Sections 4.2 to 4.4 devote themselves to the descriptions on the runoff and inundation analysis by the Two-dimensional Unsteady Flow Method.

Basically, the analysis covers the whole Study Area (195.71 km^2). However, the following two basins are omitted therefrom as the study results on the protection line (against floods) as discussed in Sector Report D:

- C6: Bassac Riverside Basin (1.58 km^2), and
- E4: Sap Riverside Basin (1.27 km^2).

Thus, the total area subject to the runoff and inundation analysis is 192.86 km^2. The area is in turn divided into two in response to the study requirement as follows:

- Suburban Area, with an area of 157.99 km^2; and
- City Core (23.71 km^2) including Tompun Basin (11.16 km^2), totaling 34.87 km^2, which requires more detailed examination.

Figures B4-2 and B4-3 present the hydraulic models for the runoff and inundation analysis in the Suburban Area and City Core, respectively. These models have been constructed in the following procedure:

(a) Firstly, in view of the location of major channels, roads, dikes, embankments and other facilities controlling flood flow, the Suburban Area is divided, based on the watershed definition described in Subsection 2.1.2, into 117 blocks with areas of 20 to 460 ha, while the City Core into 77 blocks with areas of 6 to 156 ha;

(b) In order to realize inundation condition, a rating curve (so-called H-V curve) is developed for each block using the topographic maps with a scale of 1/2,000;

(c) The boundary between adjoining two blocks is classified into two conditions in terms of the elevation of the boundary: whether surface runoff can pass through the boundary or not? (However, when a sewer system is provided through the boundary, runoff in sewers is included in the surface runoff discharge);

(d) Along boundaries working as obstruction against flood flow, sluiceways and openings are identified mainly through field investigations;

(e) Pumping stations, regulation ponds and drainage mains are depicted on the plan; and

(f) Finally, 4,860 meshes are superimposed on the Study Area to express a result of the analysis (inundation water depths).

4.3 Calculation Conditions and Cases

4.3.1 Calculation Conditions

Table B4-1 shows major conditions for the runoff and inundation analysis, like Manning's roughness coefficients, initial water levels/depths, and pump capacities.

4.3.2 Calculation Cases

Table B4-2 shows the calculation cases of the runoff and inundation analysis required for formulating the Master Plan and conducting the feasibility studies, which are summarized as below:

(a) Case 1: Year 1996 flood for the verification of the hydrological and hydraulic models and assumed conditions;

(b) Case 2 to 9: to realize the effect of drainage improvement projects, with rainfall probabilities of 2-, 5-, 10- and 30-year, under with- and without-project conditions; and

(c) Case 10 and 11: to identify the possibility of flood protection projects, with water level probability of 10- and 30-year, under without-project conditions.

4.4 Results of Runoff and Inundation Analysis

4.4.1 Design Discharges and Hydrographs

One purpose of the runoff and inundation analysis is to give the design discharges and volumes of major drainage facilities such as pumping stations, regulation ponds and drainage mains with a design magnitude of 5-year return period. To this end, flow rates and flow directions through every block boundary, and hydrographs at the pumping station sites are estimated through the Two-dimensional Unsteady Flow Method. The results are depicted in figures as follows:

(a) Flow directions and peak discharges of Case 5 in Suburban Area (With-project, R.P. = 5-year): Figure B4-4;

(b) Flow directions and peak discharges of Case 5 in City Core (With-project, R.P. = 5-year): Figure B4-5; and

(c) Design Hydrographs at the Inlets of Tompun, Trabek and Pochentong pumping stations (With-project, R.P. = 5-year): Figure B4-6.

4.4.2 Inundation Analysis

The inundation analysis aims at clarifying the inundation conditions, with and without projects, for various return periods of rainfall or water level to assess the benefits induced by the project implementation. The results are summarized in the following figures:

(a) Simulated inundation map of Case 1 (Year 1996) : Figure B4-7

(b) Simulated inundation map of Case 2 (2-year return period, Without-project) : Figure B4-8

(c) Simulated inundation map of Case 3 (2-year return period, With-project) : Figure B4-9

(d) Simulated inundation map of Case 4 (5-year return period, Without-project) : Figure B4-10

(e) Simulated inundation map of Case 5 (5-year return period, With-project) : Figure B4-11

(f) Simulated inundation map of Case 6 (10-year return period, Without-project) : Figure B4-12

(g) Simulated inundation map of Case 7 (10-year return period, With-project) : Figure B4-13

(h) Simulated inundation map of Case 8 (30-year return period, Without-project) : Figure B4-14

(i) Simulated inundation map of Case 9 (30-year return period, With-project) : Figure B4-15

(j) Simulated inundation map of Case 10 (Overflow with a 10-year return period water level) : Figure B4-16

(k) Simulated inundation map of Case 11 (Overflow with a 30-year return period water level) : Figure B4-17

Table B2-1 Characteristics of Each Basin (1/3)

Name of Basin	Area (km^2)	Characteristics
<u>CITY CORE</u>	(25.29)	
C1: Wat Phnom Basin	0.89	- Offices, hotels, houses, etc. densely located. - This area is the highest portion (over EL. 10.5 m) and local runoff drained to the Tonle Sap River by gravity.
C2: Kak Lakeshore Basin	0.51	- Offices, a hospital, French embassy, houses, etc. situated. - Local runoff drained to Boeng Kak.
C3: Boeng Kak Basin	1.14	- Lake area which will be a recreational zone in the city. - Water discharges northwards to E1 area.
C4: Tuol Kork Basin	3.32	- New housing area with high to medium density. - Runoff drained out by 2 pumping stations and by gravity.
C5: University Basin	0.71	- University zone and ponds/swamps of a slender shape. - Runoff reserved therein due to its low topography.
C6: Bassac Riverside Basin	1.58	- Hotels, offices, embassies, factories, etc. located and a lot of squatters spread in the river front. - Local runoff drained directly to the Tonle Bassac River.
C7: Trabek Basin	10.83	- Urban center shares its upstream reaches and dense residential area its downstream ones. - Local runoff drained out through open channels and by Trabek pumping station to Boeng Cheung Ek. A major watershed in the City Core.
C8: Salang Basin	5.53	- Urban center located upstream and dense residential area downstream with a new urban scheme in Salang area. - Local runoff drained by pumps and by gravity outside Inner Ring Dike, led to Tompun pumping station. Another important watershed in the City Core.
C9: Tum Nup Toek Basin	0.68	- Small but dense residential area inclusive. - Local runoff drained by pumps outside Inner Ring Dike.
C10: Toek Laak Basin	0.10	- ditto-

Table B2-1 Characteristics of Each Basin (2/3)

Name of Basin	Area (km^2)	Characteristics
NORTHEAST AREA	(40.23)	
E1: Poungpeay East Basin	13.53	- Many developments (mainly factories) found in the southern part, while fishponds still in the north. - This area divided into some ten portions by road/railway embankments with drain pipes. Runoff drained out to E2.
E2: Boeng Poungpeay Basin	24.18	- Lake/swamp area whose perimeter is already intruded by developments (factories, sand mining, etc.) in places. - All runoff from Northeast and Northwest areas gathers herein, discharging to the Tonle Sap River through a sluiceway at Syay Pek.
E3: Krom Sala Basin	1.25	- Farmland and fishponds occupy with some housing. - Local runoff directly led to the Tonle Sap River through a pipe culvert.
E4: Sap Riverside Basin	1.27	- Narrow strip facing the Tonle Sap River with factories, workshops, schools, shops, shanties, etc. located. - Local runoff drained directly to the Tonle Sap River.
NORTHWEST AREA	50.79	- Farmland with small villages scattering. - Rainfall mostly reserved in the paddy fields and storage ponds for irrigation, then less flow down into the Northeast Area.
MIDDLE AREA	(38.80)	
M1: Tompun Basin	11.16	- Many houses found on the highland and they encroach on the ex-swamp area around Boeng Tompun. - Flood prevented by Tompun dike and runoff from C8, C9, C10, M1, M2 & M3 areas drained here by pumps.
M2: Pochentong East Basin	15.35	- This is a newly developed area. The airport, factories, warehouses, offices, schools, shops and houses located with decreasing farmland left in the center. - Local runoff drained by gravity towards the east (to Tompun Basin) and by pumps towards the south.
M3: Pochentong West Basin	11.59	- Villages still scatter on farmland, however large-scale constructions (e.g. for a dry port) start in places. - Local runoff drained to the Pochentong Airport direction and to Northwest Area.
M4: Prey Pring Basin	0.70	- Village with farmland occupies. - Local runoff naturally drained outside the Study Area

Table B2-1 Characteristics of Each Basin (3/3)

Name of Basin	Area (km^2)	Characteristics
SOUTH AREA	(40.60)	
S1: BOT Road South Basin	6.46	- Factories rapidly develops with reclamation works. Along the southern border of this area, a road bypass planned (named Tompun extension). - Runoff drained to the south.
S2: Prey Sar Basin	34.14	- Farmland and villages spread with less development. - Flood enters through 3 openings from the outside of the Study Area (from the Prek Thnot River), and runoff drained through the openings.
Total	195.71	-

Table B2-2 Inventory of Available Data on Meteorology and Water Levels

Meteorological Data at Pochentong

Item	Data Type	Year																	
		80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97
Rainfall	Daily	-	A	A	A	A	A	A	A	A	A	A	B	A	A	A	A	A	A
Evaporation	Daily	-	A	A	B	A	A	A	B	A	A	A	A	B	B	-	A	A	B
Max. Temperature	Daily	-	-	-	-	-	A	B	A	A	A	A	A	A	A	A	A	A	A
Min. Temperature	Daily	-	-	-	-	-	A	B	B	A	A	A	A	A	A	A	A	A	A
Relative Humidity	Daily	-	-	-	-	-	A	A	A	A	A	A	A	A	A	A	A	A	B
Sunshine	Daily	-	A	A	B	A	A	A	B	B	-	-	-	-	-	-	A	A	A
Atmospheric Pressure	Monthly	A	A	A	A	A	B	B	A	A	A	A	A	B	A	A	A	A	A
Wind	Monthly	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A

Rainfall Data

Station Name	Data Type	Year																	
		80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97
Bassac	Daily	-	-	-	-	A	A	A	A	A	A	A	A	A	A	B	A	A	A
Changavar	Daily	-	A	A	A	A	A	A	A	A	B	B	A	A	A	B	-	-	-

Water Level Data

Station Name	Data Type	Year																	
		60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77
Chaktomuk	Daily	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	-	-	-

Station Name	Data Type	Year																	
		80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97
Chaktomuk	Daily	B	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Phnom Penh Port	Daily	-	-	-	-	-	-	-	-	-	-	-	-	-	A	A	A	A	A
Changavar	Daily	-	-	-	-	-	-	-	-	-	-	-	-	-	A	A	A	A	A

Notes: A means the data are complete.
B means the data are incomplete.
At Chaktomuk, data was collected until October 19, 1998.

Table B2-3 Monthly Means at Pochentong Meteorolocical Station

Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Season	Dry Season				Rainy Season							Dry	Total
Rainfall (mm)	2.8	0.0	23.0	61.4	125.0	125.0	160.3	180.8	303.9	219.2	119.1	6.4	1327
Evaporation (mm)	143.8	160.3	205.2	190.1	155.0	126.9	115.1	118.8	93.5	83.7	102.0	128.3	1623
Max. DailyTemp (°C)	31.1	32.6	34.3	34.9	34.4	33.2	32.4	32.1	31.5	30.9	30.6	30.4	-
Mean Temp (°C)	26.1	27.5	29.2	30.2	29.9	29.3	28.5	28.6	27.8	27.3	26.6	25.9	-
Min. Daily Temp (°C)	21.1	22.3	24.0	25.4	25.4	25.4	24.6	25.1	24.0	23.8	22.7	21.3	-
Relative Humidity (%)	71.6	69.7	68.2	70.2	76.5	78.3	81.6	82.8	85.8	85.4	80.2	76.0	-
Daily Sunshine (hr)	9.2	9.2	9.4	8.3	7.4	6.8	6.6	6.5	5.9	6.4	6.9	9.2	-
Atmospheric Pressure (mb)	1010.9	1009.7	1009.2	1007.5	1006.5	1006.0	1006.0	1006.1	1007.2	1008.2	1009.4	1011.9	-
Max. Wind (m/s)	5.4	6.9	9.0	10.6	11.4	11.8	12.2	10.2	9.6	9.4	8.8	6.0	-
Wind Direction	N	S	S	S	S	W	W	W	SW	N	NE	N	-

Table B2-4 Monthly Rainfall

Station: Pochentong Years : 1981-1997 Unit : mm

Year	Month												Annual	Max.Daily	
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Amount	Date
1981	2	0	0	61	111	72	231	126	209	151	283	0	1,245	86	26-Sep
1982	0	0	14	181	197	159	75	161	247	219	108	0	1,360	95	11-Sep
1983	0	0	0	0	48	55	170	312	174	203	155	3	1,121	80	29-Aug
1984	1	0	0	129	62	143	127	106	264	293	52	1	1,178	83	25-Apr
1985	0	0	0	158	103	77	118	93	284	261	189	1	1,281	63	19-Oct
1986	0	0	5	49	150	91	181	225	301	235	87	24	1,347	75	17-Nov
1987	0	0	0	0	25	150	138	184	474	257	324	0	1,552	114	5-Sep
1988	0	0	22	96	70	173	153	178	445	137	71	0	1,346	128	18-Sep
1989	15	0	54	63	184	38	87	162	399	329	107	0	1,438	97	13-Sep
1990	0	0	0	26	227	64	167	175	247	98	139	0	1,142	74	19-May
1991	-	0	-	83	53	305	284	194	120	210	2	2	1,254	85	6-Jun
1992	3	0	1	35	93	114	220	198	217	197	11	4	1,092	80	29-Sep
1993	0	0	0	0	48	55	170	312	174	203	155	3	1,121	80	29-Aug
1994	0	0	164	61	158	106	97	154	333	127	6	18	1,224	79	19-May
1995	0	0	18	94	235	147	156	209	277	244	22	11	1,413	111	8-May
1996	15	0	5	112	173	170	100	147	343	213	346	14	1,639	137	13-Nov
1997	0	0	7	20	108	135	213	120	338	338	90	6	1,374	123	21-Sep
Aver.	3	0	23	61	125	125	160	181	304	219	119	6	1,327	-	-

Station: Bassac Years : 1984-1997 Unit : mm

Year	Month												Annual	Max.Daily	
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Amount	Date
1984	0	5	0	137	120	113	233	135	213	203	57	8	1,223	83	26-Apr
1985	2	0	0	138	97	123	116	145	304	278	167	7	1,375	63	28-Sep
1986	0	2	10	38	220	100	118	223	239	312	31	29	1,320	75	30-Sep
1987	0	0	0	1	83	109	64	146	186	202	282	15	1,087	114	10-Nov
1988	0	12	10	86	84	253	100	259	289	151	58	0	1,302	128	26-Sep
1989	23	0	108	106	122	71	104	145	317	217	86	0	1,299	97	20-Mar
1990	0	0	0	19	106	84	346	183	180	176	132	0	1,226	74	15-Jul
1991	0	0	0	35	84	201	236	225	159	220	0	0	1,161	85	11-Jun
1992	0	0	0	29	0	0	0	141	244	195	10	9	628	80	29-Sep
1993	19	0	187	0	96	225	158	58	263	330	35	30	1,400	80	21-Jun
1994	0	0	278	-	-	-	-	-	-	-	-	-	-	79	14-Mar
1995	0	0	33	46	181	110	252	193	231	262	41	0	1,348	111	8-May
1996	4	0	3	26	93	172	77	130	133	292	160	11	1,099	137	5-Oct
1997	4	7	0	24	81	49	166	105	253	252	38	0	978	123	21-Sep
Aver.	4	2	48	45	104	125	145	163	233	240	87	8	1,204	-	-

Station: Changvar Years : 1981-1994 Unit : mm

Year	Month												Annual	Max.Daily	
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Amount	Date
1981	0	0	0	0	138	79	172	145	215	188	196	0	1,133	53	24-Nov
1982	0	0	18	0	32	247	66	247	109	298	118	0	1,135	68	25-Oct
1983	0	0	0	0	42	103	139	314	246	201	166	0	1,212	66	31-Jul
1984	0	0	20	151	200	81	185	50	210	169	63	13	1,143	106	26-Apr
1985	0	0	0	91	134	118	70	104	303	332	170	0	1,323	91	26-Oct
1986	0	4	0	60	242	93	86	185	156	202	48	25	1,101	55	11-Apr
1987	0	0	0	1	33	69	61	30	176	114	376	0	860	110	8-Nov
1988	0	3	0	20	105	67	109	280	401	0	474	36	1,496	125	16-Sep
1989	0	0	0	34	16	-	-	-	-	-	-	-	-	-	-
1990	0	0	0	0	0	0	0	129	110	255	110	0	-	-	-
1991	0	0	0	45	9	205	236	125	59	56	0	1	735	83	29-Jun
1992	0	0	0	0	20	151	68	60	153	148	0	5	606	60	31-May
1993	8	0	60	0	53	79	69	6	144	174	27	3	623	-	-
1994	0	0	177	-	-	-	-	-	-	-	-	-	-	-	-
Aver.	1	1	24	28	68	98	87	115	188	160	151	9	928	-	-

Table B2-5 Monthly Evaporation

Station: Pochentong Years : 1981-1997 Unit : mm

Year	Month												Annual
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1981	187.7	202.5	284.4	258.6	153.0	182.6	164.4	145.7	108.4	111.9	103.8	163.6	2066.6
1982	169.1	176.0	257.8	152.8	158.6	120.4	141.7	127.8	109.6	100.4	108.4	160.6	1783.2
1983	183.9	-	-	-	-	222.4	144.1	103.9	94.3	91.7	120.4	152.1	-
1984	171.5	215.6	285.2	233.3	169.8	141.9	131.8	194.2	82.1	67.3	126.3	166.5	1985.5
1985	189.8	216.8	266.9	202.7	190.2	132.0	137.9	158.1	89.1	85.2	88.9	126.0	1883.6
1986	163.2	154.7	241.7	188.2	126.1	124.1	136.7	111.1	73.0	80.1	96.6	115.6	1611.1
1987	138.5	154.2	232.9	212.7	217.3	142.6	156.4	115.6	-	69.1	65.9	-	-
1988	134.6	148.4	215.7	142.0	129.0	118.4	95.3	91.3	77.3	77.6	107.4	147.2	1484.2
1989	140.3	157.7	161.8	181.2	136.1	142.3	117.3	137.5	85.1	82.6	110.6	134.6	1587.1
1990	139.7	173.1	188.0	224.7	139.9	165.7	141.3	120.7	80.9	85.3	99.8	134.8	1693.9
1991	129.6	157.6	209.1	218.1	169.9	113.6	84.0	100.6	73.1	71.6	117.2	155.6	1600.0
1992	159.9	180.6	224.5	223.6	208.7	132.6	-	-	-	-	137.2	124.4	-
1993	144.3	142.2	175.2	183.2	195.7	186.3	206.2	247.1	197.7	174.1	161.1	132.2	2145.3
1994	-	-	-	-	-	-	-	-	-	-	-	-	-
1995	149.5	192.0	172.0	202.3	132.3	80.7	65.7	83.4	69.6	55.8	104.7	136.2	1444.2
1996	159.8	145.1	235.0	144.9	97.1	63.4	39.8	50.9	62.0	51.2	62.5	112.1	1223.8
1997	75.9	101.0	139.2	157.6	117.6	121.6	85.1	91.0	127.4	88.5	71.9	92.9	1269.7
Aver.	143.8	160.3	205.2	190.1	155.0	126.9	115.1	118.8	93.5	83.7	102.0	128.3	1622.7

