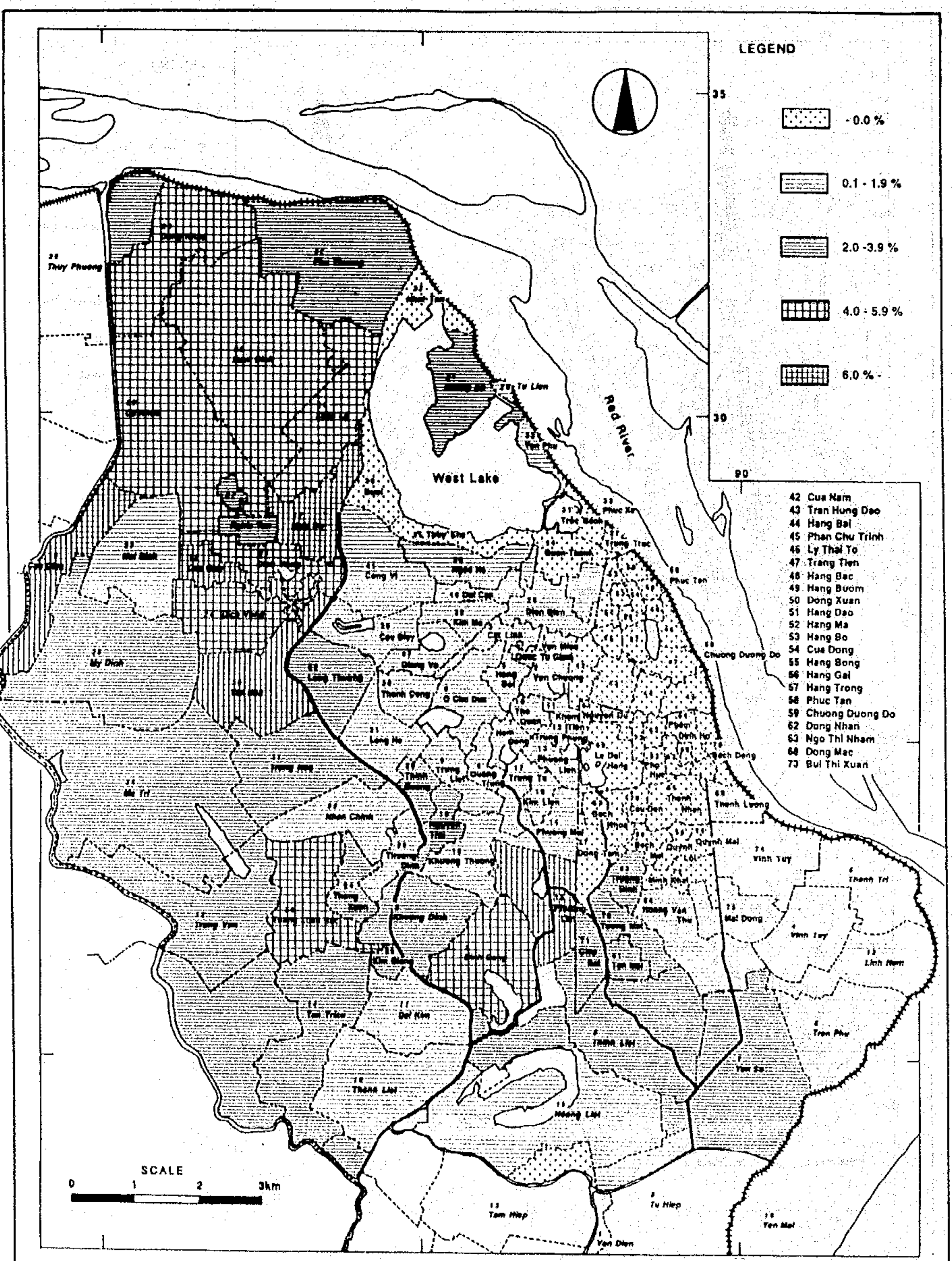

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Fig. B2.3

Population Growth, 1992-2010

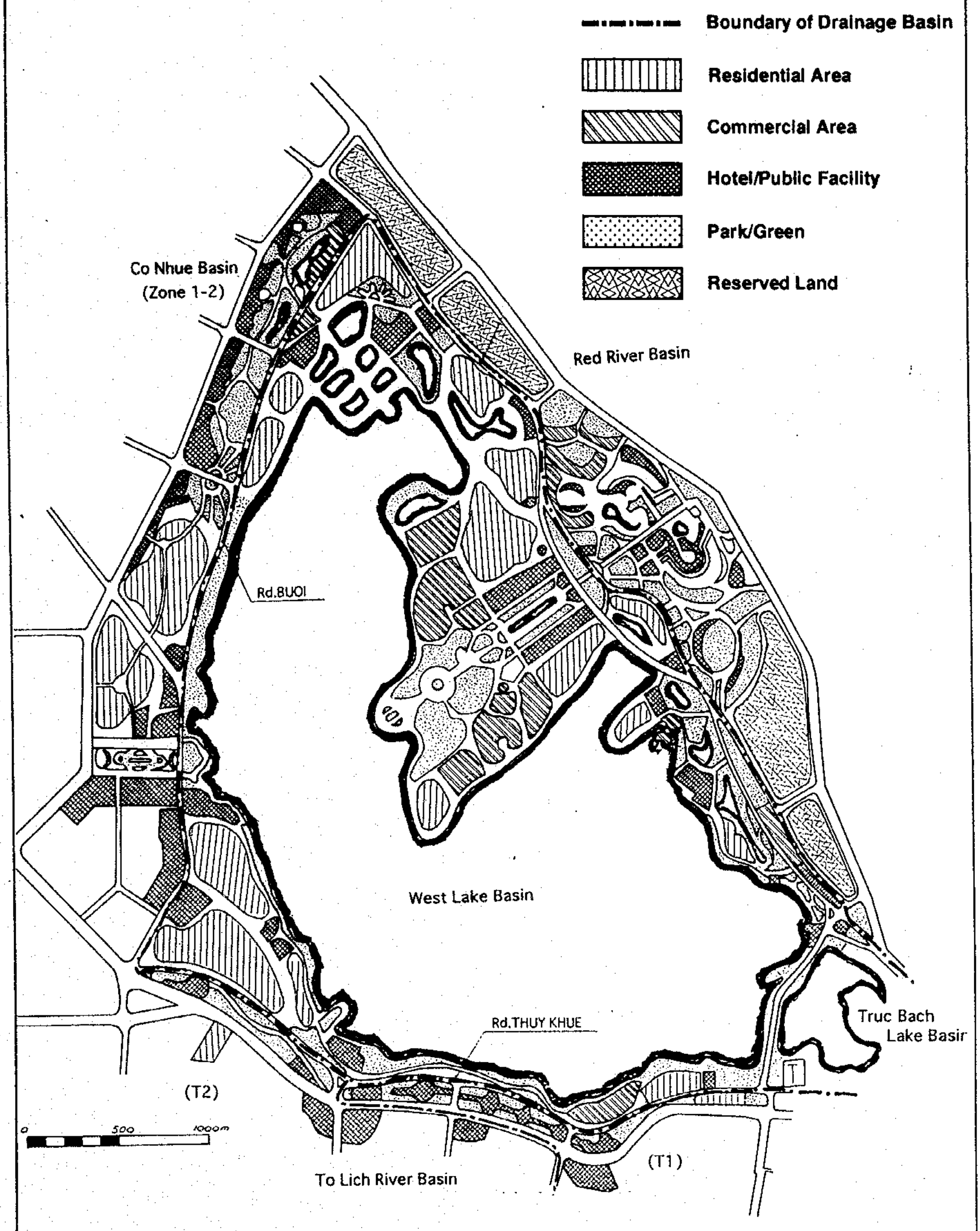

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Fig. B2.4

Land Use Plan in Ho Tay Basin and Surrounding Area

THE STUDY
ON
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DISPOSAL SYSTEM
IN
HANOI CITY

APPENDIX (C)

HYDROLOGY

FEBRUARY 1995

THE STUDY ON
URBAN DRAINAGE AND WASTEWATER DISPOSAL SYSTEM
IN
HANOI CITY

APPENDIX (C)
HYDROLOGY

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C1. INTRODUCTION

The objective of the hydrological study is to provide basic data and information required for the studies on the drainage plan and the wastewater disposal plan.

The study consists of the following major items

1) The studies on data availability, general hydrological conditions and hydrological mechanisms causing inundation

2) The study on low flow conditions to obtain observed data and information

3) Rainfall analysis in order to achieve a design scale for the drainage plan and to evaluate a rainfall intensity formula for the wastewater disposal plan

4) Flood runoff analysis to delineate a design hydrograph for the drainage plan

5) Channel characteristic analysis to calculate the present channel capacity and the influence of backwater, for the drainage plan

6) Inundation analysis to decide landside water levels for the drainage plan

7) Flow regime analysis to obtain basic information for the drainage plan

8) Proposal of suitable installation sites for new rain gauges and water gauges

C2. EXISTING DATA AVAILABLE

2.1 Rainfall Data

2.1.1 Data of GDOMH (General Department of Meteorology and Hydrology)

Availability of rainfall data belonging to GDOMH in the Study Area is as follows:

<u>1890 - 1954</u>

Several stations in Hanoi city area observes rainfall but the data were intermittent and not complete. The locations of these stations are presently not known.

<u>1955 - 1994</u>

Rainfall has been observed at the Lang meteorological station daily, since the middle of 1955, and hourly from 1957 until now. The data is continuous and the quality is good because this station is a member of the international meteorological network of observatories.