Table B2-6 Monthly Means of Maximum and Minimum Daily Temperatures

Station: Pochentong Years : 1985-1997

Monthly Means of Maximum Daily Temperature Unit : °C

Year	Month												Annual
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1985	31.5	33.6	34.9	34.9	32.6	31.8	32.4	32.7	31.1	30.5	30.3	29.7	32.2
1986	30.0	32.6	34.5	34.9	33.1	33.4	33.0	31.7	31.0	31.1	29.5	29.6	32.0
1987	31.0	32.2	35.1	36.6	36.8	34.2	34.8	33.4	31.9	31.4	31.0	28.9	33.1
1988	32.2	33.6	35.9	35.2	34.7	33.3	32.6	32.4	32.2	30.1	28.9	29.6	32.6
1989	32.1	32.2	33.0	35.6	33.9	33.8	32.8	33.2	31.8	30.8	30.2	30.4	32.5
1990	31.9	31.9	34.5	36.6	34.4	33.8	34.0	32.2	31.7	30.8	30.4	30.6	32.7
1991	32.3	33.2	34.7	35.7	35.1	32.8	31.3	30.8	31.4	30.1	30.0	30.8	32.3
1992	30.7	33.3	35.5	30.1	36.7	33.5	32.2	31.4	32.4	29.8	29.7	30.8	32.2
1993	29.9	31.9	33.3	34.9	33.3	31.2	30.8	30.3	30.6	30.6	31.6	30.2	31.5
1994	32.2	34.4	33.8	34.8	34.3	33.2	32.1	32.9	31.1	31.6	31.6	31.7	32.8
1995	29.7	30.2	33.5	34.7	33.6	32.8	32.2	32.7	31.3	31.8	31.7	31.3	32.1
1996	30.3	32.0	33.2	34.7	33.1	32.4	31.0	30.7	31.1	31.2	31.5	29.9	31.8
1997	30.9	32.6	34.4	35.3	35.0	35.1	32.3	32.7	32.0	31.5	31.1	32.1	32.9
Aver.	31.1	32.6	34.3	34.9	34.4	33.2	32.4	32.1	31.5	30.9	30.6	30.4	32.4

Monthly Means of Minimum Daily Temperature Unit : °C

Year	Month												Annual
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1985	21.2	23.7	24.8	25.1	24.9	25.0	24.3	24.5	24.0	24.0	24.0	22.1	24.0
1986	19.7	21.9	23.2	25.5	25.0	24.6	24.4	24.4	24.1	24.5	24.1	21.4	23.6
1987	20.7	21.5	24.5	26.6	26.1	25.4	25.2	24.5	24.7	24.4	24.5	21.0	24.1
1988	21.7	23.3	24.8	25.2	25.1	24.6	24.2	24.7	24.2	23.7	22.2	20.1	23.7
1989	21.5	21.3	23.4	24.7	24.8	24.8	24.5	32.1	24.0	23.9	22.9	21.5	24.1
1990	21.9	22.8	24.7	26.0	25.5	24.9	24.6	24.1	24.1	24.5	22.9	21.4	24.0
1991	21.9	22.1	23.9	25.6	25.8	24.7	24.6	24.6	24.7	23.6	22.4	21.8	23.8
1992	20.6	22.9	24.0	25.8	26.3	24.9	24.7	24.1	22.1	22.6	20.9	20.8	23.3
1993	21.9	21.5	23.6	24.8	25.7	31.4	24.9	24.4	24.3	23.1	20.7	20.9	23.9
1994	20.5	22.9	23.6	25.2	25.3	24.8	24.5	24.4	23.7	23.4	20.7	22.2	23.4
1995	21.0	21.5	24.1	25.7	24.7	24.8	24.5	24.6	22.7	23.0	21.4	20.4	23.2
1996	20.9	21.8	23.5	25.3	25.0	24.9	24.4	24.8	24.8	24.2	23.8	20.8	23.7
1997	20.6	23.3	23.6	24.9	25.6	25.3	24.7	24.9	24.5	24.6	24.2	23.0	24.1
Aver.	21.1	22.3	24.0	25.4	25.4	25.4	24.6	25.1	24.0	23.8	22.7	21.3	23.8

Table B2-7 Monthly Mean Relative Humidity

Station: Pochentong Years : 1985-1997 Unit : %

Yea	Month												Annual
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1985	67.0	66.5	61.2	71.3	80.3	78.5	77.3	76.7	84.2	84.1	83.0	75.3	75.4
1986	67.1	69.8	63.7	69.0	79.0	79.1	79.0	82.5	85.4	83.5	78.6	77.1	76.1
1987	69.5	68.0	64.6	64.2	66.7	77.0	74.6	80.3	84.4	84.8	85.6	77.3	74.8
1988	73.5	71.4	64.6	74.1	78.9	79.7	82.7	85.5	85.9	86.3	79.7	73.3	78.0
1989	72.9	70.7	74.9	71.7	82.5	80.4	82.5	81.8	85.7	86.3	79.3	72.6	78.4
1990	72.4	68.4	66.9	66.6	76.9	77.6	78.5	81.3	85.7	85.8	82.2	76.6	76.6
1991	72.0	68.0	66.6	67.9	74.8	80.7	84.9	84.6	86.8	86.6	78.3	74.9	77.2
1992	71.7	68.7	68.3	71.3	75.3	78.1	81.8	84.3	85.0	85.0	76.3	76.5	76.9
1993	72.7	68.4	70.7	67.6	77.5	79.1	83.4	83.1	85.0	82.7	77.1	77.3	77.1
1994	76.4	75.0	77.0	72.2	74.8	77.4	85.9	82.0	88.7	86.7	80.4	83.8	80.0
1995	71.4	69.3	68.7	68.2	75.3	78.9	80.7	83.7	85.4	85.0	79.8	75.1	76.8
1996	72.1	67.1	65.7	75.3	78.8	78.9	89.5	90.0	89.7	88.8	82.5	72.4	79.2
1997	72.6	74.4	73.1	72.9	74.1	73.1	80.6	80.8	83.5	84.5	80.3	-	77.3
Aver.	71.6	69.7	68.2	70.2	76.5	78.3	81.6	82.8	85.8	85.4	80.2	76.0	77.2

Table B2-8 Monthly Means of Daily Sunshine Hours

Station: Pochentong Years : 1981-1997

Unit : hr/day

Year	Month												Annual
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1981	8.8	8.7	9.4	7.4	7.6	5.0	7.1	5.0	6.4	6.6	5.7	7.8	7.1
1982	9.6	8.4	9.2	7.7	8.0	5.1	6.0	5.6	6.2	8.3	8.6	9.5	7.7
1983	9.5	9.5	9.5	8.5	7.8	7.3	7.0	5.2	6.7	5.7	8.3	8.0	7.8
1984	8.3	8.9	10.1	8.9	8.1	5.8	7.6	5.3	6.1	7.8	8.9	8.6	7.9
1985	9.7	9.6	9.1	8.2	8.9	5.4	9.3	6.4	6.1	7.3	7.9	9.3	8.1
1986	9.1	10.1	10.6	8.7	6.2	7.5	7.3	5.4	5.9	7.7	6.7	9.8	7.9
1987	9.5	10.4	9.8	8.5	8.4	6.6	5.8	7.6	6.2	6.6	6.8	9.3	8.0
1988	10.0	9.3	10.2	9.0	8.0	6.8	8.0	7.8	7.7	5.3	7.0	9.6	8.2
1989	-	-	-	-	-	-	-	-	-	-	-	-	-
1990	-	-	-	-	-	-	-	-	-	-	-	-	-
1991	-	-	-	-	-	-	-	-	-	-	-	-	-
1992	-	-	-	-	-	-	-	-	-	-	-	-	-
1993	-	-	-	-	-	-	-	-	-	-	-	-	-
1994	-	-	-	-	-	-	-	-	-	-	-	-	-
1995	8.4	9.7	7.9	9.8	7.6	7.1	6.3	6.6	4.9	6.1	5.8	7.7	7.3
1996	8.8	8.6	9.5	7.2	6.2	7.1	5.0	6.5	4.4	5.2	6.0	-	6.8
1997	9.1	7.1	9.0	6.9	6.2	7.3	4.4	5.1	5.6	6.5	8.0	9.6	7.1
Aver.	9.2	9.2	9.4	8.3	7.4	6.8	6.6	6.5	5.9	6.4	6.9	9.2	7.7

Table B2-9 Monthly Mean Atmospheric Pressure

Station:Pochentong Years : 1981-1997

Unit : mb

Year	Month												Annual
	Jan	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
1981	1012.0	1010.1	1010.2	1008.3	1006.7	1006.6	1005.6	1005.8	1006.7	1007.7	1008.7	1012.7	1008.4
1982	1011.6	1009.6	1008.5	1008.2	1007.0	1006.8	1006.0	1006.7	1007.8	1009.1	1009.5	1011.5	1008.5
1983	1012.6	1011.1	1009.9	1007.6	1006.8	1006.3	1006.2	1006.5	1007.3	1007.1	1011.0	1011.3	1008.6
1984	1009.9	1008.6	1008.5	1006.6	1005.8	1004.8	1005.2	1004.6	1007.1	1008.2	1004.4	1009.2	1006.9
1985	1010.9	1006.2	1008.6	1005.8	-	-	-	-	-	-	-	-	-
1986	-	-	-	-	-	1005.0	1006.4	1004.7	1007.3	1008.9	1009.2	1011.8	-
1987	1012.4	1012.3	1009.1	1008.2	1007.2	1006.0	1006.5	1006.6	1007.3	1008.6	1008.2	1012.2	1008.7
1988	1009.8	1009.3	1007.1	1007.6	1006.1	1005.6	1005.8	1006.4	1005.8	1005.8	1009.3	1011.4	1007.5
1989	1008.6	1009.6	1007.8	1006.3	1005.3	1006.2	1005.7	1005.0	1006.4	1007.6	1010.0	1011.4	1007.5
1990	1009.9	1010.4	1009.9	1006.2	1005.6	1005.0	1005.4	1005.3	1006.4	1007.8	1008.9	1011.4	1007.7
1991	1009.8	1010.0	1008.5	1007.2	1007.0	1006.3	1005.5	1005.7	1006.9	1007.6	1010.3	1010.5	1007.9
1992	1012.8	1008.5	1009.1	1007.1	1005.9	1005.0	1006.5	1005.3	-	1007.6	1010.3	1011.2	-
1993	1009.8	1010.1	1011.1	1008.5	1007.6	1006.5	1005.8	1007.4	1007.6	1009.7	1009.0	1011.3	1008.7
1994	1010.3	1008.8	1009.9	1007.2	1006.7	1005.1	1005.2	1006.6	1007.4	1009.4	1010.7	1011.0	1008.2
1995	1011.8	1007.5	1009.0	1007.8	1006.8	1005.8	1006.0	1006.1	1007.0	1007.2	1009.2	1011.9	1008.0
1996	1010.3	1010.4	1008.4	1007.4	1007.0	1008.5	1007.5	1008.1	1006.8	1008.6	1010.1	1019.5	1009.4
1997	1012.2	1013.3	1011.2	1009.4	-	1006.8	-	1006.8	1009.5	1010.9	1011.1	1011.7	-
Aver.	1010.9	1009.7	1009.2	1007.5	1006.5	1006.0	1006.0	1006.1	1007.2	1008.2	1009.4	1011.9	1008.2

Table B2-10 Monthly Maximum Wind

Station: Pochentong Years: 1981-1997

Unit : m/s

	Jan.		Feb.		Mar.		Apr.		May		Jun.		Jul.		Aug.		Sep.		Oct.		Nov.		Dec.	
Year	Dir.	Vel.	Dir.	Vel.	Dir.	Vel.	Dir.	Vel.	Dir.	Vel.	Dir.	Vel.	Dir.	Vel.	Dir.	Vel.	Dir.	Vel.	Dir.	Vel.	Dir.	Vel.	Dir.	Vel.
1981	N	8.0	SE	8.0	SE	8.0	S/SE	8.0	SE	8.0	S/W	10.0	W	12.0	W	18.0	W	10.0	WNW	8.0	S	12.0	N	8.0
1982	NNE	8.0	S	0.8	E	0.8	N	6.0	S	6.0	W	8.0	W	12.0	WNW	12.0	W	12.0	SSW	12.0	E	16.0	N	12.0
1983	N	12.0	S	8.0	E	8.0	S	12.0	S	16.0	W	12.0	SSE	16.0	NW	16.0	E	14.0	NE	16.0	E	12.0	NE	0.8
1984	NE	0.8	W	12.0	S	12.0	S	14.0	W	10.0	W	12.0	S	16.0	NE	8.0	E	12.0	NW	10.0	W	12.0	N	8.0
1985	NE	8.0	SE	12.0	S	12.0	W	16.0	SW	12.0	W	18.0	W	20.0	W	12.0	NW	14.0	N	0.8	NNW	12.0	N	6.0
1986	N	0.8	E	6.0	SE	10.0	E	8.0	S	14.0	W	12.0	NW	10.0	W	8.0	SW	10.0	N	8.0	NNE	8.0	N	0.6
1987	N	0.6	N	6.0	S	8.0	S	16.0	E	16.0	SW	14.0	W	16.0	NW	12.0	N	6.0	SE	6.0	S	8.0	N	0.6
1988	N	6.0	SE	6.0	E	6.0	SE	10.0	S	8.0	SE	16.0	W	16.0	SW	12.0	SW	12.0	W	16.0	N	10.0	NNE	8.0
1989	N	6.0	S	6.0	E	14.0	N	12.0	W	18.0	W	16.0	SSW	15.0	W	16.0	SW	14.0	S	12.0	NE	9.0	N	10.0
1990	N	4.0	E	7.0	NE	8.0	W	10.0	S	12.0	S	10.0	W	14.0	WSW	7.0	SW	6.0	E	12.0	NW	6.0	NNE	6.0
1991	NE	4.0	NNE	6.0	SE	6.0	NNE	8.0	SE	10.0	W	10.0	W	8.0	W	8.0	W	8.0	NW	14.0	N	6.0	N	6.0
1992	N	6.0	S	6.0	SE	6.0	S	10.0	SE	16.0	SW	12.0	W	4.0	S	8.0	W	8.0	N	8.0	NE	8.0	NE	6.0
1993	SE	4.0	S	8.0	W	18.0	S	16.0	S	12.0	W	8.0	W	10.0	S	8.0	W	7.0	NE	8.0	N	6.0	N	7.0
1994	NE	7.0	S	5.0	NE	16.0	W	6.0	SW	8.0	SE	13.0	W	6.0	W	8.0	SW	14.0	N	7.0	NE	6.0	N	5.0
1995	N	5.0	NE	5.0	S	6.0	ENE	14.0	W	8.0	W	14.0	SW	8.0	SW	8.0	NNW	6.0	NE	6.0	NNE	6.0	N	6.0
1996	N	5.0	NE	8.0	S	6.0	SW	5.0	W	8.0	W	6.0	SE	8.0	W	6.0	SW	4.0	N	4.0	NE	6.0	N	6.0
1997	N	6.0	SE	7.0	NE	8.0	SE	10.0	S	12.0	S	10.0	NW	16.0	WSW	7.0	SW	6.0	E	12.0	NW	6.0	N	6.0
Aver.		5.4		6.9		9.0		10.6		11.4		11.8		12.2		10.2		9.6		9.4		8.8		6.0

Note: Dir. means the direction and Vel. the velocity.

Table B2-11 Annual Water Levels of Mekong River System
(Chaktomuk Station)

Year	Highest (EL. m)		Mean (EL. m)	Loweat (EL. m)	Maximum Water Level Deference (m)
1960	8.93	(15)	3.68	0.20	8.73
1961	9.96	(1)	4.65	0.72	9.24
1962 *	9.14	(10)	4.34	0.69	8.45
1963 *	8.75	(23)	3.97	0.53	8.22
1964	9.04	(13)	4.06	0.70	8.34
1965	8.29	(28)	4.12	0.64	7.65
1966	9.91	(3)	4.33	0.62	9.29
1967	8.74	(24)	3.76	0.64	8.10
1968	8.66	(27)	3.46	0.64	8.02
1969	8.77	(22)	3.93	0.31	8.46
1970	9.14	(10)	4.22	0.58	8.56
1971	8.82	(19)	4.35	0.68	8.14
1972	9.16	(9)	4.18	0.64	8.52
1973	8.86	(18)	3.92	0.60	8.26
1974	8.82	(19)	3.82	0.78	8.04
1975	-	-	-	-	-
1976	-	-	-	-	-
1977	-	-	-	-	-
1978	-	-	-	-	-
1979	-	-	-	-	-
1980	9.19	(8)	-	-	-
1981	9.45	(7)	4.80	0.70	8.75
1982	8.92	(16)	4.06	0.90	8.02
1983	8.72	(25)	3.77	0.72	8.00
1984	9.61	(4)	4.46	0.76	8.85
1985	8.87	(17)	4.35	0.74	8.13
1986	8.70	(26)	4.20	0.67	8.03
1987	8.07	(29)	3.56	0.63	7.44
1988	7.30	(33)	3.46	0.74	6.56
1989	7.80	(32)	3.66	0.63	7.17
1990	8.80	(21)	4.35	0.60	8.20
1991	9.54	(5)	4.21	0.64	8.90
1992	7.99	(30)	3.53	0.68	7.31
1993	7.93	(31)	3.53	0.56	7.37
1994	9.51	(6)	4.33	0.64	8.87
1995	9.12	(12)	4.13	0.63	8.49
1996	9.92	(2)	4.51	0.89	9.03
1997	9.03	(14)	4.39	0.99	8.04
1998	6.90	(34)	-	0.67	6.23
Maximum	9.96		4.80	0.99	9.29
Minimum	6.90		3.46	0.20	6.23
Average	8.83		4.07	0.66	8.16

Table B2-12 Flood Condition in Year 1995 and 1996

Item	Year 1995	Year 1996
Flood Characteristics		
(1) Peak Water Level at Chaktomuk	EL. 9.12 m (Sep. 18 & 19)	EL. 9.92 m (Oct. 02)
(2) Duration over EL. 8.5 m	47 days (Sep. 07 to Oct. 23)	44 days (Sep. 21 to Nov. 03)
(3) Type of Hydrograph	Flat	Sharp
Damage and Flood Defense Activity in the Year 1996 Flood		
(1) General	This flood is the second biggest in the last 38 years in terms of the water level. So, sever damage was inflicted on the municipality of Phnom Penh at many locations. However, the great effort for the flood defense activity by official /private organizations concerned could barely avoid fatal result.	
(2) Kop Srov Dike	- In the eastern approx. 6 km section of Kop Srov dike starting from NR-5, the flood stage reached nearly the dike crest whose elevations are 10.1 to 10.7 m (however, no spill-over occurred). - The head of 3 to 4 m (at the highest water stage) between the water levels inside and outside the dike generated more than 20 places of piping holes, most of which penetrated the dike body or its foundation entirely from the outside to the land side, water leaking through them. - Moreover, the dike slopes were damaged by local rainfall and wave action, jeopardizing the dike's stability. - To protect the dike from breaching due to the above phenomena, 92 trucks of soil were brought in the site to fill up the piping holes, and to cover the damaged dike slopes by using sand bags.	
(3) Tompun Dike	- Likewise, Tompun dike, whose crest elevations are 10.0 to 10.4 m, was suffered from serious danger during the flood. A lot of piping holes and slope erosion were found in places along the whole stretch, where the water balance between both sides reached nearly 5 m. - 119 tracks of soil were carried therein to repair such piping holes and dike slopes.	
(4) Tonle Sap and Bassac Riverfront	- In the lower portions of the Outer Ring Dike, the floodwater level had nearly exceeded their crests, whereas the construction of temporary embankments on the dike, with 30 trucks of soil, prevented overflowing at each location (see Figure B2-7). - A pipe culvert was broken in the event of the flood at the upstream portion. To prevent floodwater from entering through the culvert into the land side, sand bags were cast therein.	

Table B2-13 Inundation Condition in Year 1995 and 1996

Item	Year 1995	Year 1996
Rainfall Characteristics (1) Annual Rainfall	1,413 mm	1,639 mm
(2) Daily Rainfall (a) Over 50 mm	5 times Apr. 30 : 54 mm May 08 : 111 mm Sep. 02 : 55 mm Sep. 28 : 53 mm Oct. 06 : 51 mm	6 times Jun. 16 : 52 mm Aug. 08 : 62 mm Sep. 09 : 57 mm Nov. 03 : 58 mm Nov. 13 : 137 mm Nov. 23 : 58 mm
(b) Over 30 mm	16 times	15 times
Inundation Problems in the Year 1996 (1) General	The description hereunder is with reference to the inundation problems in the year 1996. However, as almost every year very similar inundation problems take place in the Study Area, all the description may be valid for other years.	
(2) Natural Levee Area	This area runs along Tonle Sap and Bassac rivers, about 1 km wide, with elevations above 10 m, so that inundation in the area is slight in magnitude. It lasts only several hours with less than 25 cm of water depths mostly. However, it has repeated some ten times a year, interrupting traffic and in turn stagnating the economy, deteriorating the sanitation, then causing social issues, particularly in City Core.	
(3) Backswamp Area	This area lies behind the Natural Levee area above with widths of 2 to 3 km, whose elevations range from 6 to 8 m, which can be divided into the following two parts:	
(a) Northern Part	This is actually a swampy area, storing runoff from the northern half of the Study Area without problematic inundation.	
(b) Southern Part	The discharge of runoff from this part depends solely on mechanical drainage because of its low elevations. Inundation lasts for a longer time and comes to the peak at the end of the heavy rain period with a maximum water depth of more than 1 m at Trabek.	
(4) West Area Fringe	The area fringes the West Area, Item (5) below, with slightly high elevations, around 10 m, mostly formed by recent artificial fills. No serious inundation is hence observed therein.	
(5) West Area	Paddy fields spread over the area which declines at mild gradients from the west (EL. 13 m) to the east (EL. 9 m). Rainfalls are reserved in the paddy fields for planting/growing rice, of course, without causing damage.	
(6) South Area	This area (EL. 8 to 10 m) is considered a part of the floodplains of the Prek Thnot River, thus hydraulics are directly affected by the river through openings provided along the Prey Sar road. The inundation depth reaches more than 1 m at maximum.	

Table B2-14 Summary of Assets and Flood Damage Survey

Item	Unit	Type of interviewees									
		Household	Shop	Office	Factory	Warehouse	School	Hospital	Farm	Livestock	Fishpond
Number of samples surveyed		416	121	11	16	10	17	9	102	30	20
Number of household members/ employees/ students/patients		6.5	6.2	22	5	3	2,624	132	6.6	6.9	4.4
Annual income in 1997	$	1,091	1,268	6,000	23,832	39,673	-	n.a	873	1,929	6,823
Size of land	m²	177	64	1,536	511	317	6,962	6,696	13,802	1,360	4,724
Floor area	m²	105	32	424	239	205	2,154	n.a	-	-	-
Frequency of flood											
-No flood	%	0.2	0.0	27.3	18.8	21.6	0.0	62.5	46.1	93.3	80.0
-Once a year	%	59.6	59.5	18.2	50.0	32.4	11.8	0.0	37.3	3.3	20.0
-Two to five times a year	%	19.0	27.3	0.0	6.3	5.4	11.8	0.0	1.0	3.3	0.0
-More	%	21.2	13.2	54.6	25.0	40.5	76.5	37.5	15.7	0.0	0.0
Height of floor level	m	0.54	0.29	0.39	0.18	0.12	0.72	n.a	-	-	-
Water depth at inundation											
-1995	m	0.62	0.39	0.41	0.52	0.36	0.57	0.57 *	1.1	0.55	1.12
-1996	m	0.60	0.35	0.39	0.57	0.34	0.53	0.57 *	1.2	0.55	0.00
Duration of inundation											
-1995	days	22	18	3	14	10	13	6 *	80	23	38
-1996	days	21	14	3	8	7	10	6 *	80	23	0
Suffer from flood											
-No answer	%	9.6	0.0	9.1	0.0	0.0	0.0	0.0 *	46.1	0.0	80.0
-Severely	%	23.3	37.2	63.6	56.3	40.0	94.1	100.0 *	10.8	6.7	10.0
-Lightly	%	41.8	43.0	9.1	37.5	60.0	5.9	0.0 *	24.5	0.0	5.0
-No	%	25.2	19.8	18.2	6.3	0.0	0.0	0.0 *	18.6	93.3	5.0
Damage in utility/infrastructure in 1996											
-Power	%	1.2	0.0	0.0	6.3	0.0	0.0	0.0	-	-	-
-Telephone	%	0.0	0.0	0.0	6.3	0.0	0.0	0.0	-	-	-
-Water	%	32.5	21.5	0.0	18.8	10.0	0.0	12.5	-	-	-
-Transportation	%	31.3	17.4	45.5	12.5	10.0	82.4	25.0	-	-	-
Flood damage in monetary value											
-1995	$	341	235	1,077	2,153	914	3,067	n.a	230	n.a	9,245
-1996	$	143	107	10,050	517	1,054	6,571	n.a	104	n.a	0
Expectation for flood mitigation											
-Strongly support	%	51.7	48.8	100.0	68.8	40.0	94.1	28.6 *	24.5	16.7	10.0
-Support	%	44.5	47.1	0.0	25.0	60.0	5.9	0.0 *	75.5	83.3	0.0
-No need	%	3.9	4.1	0.0	6.3	0.0	0.0	71.4 *	0.0	0.0	90.0
Other											
-Closure of shop/stop operation in 1996	days	-	6	0	16	0	n.a	0	-	-	-
-Total number in Phnom Penh	No.	-	4,371	534	613	164	128	29	-	-	-

Note :

(1) The values above are all average values except for percentages.

(2) The values with * are the averages of the samples with effective information only.

Source : Asset and Flood Damage Survey conducted by TEAM Consulting Engineers Co.,Ltd.

Table B2-15 Height of Gauge 0 at Each Water Level Gauging Station

Water Level Gauging Station	Status	Height of Gauge 0 (EL. m)
1. Chaktomuk (Sap River)	Existing	-1.02
2. Syay Pak (Outside)	Newly installed	0.81
3. Syay Pak (Inside)	Newly installed	0.90
4. Kop Srov Dike, 1.9 km (Outside)	Newly installed	3.60
5. Kop Srov Dike, 4.1 km (Outside)	Existing	1.29
6. Trabek Pumping Station (Inside)	Existing	-0.01
7. Tompun Pumping Station (Outside)	Newly installed	3.26
8. Tompun Pumping Station (Inside)	Existing	0.04
9. Russei Bridge	Existing	-0.06
10. Prey Sar Bridge	Newly installed	4.78
11. Tum Nap Toek Pumping Station (Outside)	Existing	0.01
12. Tum Nap Toek Pumping Station (Inside)	Existing	0.01
13. Salang Pumping Station (Inside)	Existing	-0.03
14. Toul Kork I Pumping Station (Outside)	Newly installed	3.89
15. Toul Kork I Pumping Station (Inside)	Existing	1.58
16. Toul Kork II Pumping Station (Inside)	Existing	0.03
17. Boeng Kak	Existing	-0.11

Note: Surveyed in this Study.

Table B3-1 Maximum Annual Rainfall for Each Duration between 1980 and 1997

Station: Pochentong

Upper Rows : Amount (mm)
Lower Rows : Intensity (mm/hr)

	Duration (hr)													
Years	1/4	1/2	3/4	1	2	3	4	5	6	12	24	48	72	96
1980	15.4	18.2	18.6	25.5	27.9	46.2	46.8	47.7	47.8	70.5	70.8	73.2	117.8	131.4
	61.6	36.4	24.8	25.5	14.0	15.4	11.7	9.5	8.0	5.9	3.0	1.5	1.6	1.4
1981	27.2	44.2	51.1	64.1	65.6	66.5	67.3	67.3	67.3	67.3	85.7	89.3	132.6	137.2
	108.8	88.4	68.1	64.1	32.8	22.2	16.8	13.5	11.2	5.6	3.6	1.9	1.8	1.4
1982	35.5	47.0	61.0	89.2	94.8	94.8	94.8	94.8	94.8	94.8	94.8	107.5	121.0	121.8
	142.0	94.0	81.3	89.2	47.4	31.6	23.7	19.0	15.8	7.9	4.0	2.2	1.7	1.3
1983	-	-	-	41.5	44.3	45.3	45.8	45.9	45.9	45.9	80.0	81.2	116.0	128.0
	-	-	-	41.5	22.2	15.1	11.5	9.2	7.7	3.8	3.3	1.7	1.6	1.3
1984	-	40.0	53.0	55.0	57.0	57.0	57.0	57.0	57.0	57.0	83.3	105.1	109.6	134.6
	-	80.0	70.7	55.0	28.5	19.0	14.3	11.4	9.5	4.8	3.5	2.2	1.5	1.4
1985	22.0	38.0	42.2	49.1	49.5	50.0	50.3	50.3	50.3	55.6	62.5	75.9	86.9	119.2
	88.0	76.0	56.3	49.1	24.8	16.7	12.6	10.1	8.4	4.6	2.6	1.6	1.2	1.2
1986	-	59.8	65.8	69.8	69.8	69.8	69.8	69.8	69.8	69.8	75.4	86.0	92.6	118.1
	-	119.6	87.7	69.8	34.9	23.3	17.5	14.0	11.6	5.8	3.1	1.8	1.3	1.2
1987	31.2	45.0	49.0	54.1	90.8	94.7	96.7	97.4	97.7	98.1	113.5	124.1	124.1	162.9
	124.8	90.0	65.3	54.1	45.4	31.6	24.2	19.5	16.3	8.2	4.7	2.6	1.7	1.7
1988	15.0	16.0	22.6	23.1	24.0	30.5	30.5	30.5	-	-	128.0	211.9	212.1	216.1
	60.0	32.0	30.1	23.1	12.0	10.2	7.6	6.1	-	-	5.3	4.4	2.9	2.3
1989	18.0	25.4	30.4	39.2	40.2	40.2	40.2	40.2	40.2	-	96.9	110.1	142.0	152.8
	72.0	50.8	40.5	39.2	20.1	13.4	10.1	8.0	6.7	-	4.0	2.3	2.0	1.6
1990	13.0	15.6	18.4	21.6	27.6	30.5	30.9	31.4	31.8	49.7	74.0	98.2	98.2	98.2
	52.0	31.2	24.5	21.6	13.8	10.2	7.7	6.3	5.3	4.1	3.1	2.0	1.4	1.0
1991	14.6	22.6	31.8	39.2	44.0	44.7	54.1	57.1	59.3	60.9	85.2	106.6	123.2	123.2
	58.4	45.2	42.4	39.2	22.0	14.9	13.5	11.4	9.9	5.1	3.6	2.2	1.7	1.3
1992	19.0	25.0	31.8	45.0	49.9	58.8	68.4	68.4	68.4	68.4	80.0	92.3	99.3	99.6
	76.0	50.0	42.4	45.0	25.0	19.6	17.1	13.7	11.4	5.7	3.3	1.9	1.4	1.0
1993	25.2	36.0	39.0	47.2	51.9	52.8	52.9	52.9	52.9	52.9	60.3	82.3	107.4	120.4
	100.8	72.0	52.0	47.2	26.0	17.6	13.2	10.6	8.8	4.4	2.5	1.7	1.5	1.3
1994	18.0	29.0	41.0	46.4	48.4	52.4	52.4	52.4	52.4	52.4	79.2	94.0	110.0	129.0
	72.0	58.0	54.7	46.4	24.2	17.5	13.1	10.5	8.7	4.4	3.3	2.0	1.5	1.3
1995	22.1	27.2	36.8	45.6	-	58.6	110.5	110.5	110.5	110.5	110.5	123.3	165.3	166.7
	88.4	54.4	49.1	45.6	-	19.5	27.6	22.1	18.4	9.2	4.6	2.6	2.3	1.7
1996	26.4	32.4	38.4	48.4	51.4	52.7	89.5	89.5	89.5	89.5	137.0	137.0	143.2	143.2
	105.6	64.8	51.2	48.4	25.7	17.6	22.4	17.9	14.9	7.5	5.7	2.9	2.0	1.5
1997	-	-	-	-	-	-	-	-	-	-	123.4	134.4	157.7	164.1
	-	-	-	-	-	-	-	-	-	-	5.1	2.8	2.2	1.7

Table B3-2 Probable Rainfall with Duration

Unit :mm

Return Period	15min	30min	45min	1hr	2hr	3hr	4hr	5hr	6hr	12hr	1day	2days	3days	4days
2	20.7	30.8	34.7	44.8	49.4	53.0	58.8	59.1	61.5	66.7	87.8	102.6	121.0	132.9
5	28.2	44.6	52.9	63.2	71.6	72.8	84.4	84.7	86.3	88.7	112.3	137.6	154.0	163.2
10	33.2	53.7	65.0	75.4	86.3	85.9	101.4	101.6	102.8	103.3	128.4	160.8	175.8	183.2
30	40.8	67.5	83.2	93.8	108.5	105.7	127.1	127.2	127.6	125.3	152.9	195.9	208.7	213.4
50	44.3	73.8	91.5	102.2	118.6	114.7	138.8	138.8	139.0	135.3	164.0	211.9	223.7	227.3

Table B3-3 Rainfall Intensity Equations

Return Period (Year)	(1) Talbot Type Equation	(2) Sherman Type Equation	(3) Kuno Type Equation	(4) Horner Type Equation
	Applicale Range of Rainfall Duration : less than 6hours)			
2	$I = 3{,}907.81 / (T + 33.06)$	$I = 606.47 / T^{0.68}$	$I = 203.24 / (T^{0.5} - 1.97)$	$I = 2{,}566.07 \times (T + 25.48)^{-0.93}$
5	$I = 5{,}589.21 / (T + 33.42)$	$I = 868.08 / T^{0.68}$	$I = 287.36 / (T^{0.5} - 2.04)$	$I = 5{,}009.12 \times (T + 31.38)^{-0.98}$
10	$I = 6{,}692.56 / (T + 33.37)$	$I = 1{,}040.96 / T^{0.68}$	$I = 342.51 / (T^{0.5} - 2.07)$	$I = 6{,}974.09 \times (T + 34.29)^{-1.01}$
	Applicale Range of Rainfall Duration : from 6hr to 4 days)			
2	$I = 7{,}549.89 / (T + 444.51)$	$I = 647.25 / T^{0.71}$	$I = 94.77 / (T^{0.5} - 9.89)$	$I = 381.76 \times (T - 94.66)^{-0.65}$
5	$I = 9{,}366.55 / (T + 351.63)$	$I = 1{,}099.56 / T^{0.75}$	$I = 118.79 / (T^{0.5} - 10.85)$	$I = 666.67 \times (T - 86.23)^{-0.69}$
10	$I = 10{,}570.20 / (T + 313.50)$	$I = 1{,}432.43 / T^{0.76}$	$I = 134.65 / (T^{0.5} - 11.25)$	$I = 903.62 \times (T - 78.21)^{-0.71}$

Table B3-4 Error of Each Rrainfall Intensity Equation

Return Period (Year)	Rainfall Duration	(1) Probable Rainfall Intensity (mm/hr)	Estimated Rainfall Intensities (2) Eq. of Talbot (mm/hr)	(3) Eq. of Sherman (mm/hr)	(4) Eq. of Kuno (mm/hr)	(5) Eq. of Horner (mm/hr)	Differences (1)-(2) (mm/hr)	(1)-(3) (mm/hr)	(1)-(4) (mm/hr)	(1)-(5) (mm/hr)
Rainfall Duration : less than 6 hours										
2	1/4 hr	82.8	81.3	96.2	106.8	82.1	1.5	-13.4	-24.0	0.7
	1/2 hr	61.6	62.0	60.0	57.9	61.3	-0.4	1.6	3.7	0.3
	3/4 hr	46.3	50.1	45.6	42.9	49.0	-3.8	0.7	3.4	-2.7
	1 hr	44.8	42.0	37.5	35.2	41.0	2.8	7.3	9.6	3.8
	2 hr	24.7	25.5	23.4	22.6	25.0	-0.8	1.3	2.1	-0.3
	3 hr	17.7	18.3	17.8	17.8	18.1	-0.6	-0.1	-0.1	-0.4
	4 hr	14.7	14.3	14.6	15.0	14.3	0.4	0.1	-0.3	0.4
	5 hr	11.8	11.7	12.5	13.2	11.8	0.1	-0.7	-1.4	0.0
	6 hr	10.3	9.9	11.1	12.0	10.1	0.4	-0.9	-1.8	0.2
	Standard Deviation						1.8	5.4	9.3	1.7
5	1/4 hr	112.8	115.4	137.7	156.8	116.6	2.6	24.9	44.0	3.8
	1/2 hr	89.2	88.1	85.9	83.6	88.6	1.1	3.3	5.6	0.6
	3/4 hr	70.5	71.3	65.2	61.6	71.5	0.8	5.3	8.9	1.0
	1 hr	63.2	59.8	53.6	50.4	60.0	3.4	9.6	12.8	3.2
	2 hr	35.8	36.4	33.5	32.2	36.6	0.6	2.3	3.6	0.8
	3 hr	24.3	26.2	25.4	25.3	26.4	1.9	1.1	1.0	2.1
	4 hr	21.1	20.4	20.9	21.4	20.6	0.7	0.2	0.3	0.5
	5 hr	16.9	16.8	18.0	18.8	17.0	0.1	1.1	1.9	0.1
	6 hr	14.4	14.2	15.9	17.0	14.4	0.2	1.5	2.6	0.0
	Standard Deviation						1.1	7.8	13.7	1.4
10	1/4 hr	132.8	138.4	165.1	190.0	136.1	5.6	32.3	57.2	3.3
	1/2 hr	107.4	105.6	103.0	100.5	104.1	1.8	4.4	6.9	3.3
	3/4 hr	86.7	85.4	78.2	73.8	84.2	1.3	8.5	12.9	2.5
	1 hr	75.4	71.7	64.3	60.3	70.7	3.7	11.1	15.1	4.7
	2 hr	43.2	43.6	40.1	38.6	43.0	0.5	3.1	4.6	0.1
	3 hr	28.6	31.4	30.5	30.2	30.8	2.8	1.9	1.6	2.2
	4 hr	25.4	24.5	25.1	25.5	24.0	0.9	0.3	0.1	1.4
	5 hr	20.3	20.1	21.5	22.5	19.7	0.2	1.2	2.2	0.6
	6 hr	17.1	17.0	19.0	20.3	16.7	0.1	1.9	3.2	0.4
	Standard Deviation						1.8	10.1	17.9	1.5
Rainfall Duration : from 6 hours to 4days										
2	6 hr	10.3	9.4	9.9	10.4	10.1	0.9	0.4	-0.1	0.2
	12 hr	5.6	6.5	6.1	5.6	5.8	-0.9	-0.5	0.0	-0.2
	1 day	3.7	4.0	3.7	3.4	3.5	-0.3	0.0	0.3	0.2
	2 days	2.1	2.3	2.3	2.2	2.2	-0.2	-0.2	-0.1	-0.1
	3 days	1.7	1.6	1.7	1.7	1.7	0.1	0.0	0.0	0.0
	4 days	1.4	1.2	1.4	1.4	1.4	0.2	0.0	0.0	0.0
	Standard Deviation						0.6	0.3	0.1	0.2
5	6 hr	14.4	13.2	13.3	14.6	13.9	1.2	1.1	0.2	0.5
	12 hr	7.4	8.7	7.9	7.4	7.8	1.3	0.5	0.0	0.4
	1 day	4.7	5.2	4.7	4.4	4.6	0.5	0.0	0.3	0.1
	2 days	2.9	2.9	2.8	2.8	2.8	0.0	0.1	0.1	0.1
	3 days	2.1	2.0	2.1	2.2	2.1	0.1	0.0	0.1	0.0
	4 days	1.7	1.5	1.7	1.8	1.7	0.2	0.0	0.1	0.0
	Standard Deviation						0.6	0.4	0.1	0.2
10	6 hr	17.1	15.7	16.3	17.4	16.5	1.4	0.8	0.3	0.6
	12 hr	8.6	10.2	9.6	8.6	9.2	1.6	1.0	0.0	0.6
	1 day	5.4	6.0	5.7	5.0	5.4	0.6	0.3	0.4	0.0
	2 days	3.4	3.3	3.4	3.2	3.2	0.1	0.0	0.2	0.2
	3 days	2.4	2.3	2.5	2.5	2.4	0.1	0.1	0.1	0.0
	4 days	1.9	1.7	2.0	2.1	2.0	0.2	0.1	0.2	0.1
	Standard Deviation						0.7	0.4	0.1	0.3

Table B4-1 Conditions for Runoff and Inundation Analysis

Manning's Roughness Coefficient

	Land Use Category	Roughness Coefficient	
		Without Project	With Project
1	Dense activities	0.20	0.15
2	Dense urban center	0.20	0.15
3	Dense residential	0.20	0.15
4	Loose residential	0.20	0.15
5	Loose activities	0.20	0.15
6	Agriculture land, unused land	1.00	1.00
7	Fish pond	1.00	1.00
8	Green space, park	1.00	1.00
9	Lakes, pond, river	0.035	0.035
		Orifice Coefficient	
10	Orifice	α=0.667	μ, μ'=0.35

Initial Water Levels/Depths

	Area	Without Project		With Project	
		Water Level* (EL. m)	Water Depth** (m)	Water Level* (EL. m)	Water Depth** (m)
1	Boeng Trabek	4.5		3.0	
2	Boeng Tompun	5.5		2.0	
3	Boeng Poungpeay	6.8		6.8	
4	Boeng Kak	7.3		7.3	
5	South Area	8.8***		8.8***	
6	City Core & Airport		0.0		0.0
7	Pochentong East		0.0		0.0
8	Other Areas (Agriculture land)		0.2		0.2

Note: * The design rainfall is assumed to occur when water levels of the lakes have reached at the highest
** The water depth is a depth measured from the lowest height of each block.
*** Corresponding to the floodwater level of the Prek Thnot River that intrudes into the South Area through openings.

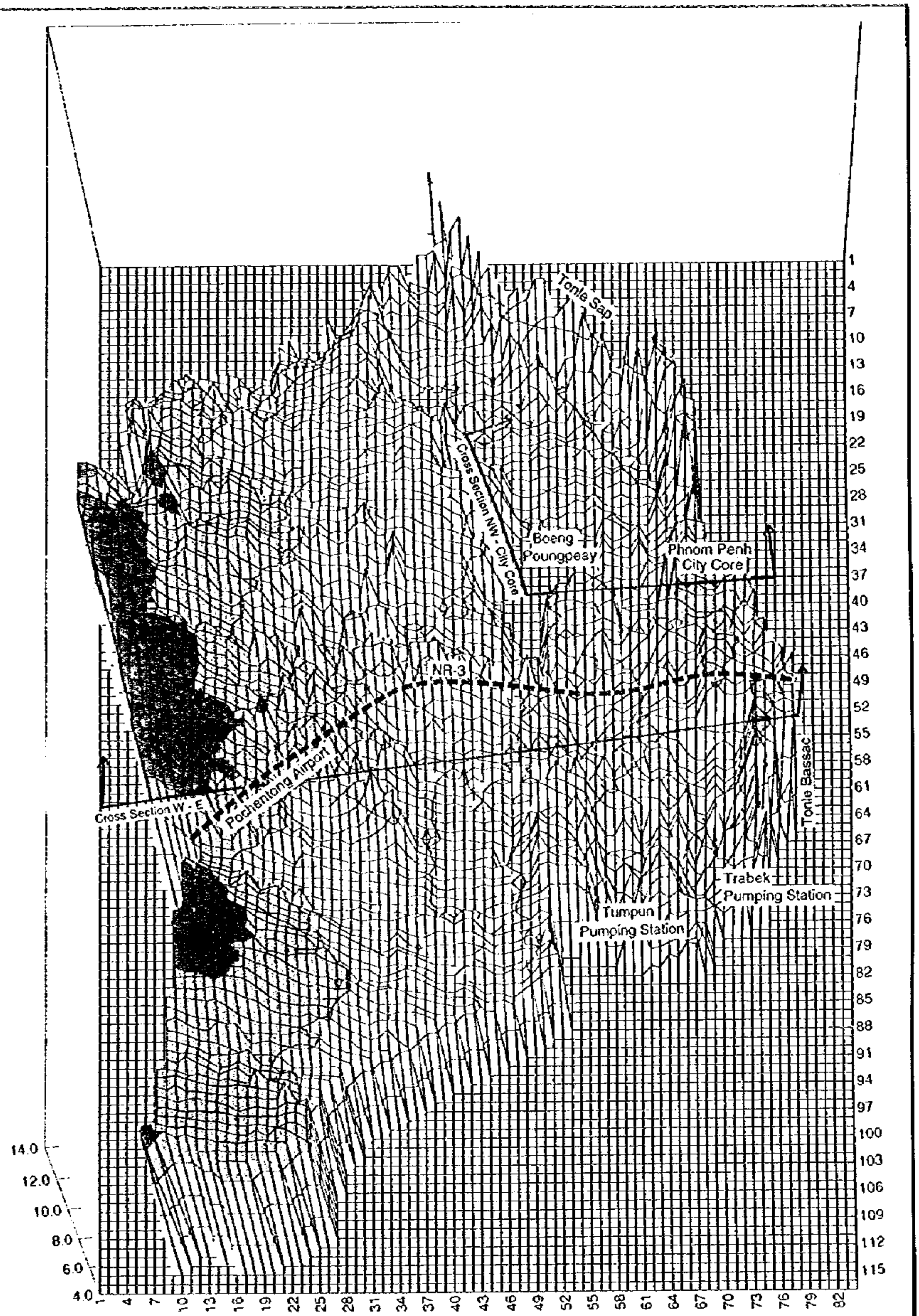
Pump Capacities

	Pumping Station	Pumping Capacity (m^3/s)	
		Without Project*	With Project
1	Trabek	2.1	8.00
2	Tompun	2.9	15.00
3	Tum Nap Toek	0.3	-
4	Salarng	1.1	-
5	Toeuk Laak	0.0	-
6	Olympic	0.0	-
7	Toul Kork I	0.3	-
8	Toul Kork II	0.3	-
9	Toul Kork III	0.0	-

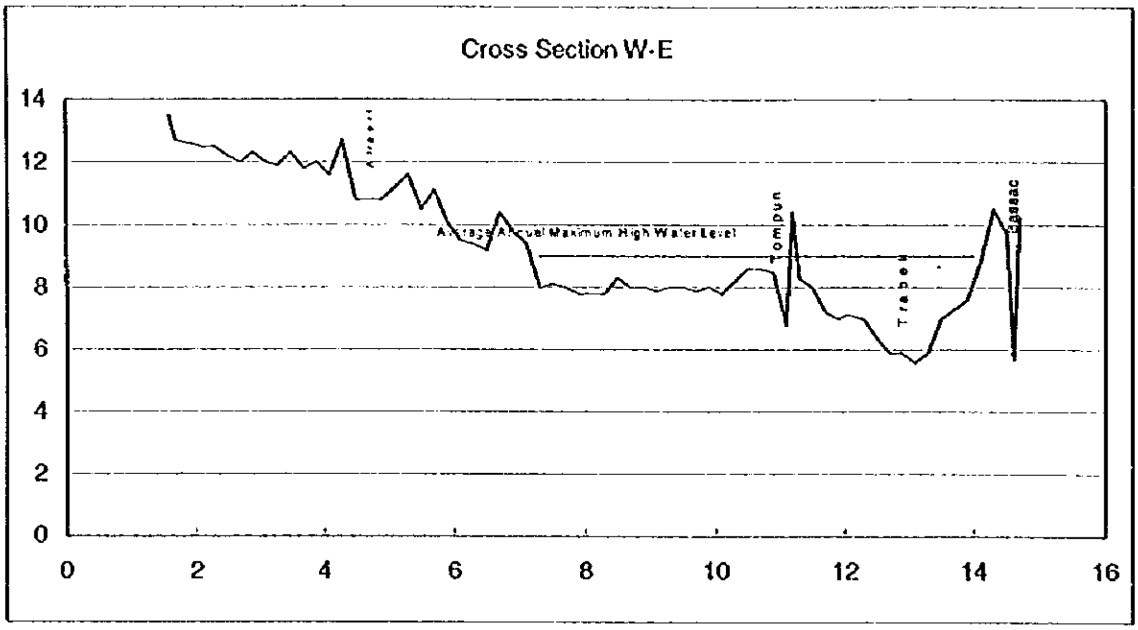
* 0.5 times the official present capacity

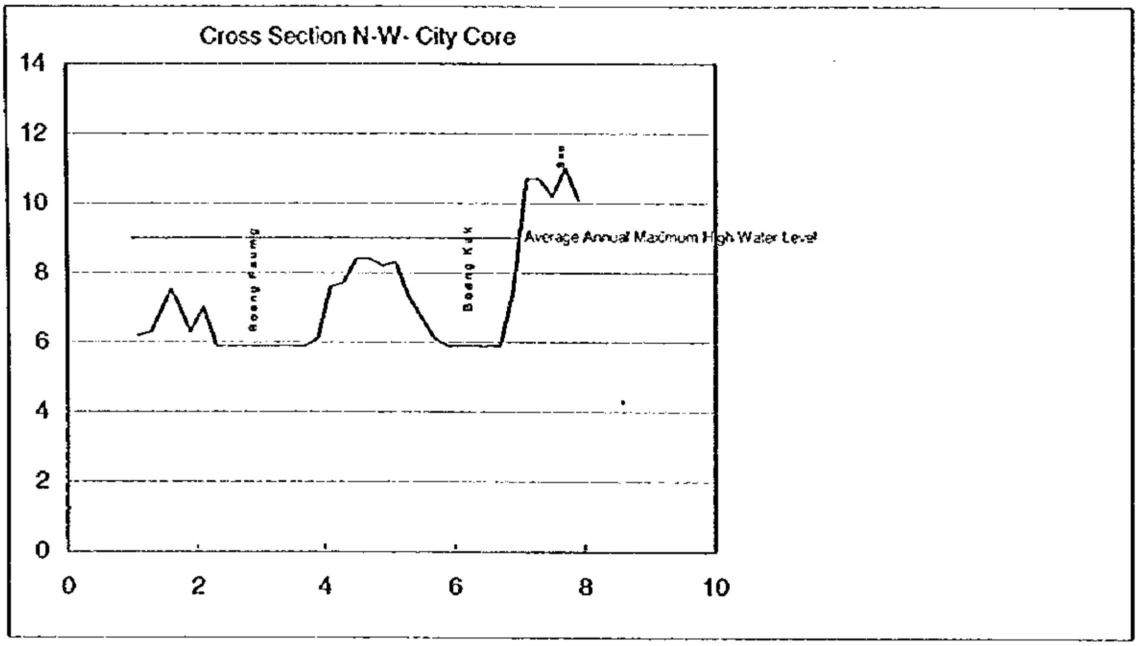
Table B4-2 Calculation Cases

Case	Rainfall / Water Level	Overflow at Kop Srov Dike	Without Project		With Project		Remarks
	(Rainfall)		Suburbs	City Core	Suburbs	City Core	
1	Nov.13,1996	Non	O	O			
2	2-year	Non	O	O			
3	〃	Non			O	O	
4	5-year	Non	O	O			
5	〃	Non			O	O	Protection Level
6	10-year	Non	O	O			
7	〃	Non			O	O	
8	30-year	Non	O	O			
9	〃	Non			O	O	
	(Water Level)						
10	10-year	O	O				EL.10.1m
11	30-year	O	O				EL.10.4m

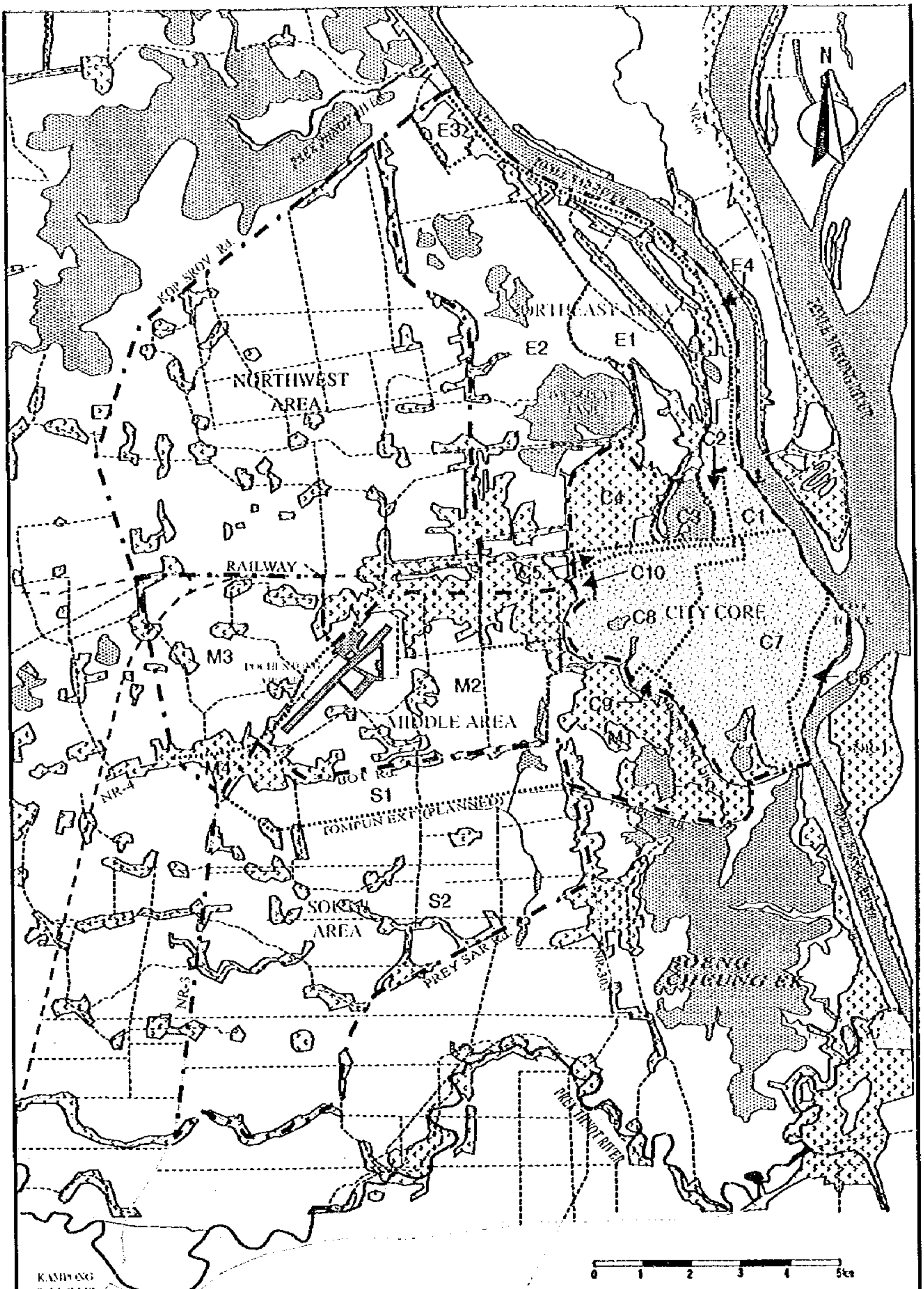


The Study on Drainage Improvement and Flood Control in the Municipality of Phnom Penh JICA - CTIE International Co., Ltd. - Nippon Koei	Figure B2-1 Three-dimensional View of Study Area

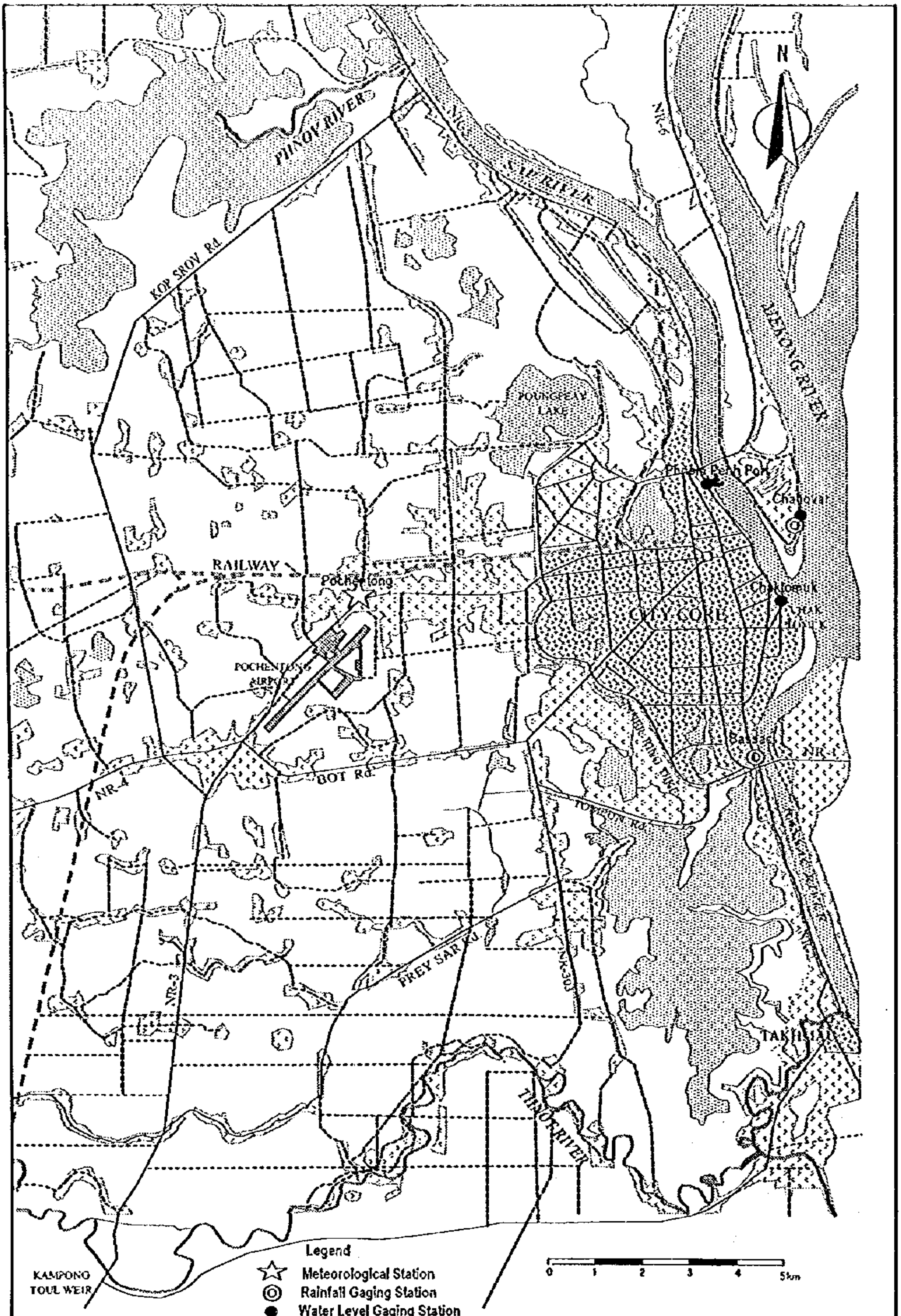




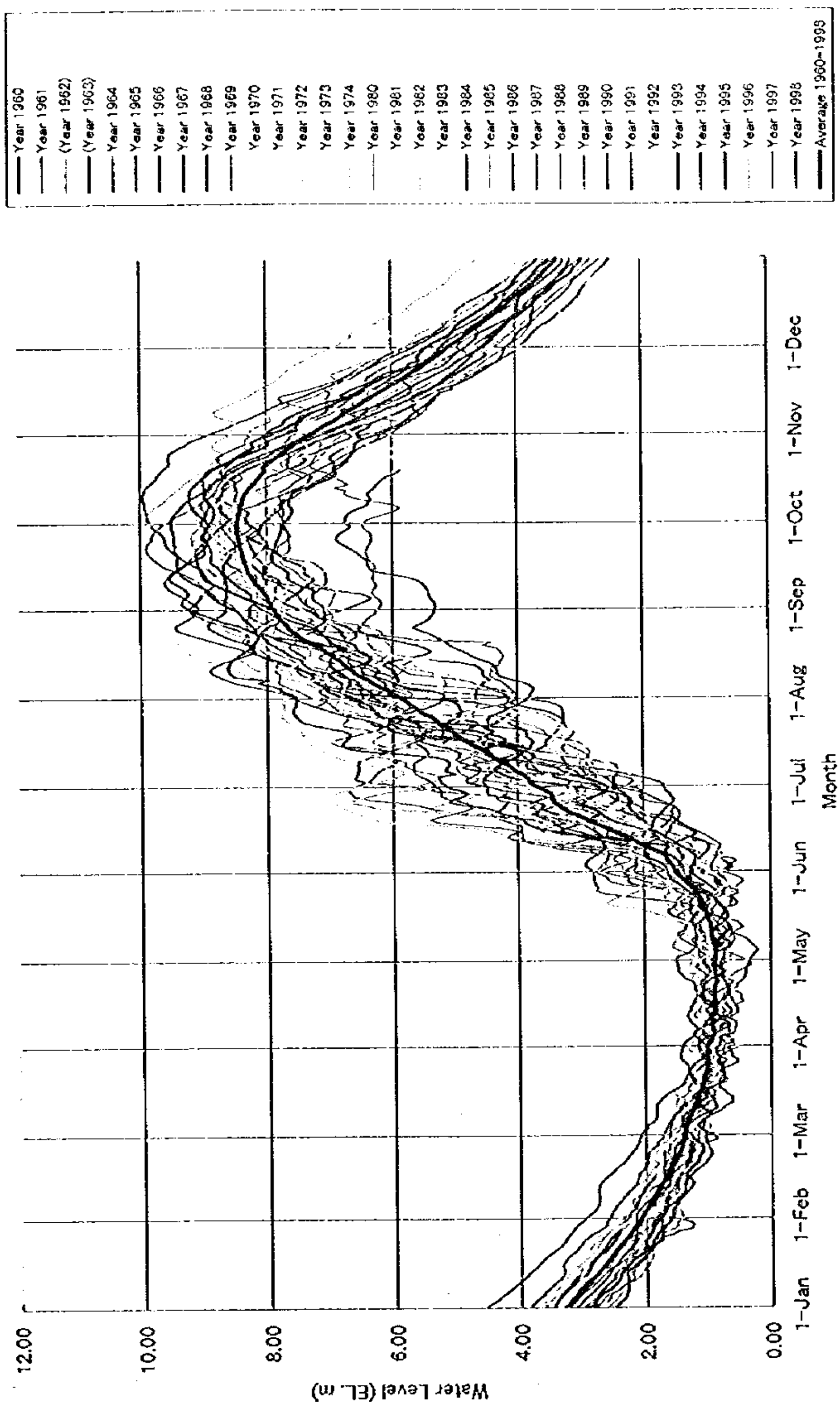
The Study on Drainage Improvement and Flood Control in the Municipality of Phnom Penh JICA-CTIE International Co., Ltd.-Nippon Koei Co., Ltd.	Figure B2-2 Profiles of Study Area



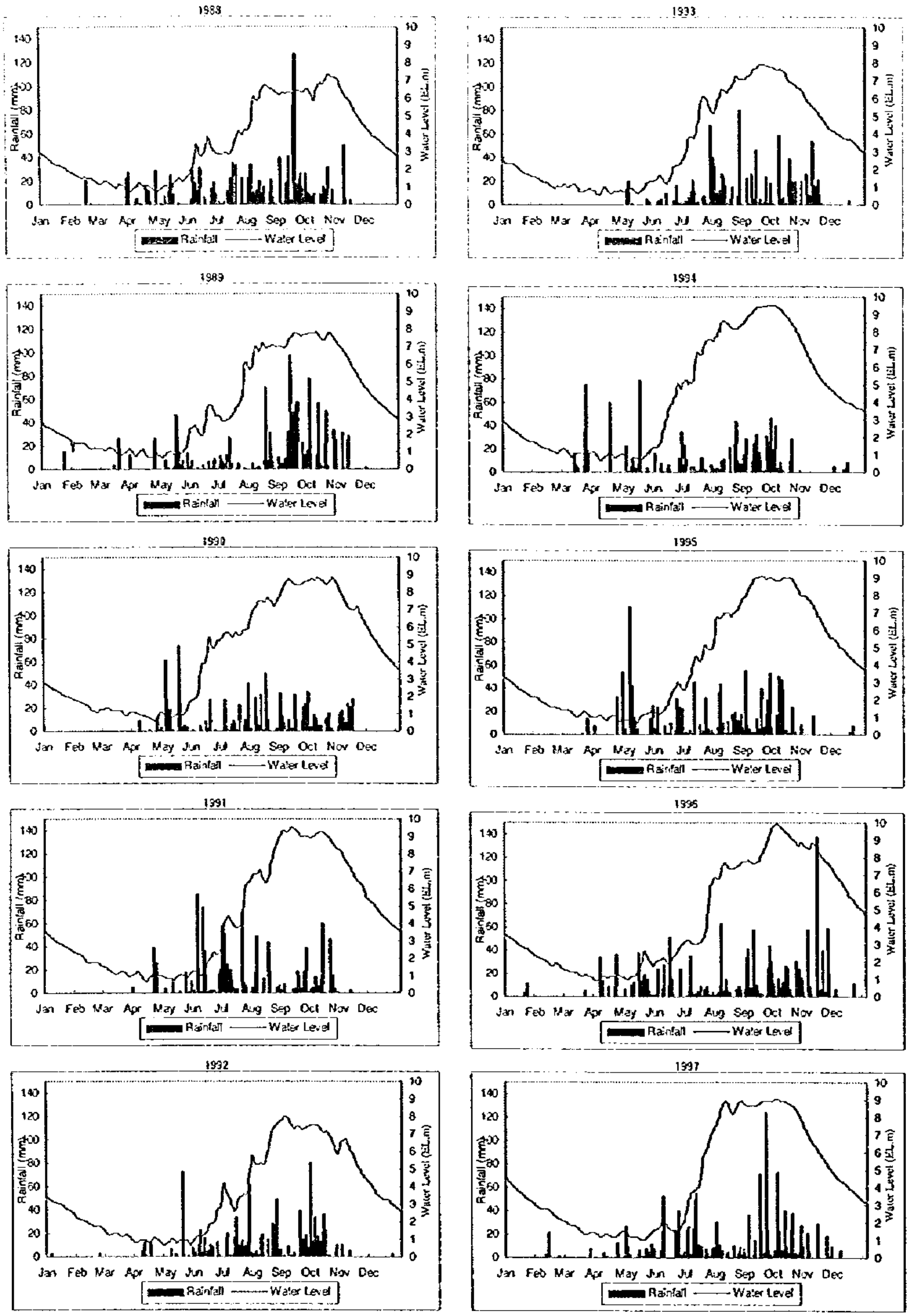
The Study on Drainage Improvement and Flood Control in the Municipality of Phnom Penh JICA - CTIE International Co., Ltd. - Nippon Koei Co., Ltd.	Figure B2-3 Watersheds



The Study on Drainage Improvement and Flood Control in the Municipality of Phnom Penh JICA - CTIE International Co., Ltd. - Nippon Koei Co., Ltd.	Figure B2-4 Location of Observation Stations

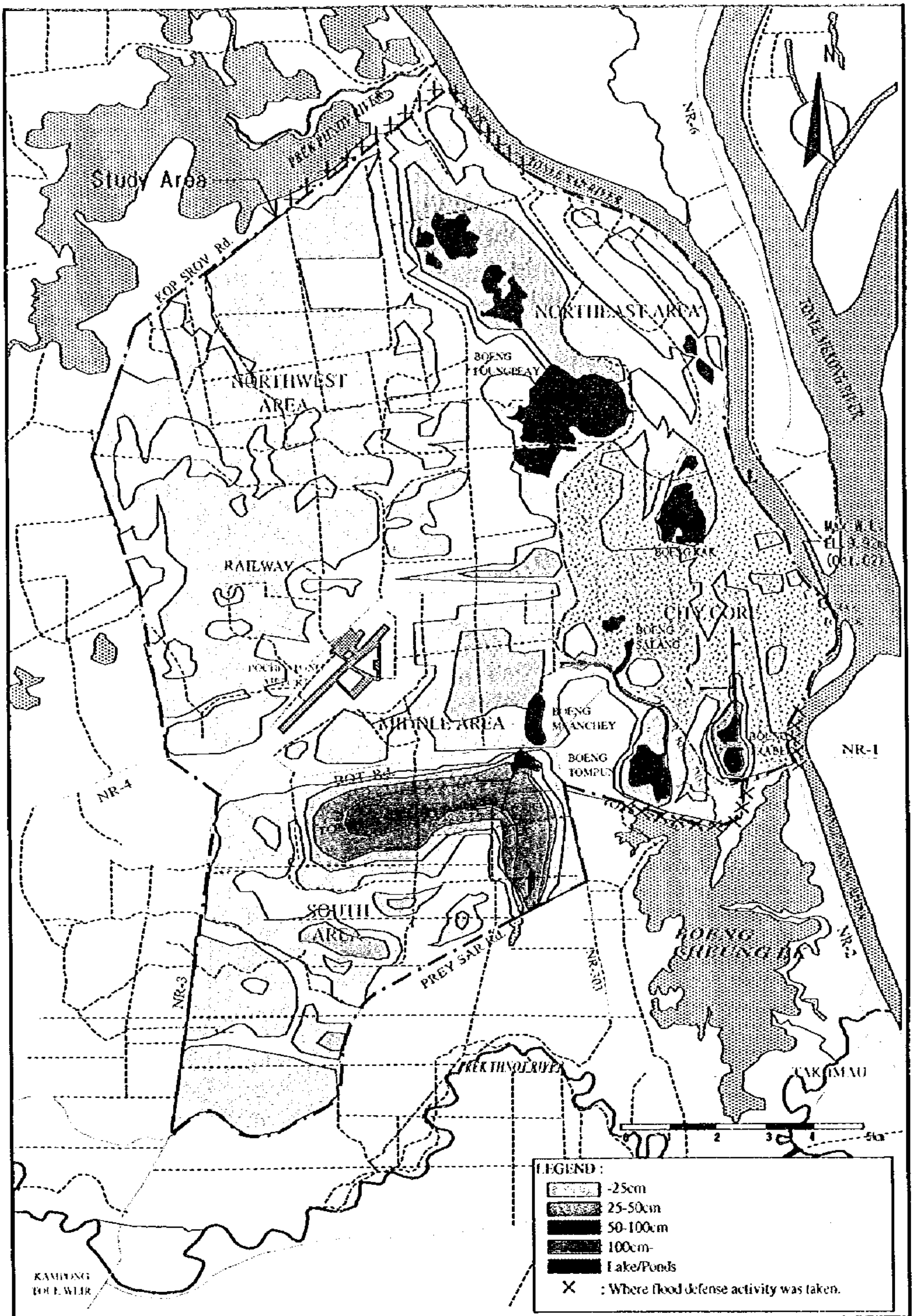


The Study on Drainage Improvement and Flood Control in the Municipality of Phnom Penh JICA-CTIE International Co., Ltd.-Nippon Koei Co., Ltd.	Figure B2-5 Seasonal Variation of Water Level at Chaktomuk Station

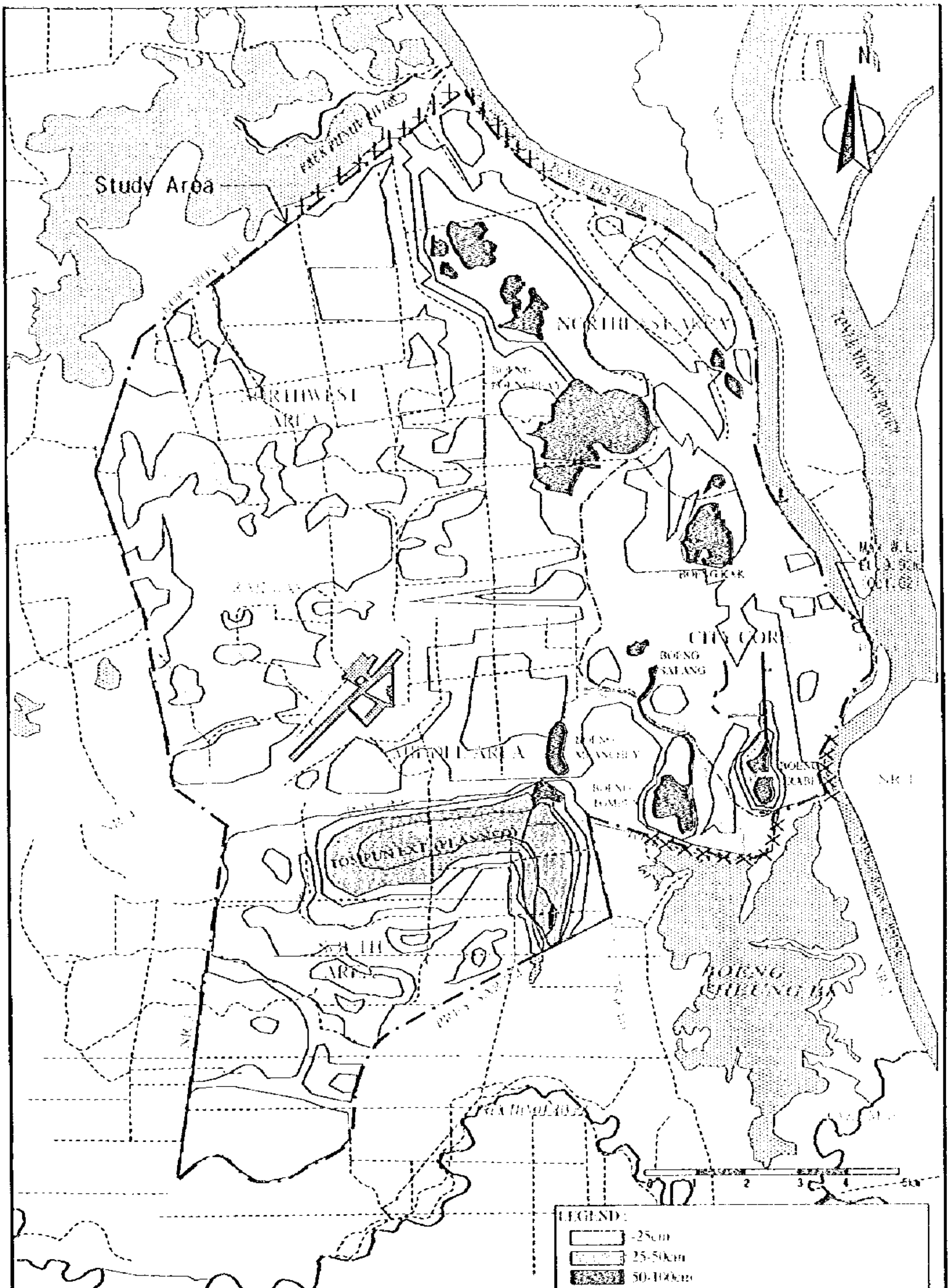


Note:Water level at Chaktomuk and rainfall at Pochentong

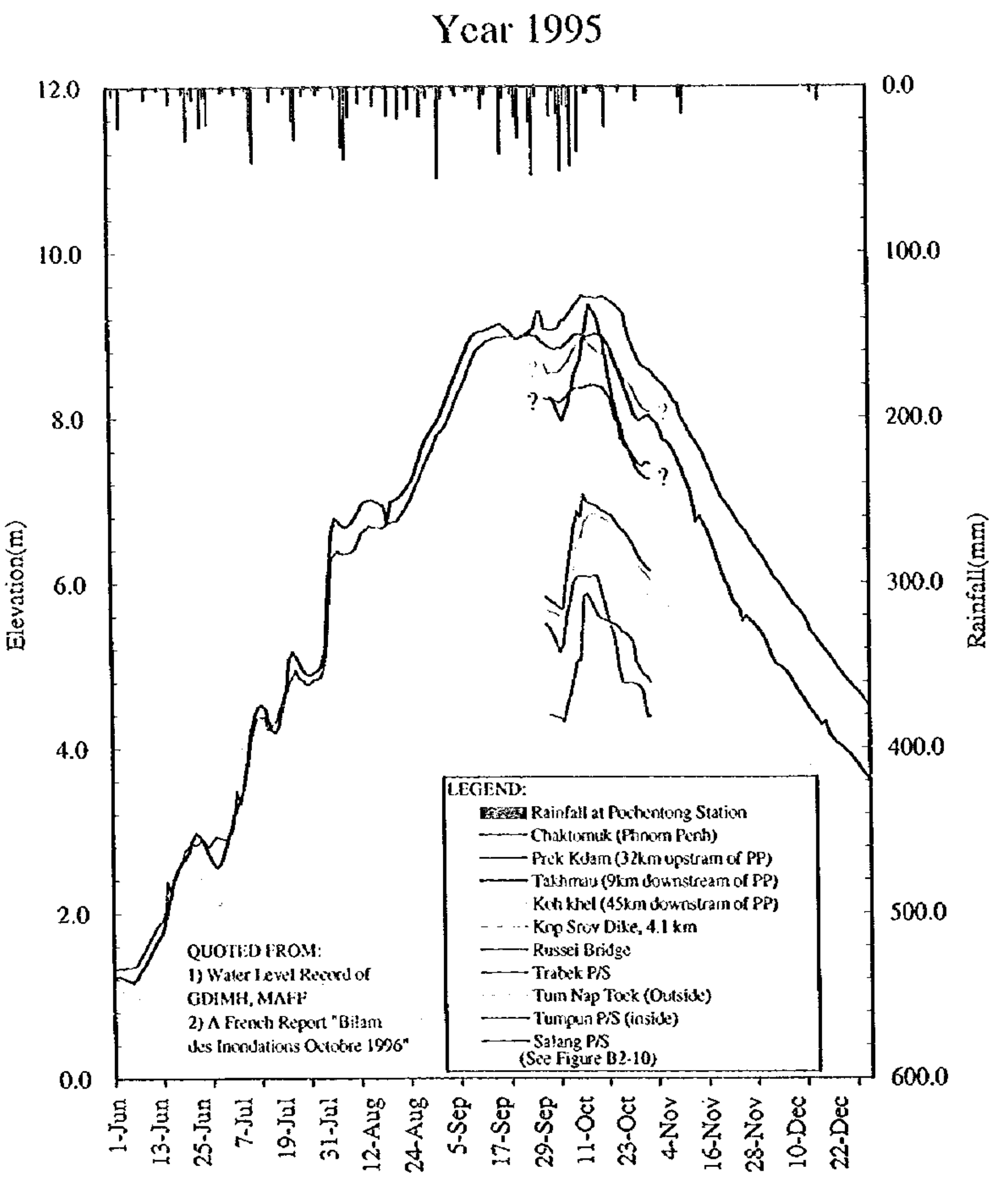
The Study on Drainage Improvement and Flood Control in the Municipality of Phnom Penh JICA-CTIE International Co., Ltd.-Nippon Koei Co., Ltd.	Figure B2-6 Water Level and Daily Rainfall in the Last Decade



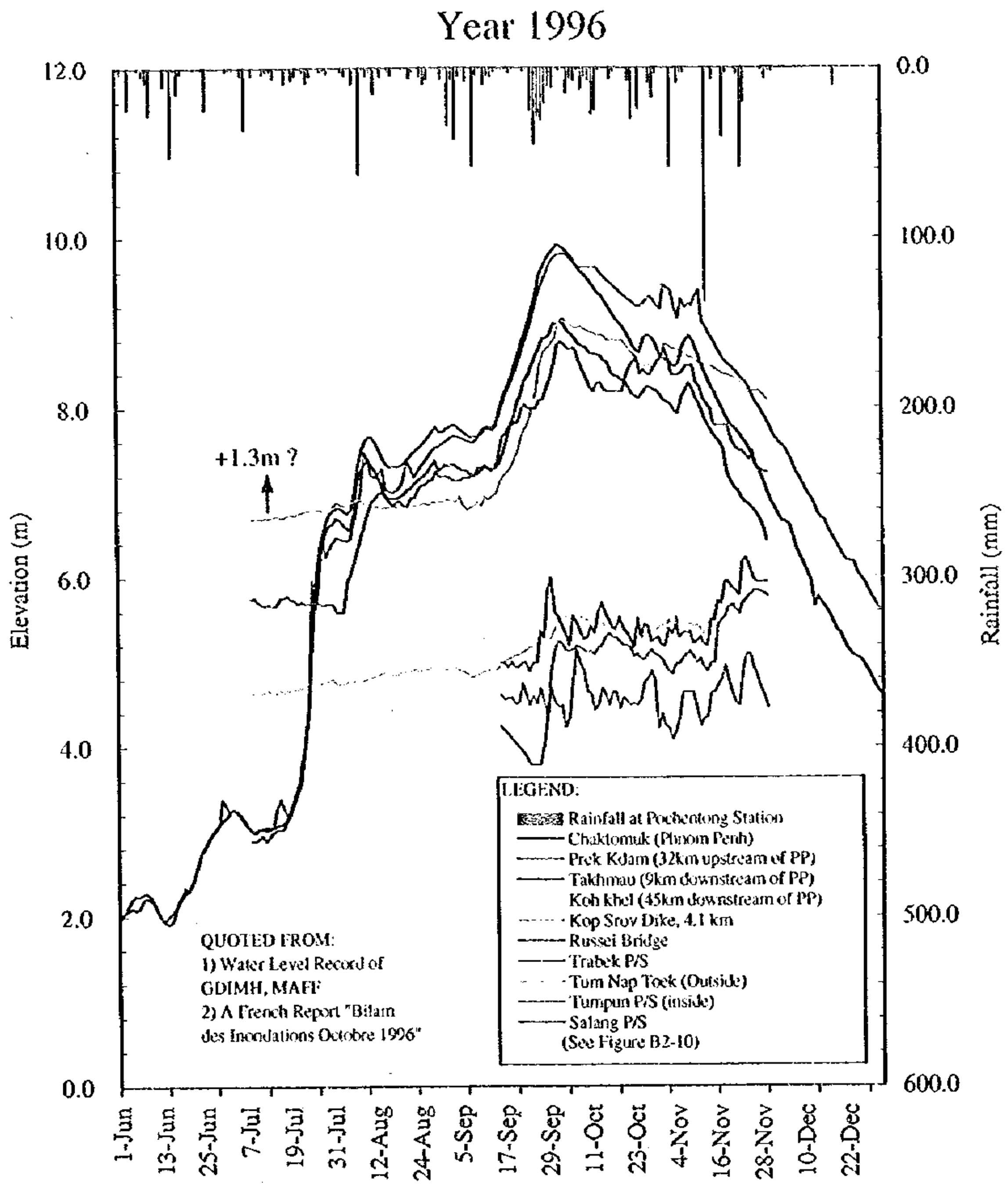
The Study on Drainage Improvement and Flood Control in the Municipality of Phnom Penh JICA - CTIE International Co., Ltd. - Nippon Koei Co., Ltd.	Figure B2-7 Flood and Inundation Map in Year 1996



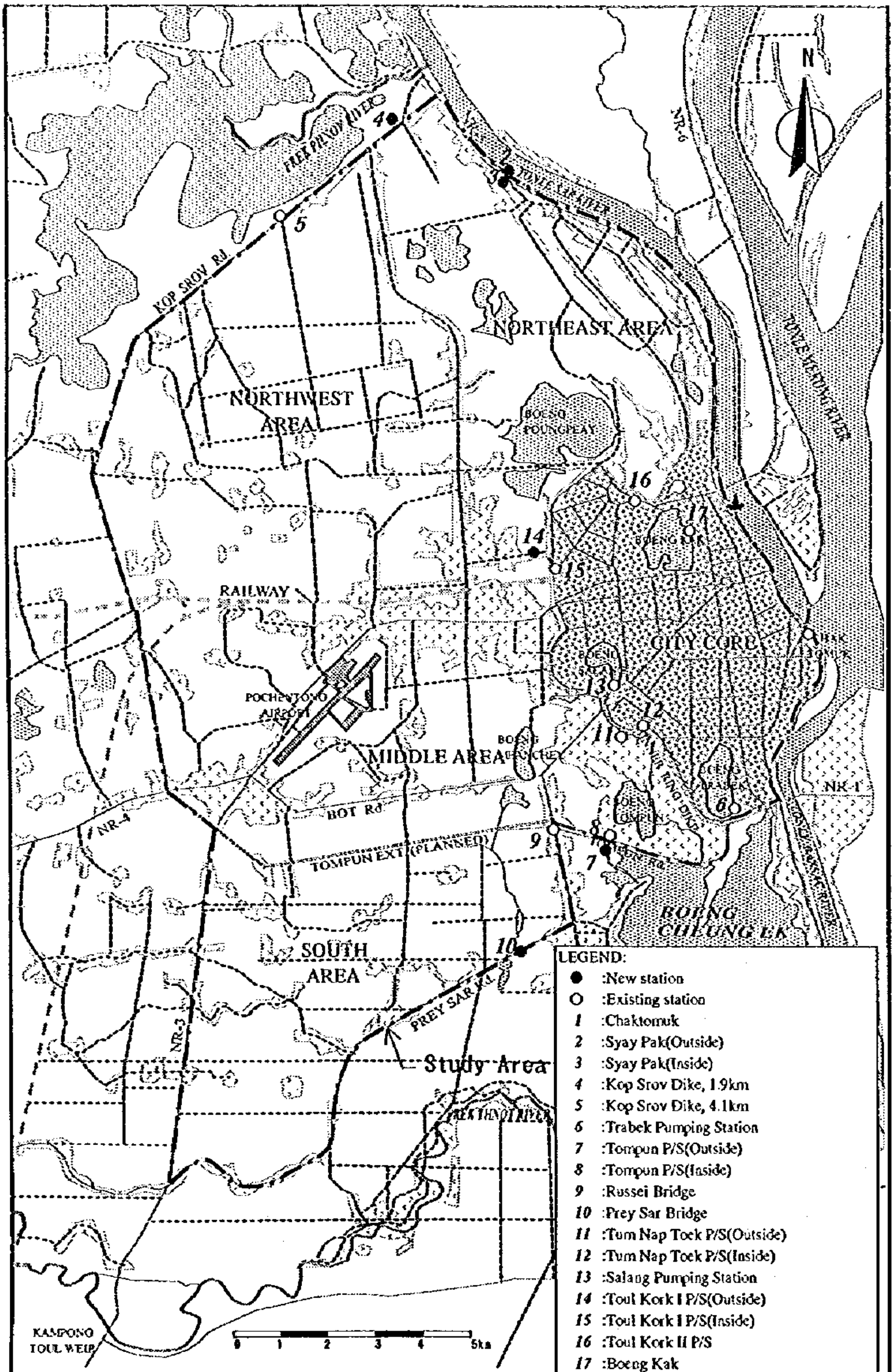
The Study on Drainage Improvement and Flood Control in the Municipality of Phnom Penh JICA - CTI International Co., Ltd. - Nippon Koei Co., Ltd.	Figure B2-7 Flood and Inundation Map in Year 1996



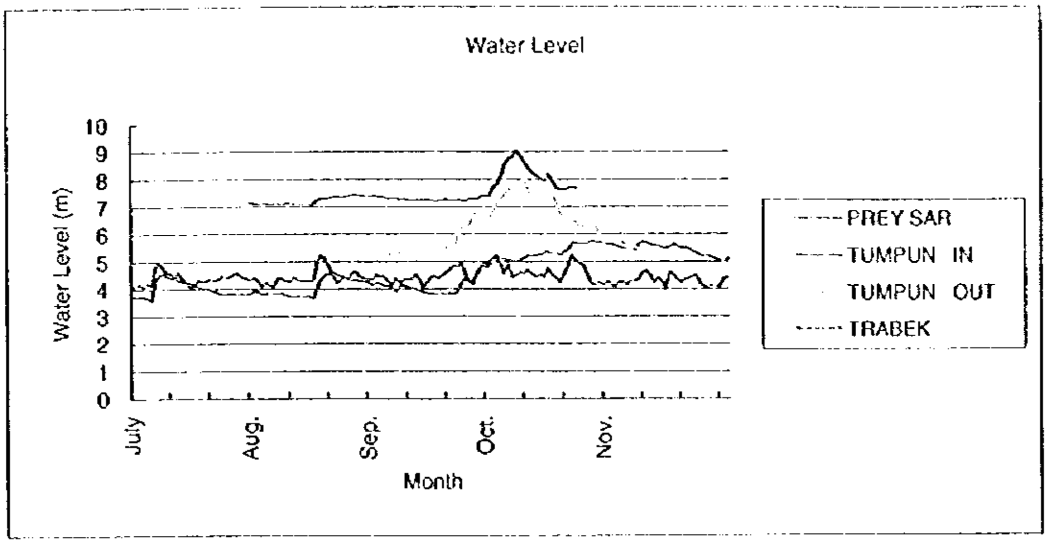
The Study on Drainage Improvement and Flood Control in the Municipality of Phnom Penh JICA - CTIE International Co., Ltd. - Nippon Koei Co., Ltd.	Figure B2-8 Water Levels and Rainfall in Year 1995

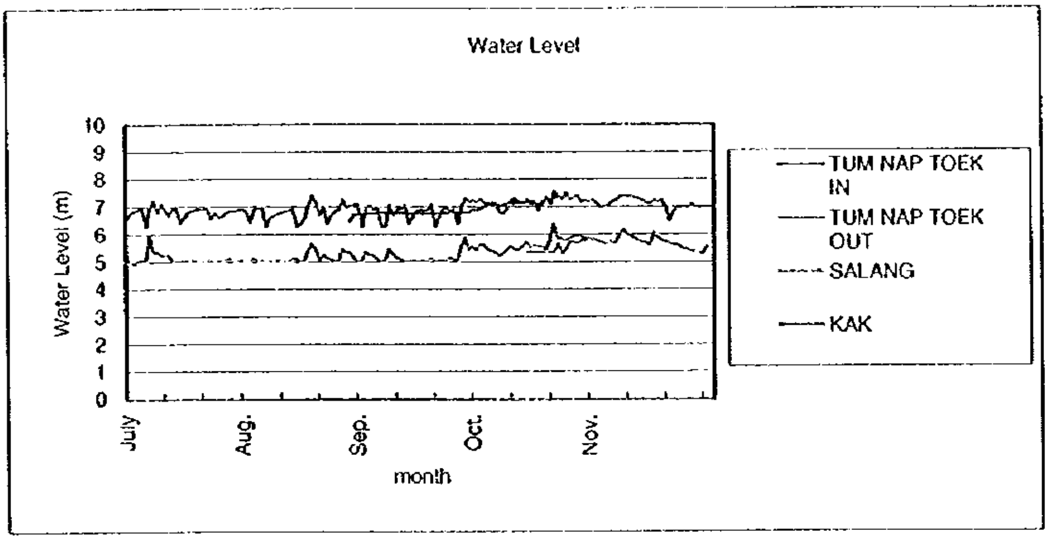


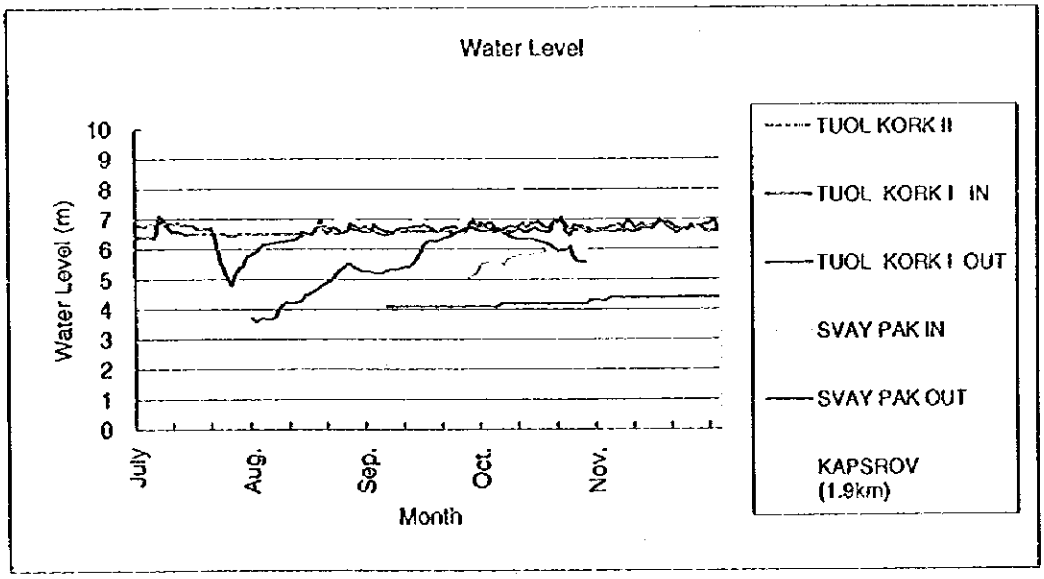
The Study on Drainage Improvement and Flood Control in the Municipality of Phnom Penh JICA - CTIE International Co., Ltd. - Nippon Koei Co., Ltd.	Figure B2-9 Water Levels and Rainfall in Year 1996



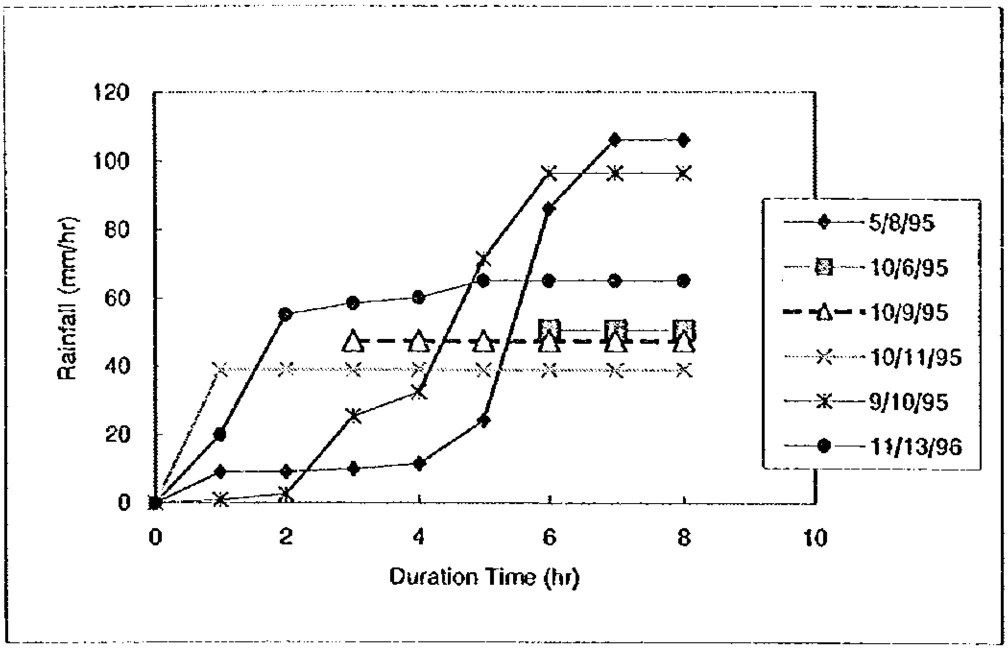
The Study on Drainage Improvement and Flood Control in the Municipality of Phnom Penh JICA - CTIE International Co., Ltd. - Nippon Koei Co., Ltd.	Figure B2-10 Water Level Gauging Stations in Study Area

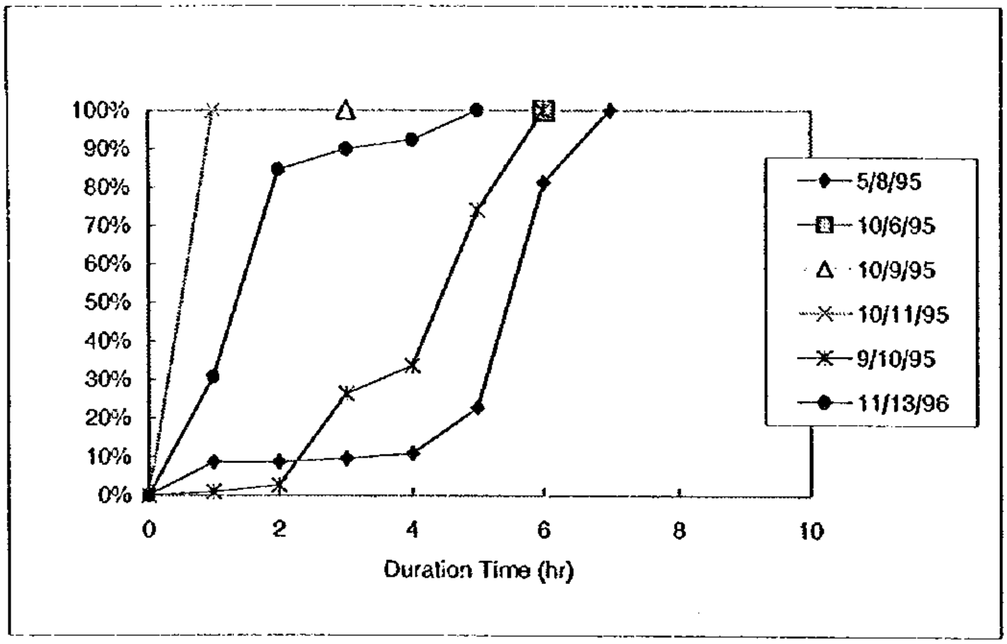




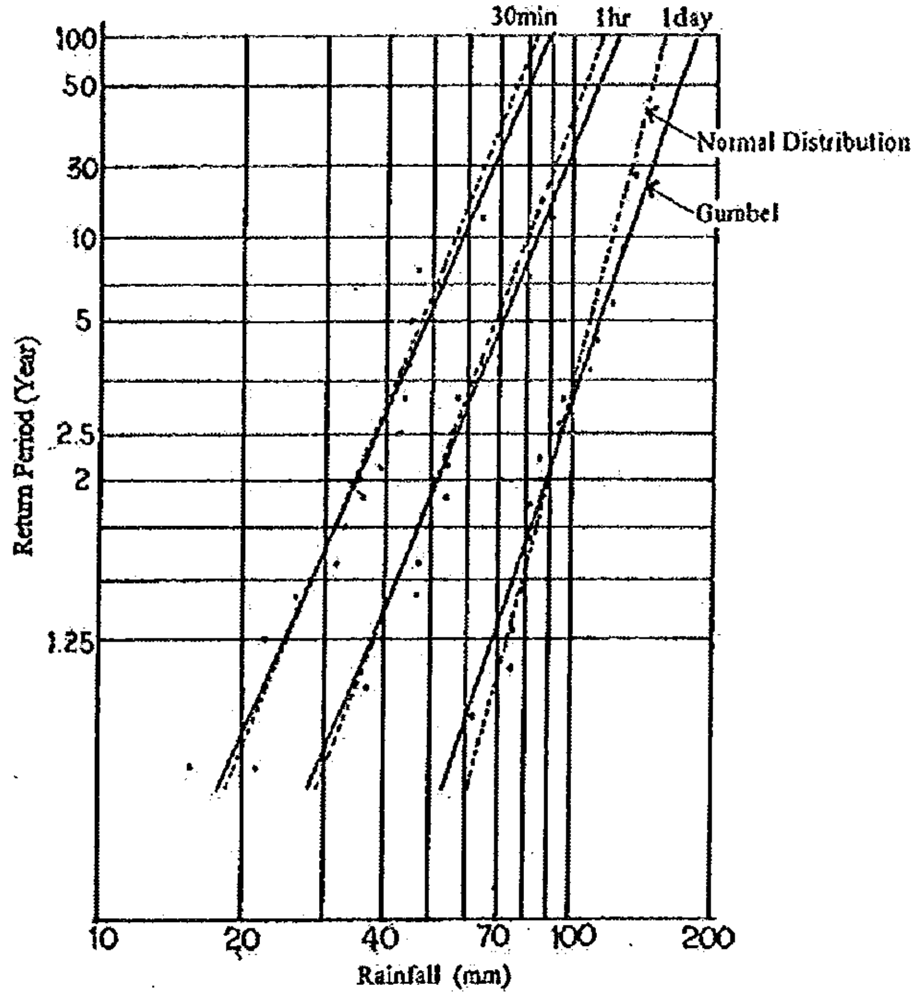


The Study on Drainage Improvement and Flood Control in the Municipality of Phnom Penh JICA-CTIE International Co., Ltd.-Nippon Koei Co., Ltd.	Figure B2-11 Water Level Variation in 1998 Rainy Season

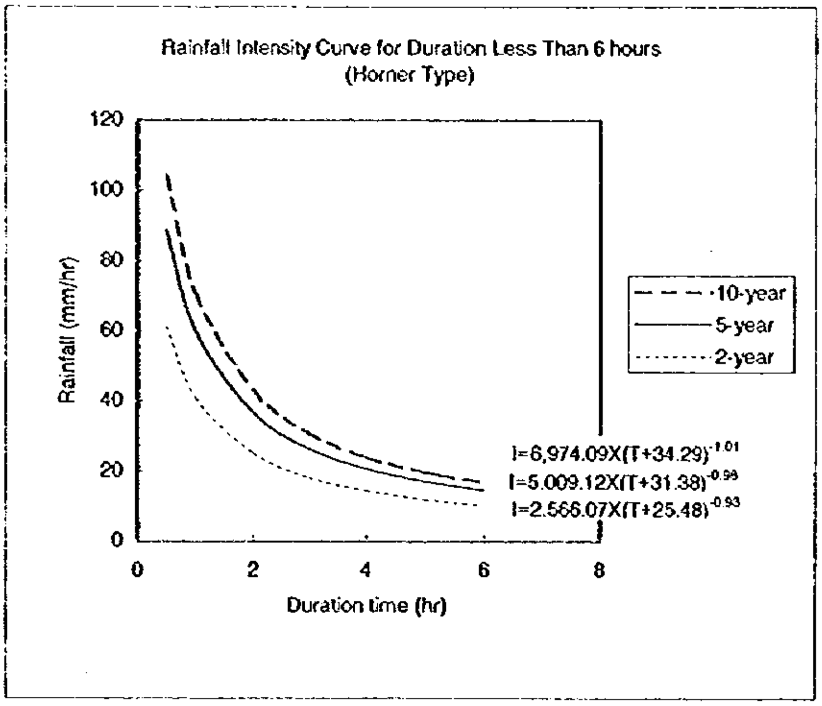


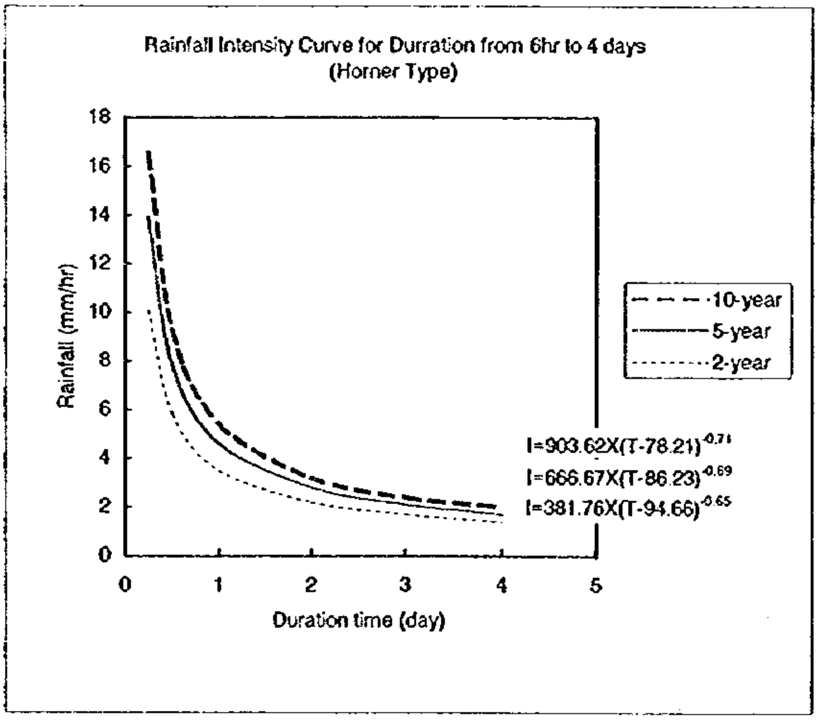


The Study on Drainage Improvement and Flood Control in the Municipality of Phnom Penh JICA-CTIE International Co., Ltd. -Nippon Koei Co., Ltd.	Figure B3-1 Actual Single Rainfall Duration



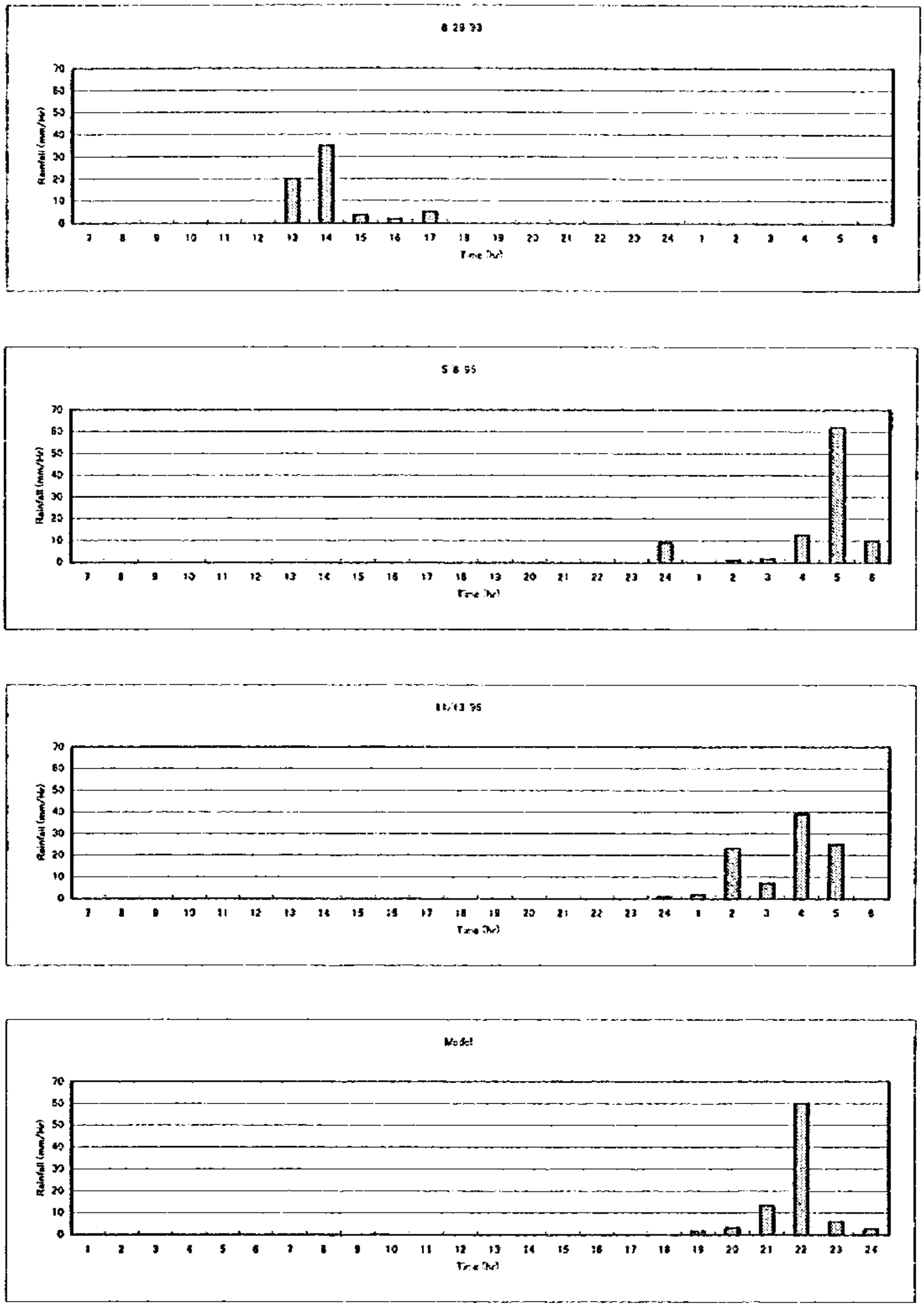
The Study on Drainage Improvement and Flood Control in the Municipality of Phnom Penh JICA - CTIE International Co.,Ltd.- Nippon Koei Co.,Ltd.	Figure B3-2 Probable Rainfall Analysis



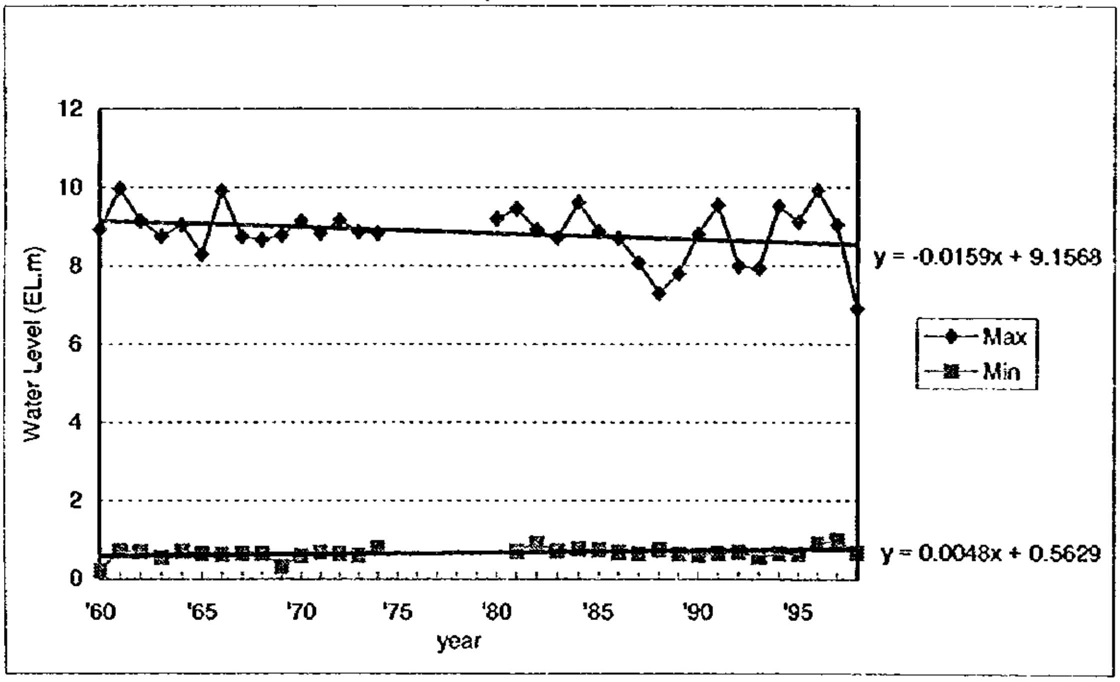


Notes : I : Rainfall Intensity (mm/hr)
T : Rainfall duration (min)

The Study on Drainage Improvement and Flood Control in the Municipality of Phnom Penh JICA-CTIE International Co., Ltd.-Nippon Koei Co., Ltd.	Figure B3-3 Rainfall Intensity Curves

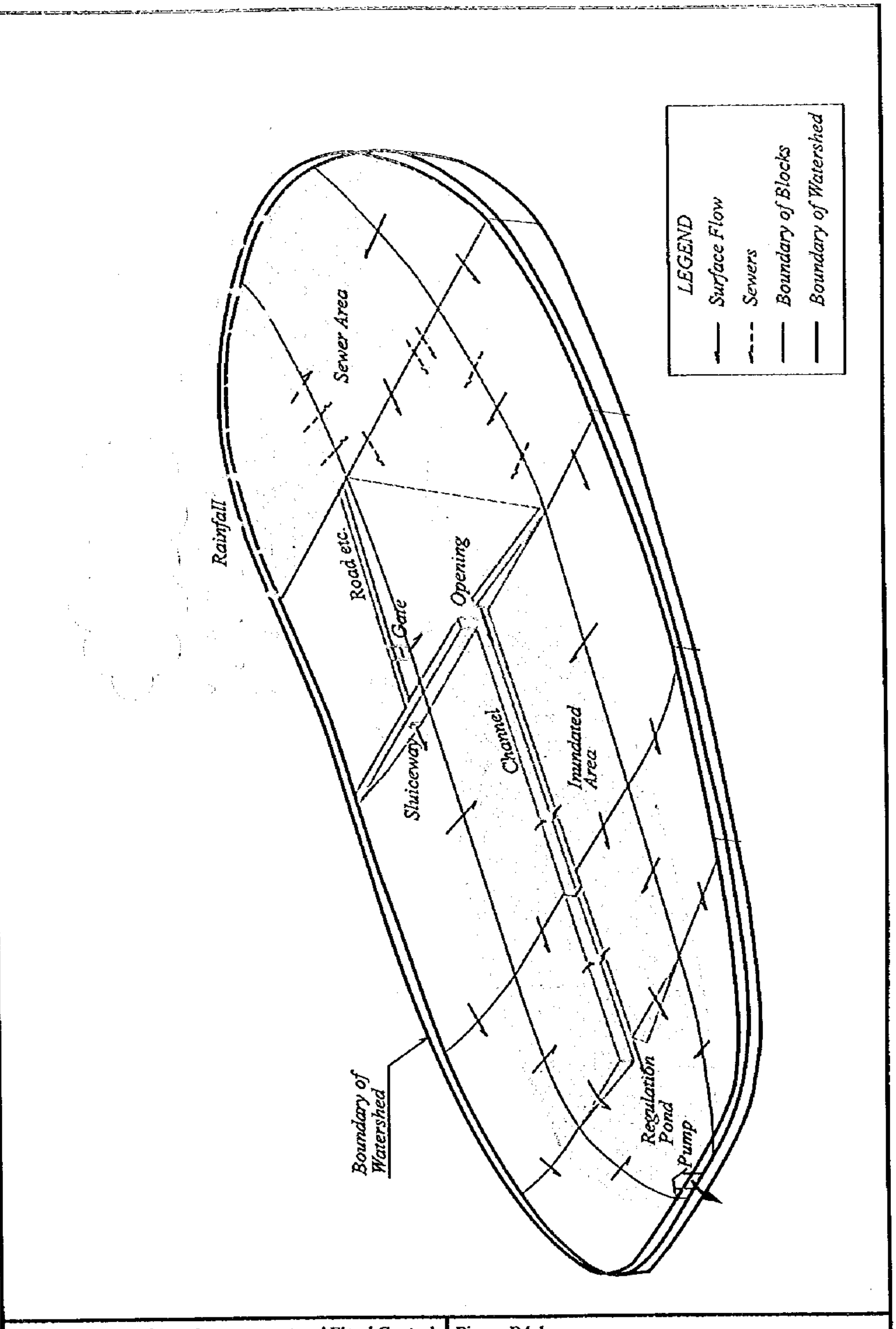


The Study on Drainage Improvement and Flood Control in the Municipality of Phnom Penh JICA-CTIE International Co., Ltd.-Nippon Koei Co., Ltd.	Figure B3-4 Actual Rainfall Patterns and Design Hyetograph (5-year Return Period)

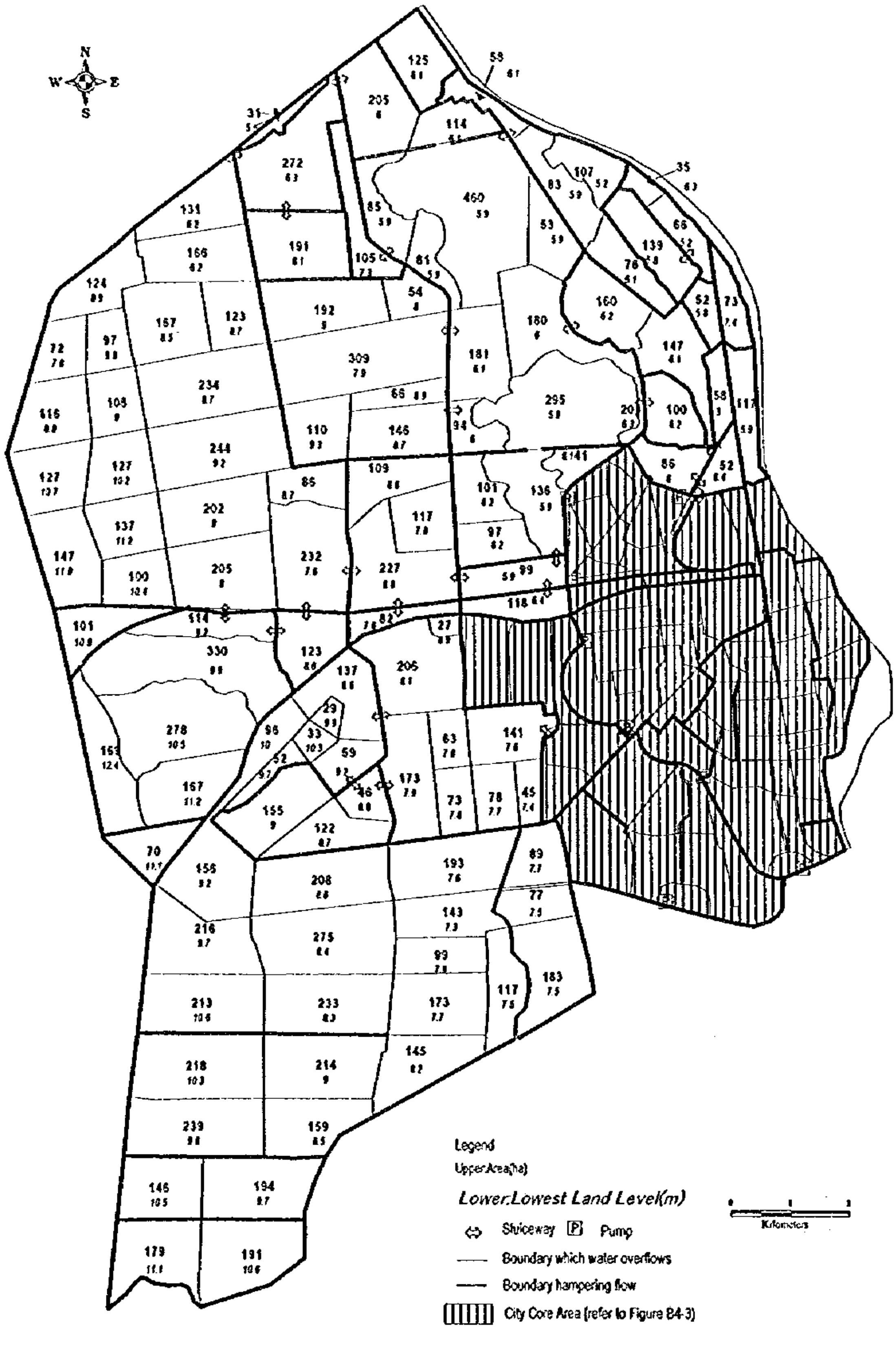


At Chaktomuk Station

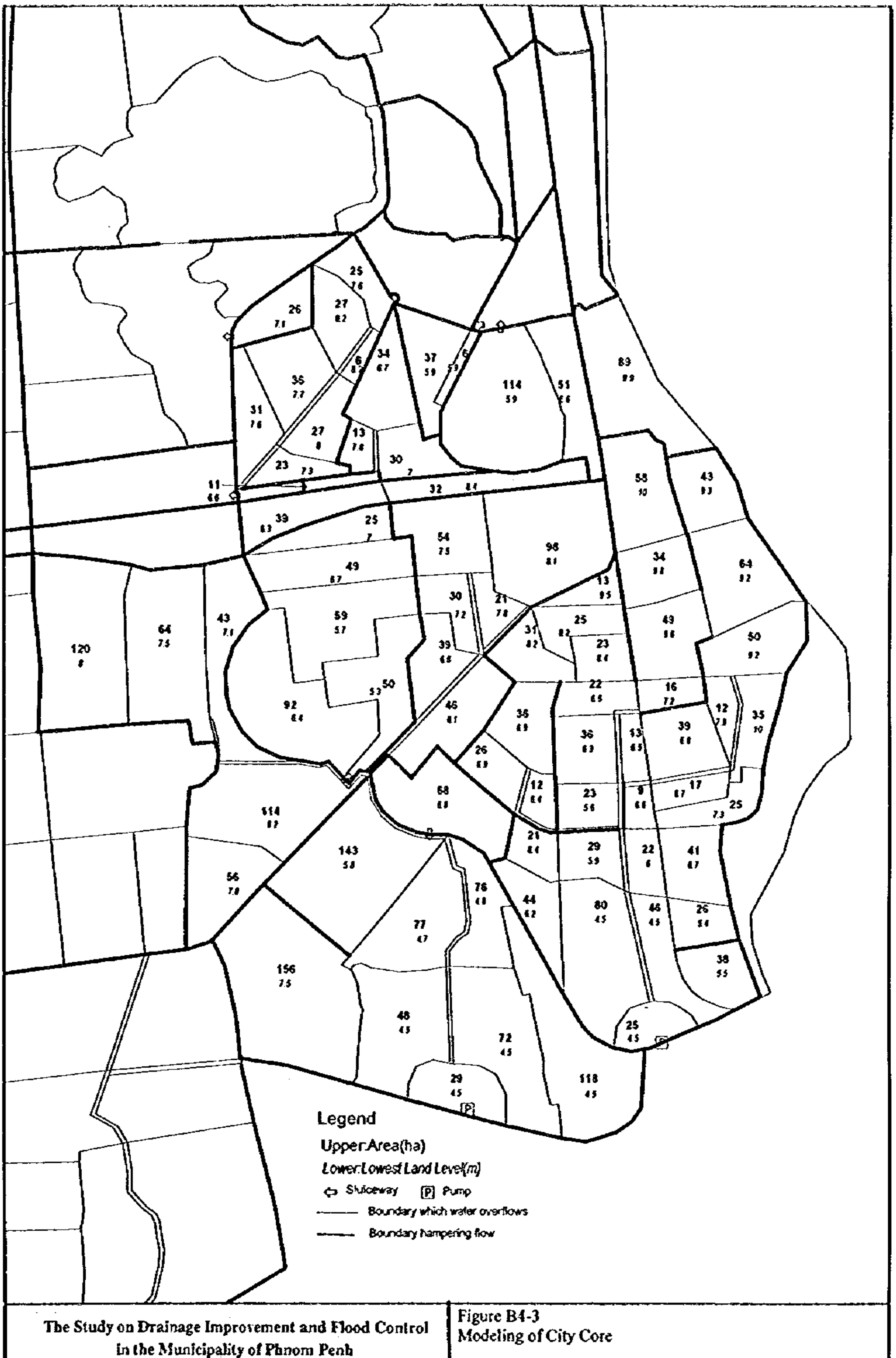
The Study on Drainage Improvement and Flood Control in the Municipality of Phnom Penh JICA-CTIE International Co., Ltd.-Nippon Koei Co., Ltd.	Figure B3-5 Annual Maximum and Minimum Water Levels with Time



The Study on Drainage Improvement and Flood Control in the Municipality of Phnom Penh JICA - CTIB International Co.,Ltd.- Nippon Koei Co.,Ltd.	Figure B4-1 Concept of 2-dimensional Unsteady Flow Runoff and Inundation Analysis



The Study on Drainage Improvement and Flood Control in the Municipality of Phnom Penh JICA - CTIE International Co., Ltd. - Nippon Koei Co., Ltd.	Figure B4-2 Modeling of Suburban Area



The Study on Drainage Improvement and Flood Control in the Municipality of Phnom Penh
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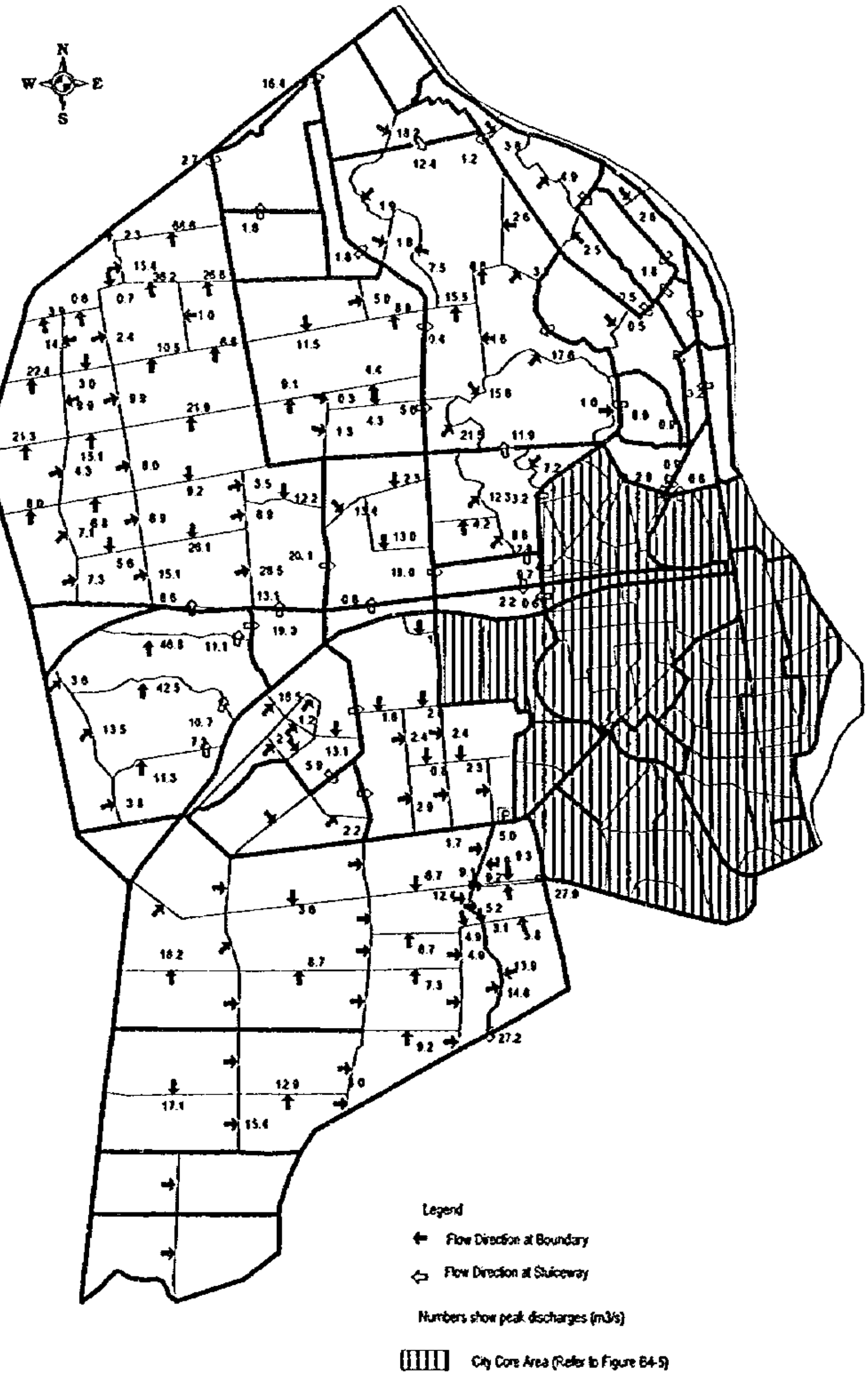
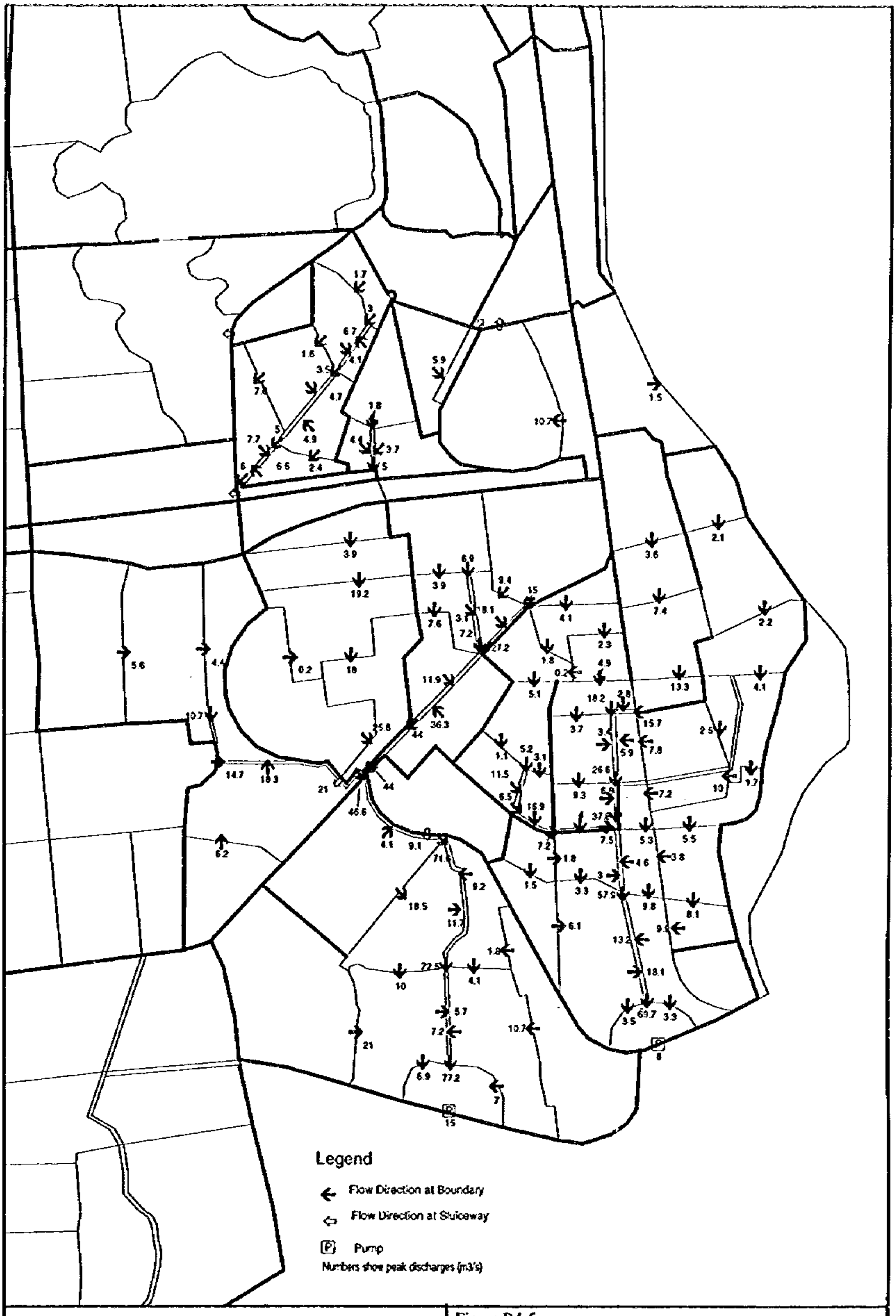
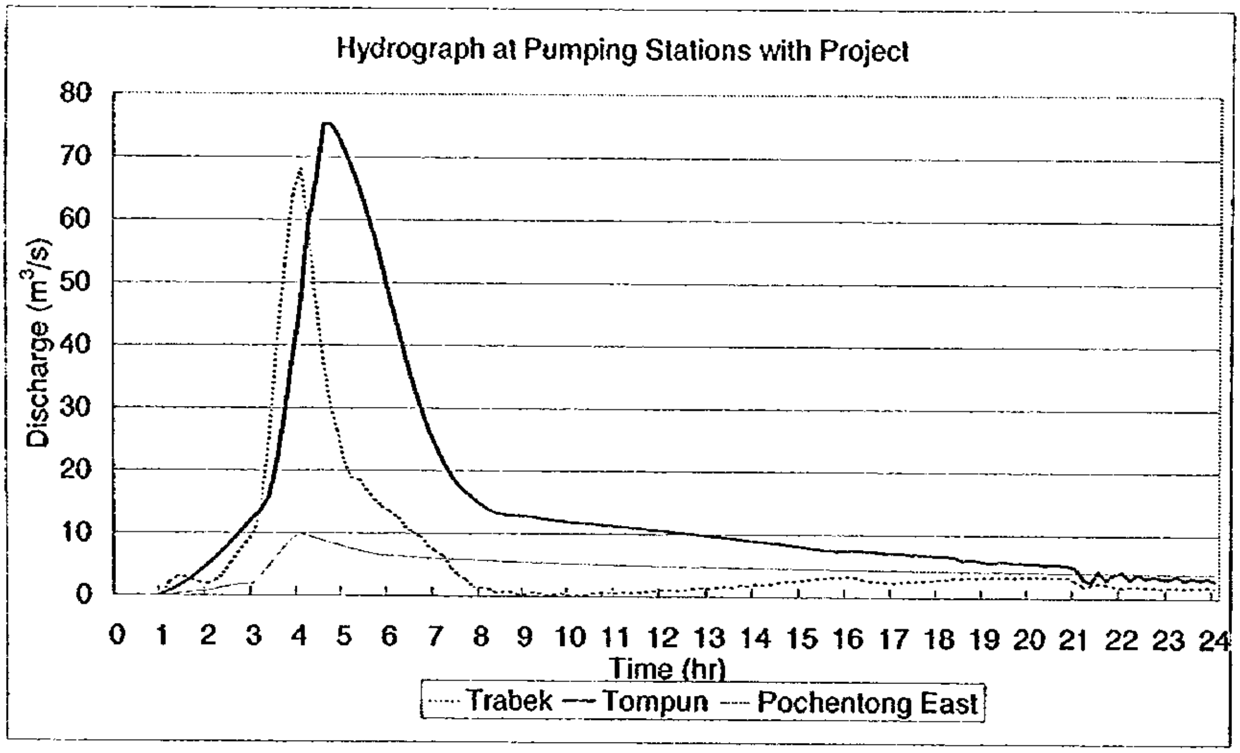
Figure B4-3
Modeling of City Core



The Study on Drainage Improvement and Flood Control in the Municipality of Phnom Penh JICA - CTIE International Co., Ltd. - Nippon Koei Co., Ltd.	Figure B4-4 Flow Directions and Peak Discharges in Case 5 for Suburban Area (5-year Return Period, With-project)



The Study on Drainage Improvement and Flood Control in the Municipality of Phnom Penh JICA - CTIE International Co., Ltd. - Nippon Koei Co., Ltd.	Figure B4-5 Flow Directions and Peak Discharges in Case 5 in City Core (5-year Return Period, With-Project)



The Study on Drainage Improvement and Flood Control in the Municipality of Phnom Penh JICA - CTIE International Co., Ltd. - Nippon Koei Co., Ltd.	Figure B4-6 Hydrograph at Pumping Station Sites (5-year Return Period, With-project)