Long station has three (3) supplementary gauging stations, at Trang Tien, Giap Bat and Gia Lam in the Hanoi City area. These stations observe daily rainfall and report data to Lang station. However, Lang station has used this data only as a reference and did not make it public, as observations have been carried out by untrained local inhabitants, and the data reliability is low.

2.1.2 Data of MOWR

Rainfall has been observed daily by MOWR at Lien Mac and Ha Dong weirs on the Nhue River in the Study Area since 1957.

Location of these gauging stations is shown in Figure C.2.1 and the observation condition is summarized in Table C2.1. In the Study Area, daily rainfall means the rainfall from 7:00PM to 7:00PM.

2.2 Water Level Data

2.2.1 Data of HSDC

Water levels have been observed daily by HSDC since 1987 along the To Lich, Lu, Set, and Kim Nguu rivers and on main lakes in the Study Area. For the present, observations have been carried out only in the rainy season (Apr.(or May) - Oct.(or Nov.)) excluding Sundays. A discharge rating curve does not exist.

2.2.2 Data of MOWR

Water levels of the Nhue River have been recorded by MOWR since 1957, at Lien Mac and Ha Dong weirs in the Study Area. Along Nhue River, there are also gauging stations at Dong Quan, Nhat Tuu and Luong Co weirs downstream from the Study Area. A discharge rating curve does not exist.

Water levels of the Red River have been recorded at Hanoi station on Long Bien bridge daily since 1902. Discharge records have also been kept since 1904. The hourly water level has been observed and monitored automatically at the Lang meteorological station since 1993.

Location of these gauging stations is shown in Figure C2.1 and the observation condition is summarized in Table C2.1.

C3. GENERAL HYDROLOGICAL CONDITION

3.1 Meteorological Condition

General meteorological conditions including monthly rainfall, evaporation and temperature at Lang Meteorological station are shown in Table C3.1 and Figure C3.1.

Monthly rainfall and evaporation in Hanoi from 1960 to 1990 are shown in Tables C3.2 and C3.3 respectively. Annual average rainfall in the Study Area is about 1670 mm in average. About 90 % of annual rainfall is measured during the rainy season from April or May to November.

The Study Area annually experiences 7.9 days of daily rainfall exceeding 50 mm, and 1.5 days exceeding 100 mm in average, as shown in Table C3.4 and Figure C3.2.

The maximum daily rainfall of 568.6mm was recorded in July 1902 and the second of 394.9mm was recorded in November 1984.

Monthly average mean temperatures range from 16.4C in January to 28.9 C in July.

3.2 Water Level

3.2.1 Red River

Monthly average water levels of the Red River at Hanoi station are shown in Table C3.5 and Figure C3.3. Water level in the rainy season is higher than the ground elevation in southern part of the Study Area (below EL.5m). It is practically impossible to drain flood water from the Study Area to the Red River by use of gravity during this period.

The frequency of annual maximum water levels for the past 86 years is shown in Figure C3.4. The highest level of EL.14.13m was recorded in 1971.

3.2.2 Nhue River

The frequency of annual maximum water level, downstream of Ha Dong weir, for the past 29 years, is shown in Figure C3.4. The highest level of EL.5.64m was recorded in September 1994. The water level frequently rises higher than EL.4.5m. This is one of the main cause of inundation in the Study Area.

3.2.3 Red River and West Lake

Monthly average water levels of the West Lake and the Red River at Hanoi are shown in Table C3.6 and Figure C3.5. It is considered that the water level of the Red River slightly influences the water level of the West Lake. The lake water level fluctuations occur only from rainfall and evaporation.

3.2.4 To Lich River Basin

Daily water levels of main lakes and rainfall in the rainy season are shown in Figure C3.7. Daily water levels at Thanh Liet floodgate on the To Lich river are shown in Figure C3.8. The water level at the floodgate reached higher than EL.5m in 1989 and 1994. The difference in levels on both sides of the gate are not so great after 1991.

C4. HYDROLOGICAL MECHANISMS CAUSING INUNDATION

4.1 Rainfall

4.1.1 Daily Rainfall

Daily rainfall of past storms in Hanoi City area are shown in Table C4.1. The one day and 2 days rainfall amounts to 73% and 91% of total rainfall, respectively.

4.1.2 Hourly Rainfall

Hourly rainfall of the past major five (5) floods in Hanoi city area are shown in Table C4.2 and Figure C4.1. The rainfall intensity and depth of the devasting Nov. 1984 flood are extremely heavy compared with the four (4) other floods.

4.1.3 Assessment of Storms Occurring in 1994

The Study Area has experienced very heavy rainfall this year. The accumulative rainfall at the end of September has already reached 2,350mm, whereas the average annual rainfall in the area was 1,670mm.

The Study Area had experienced four (4) storms up to the end of September this year. Inundation in Hanoi city area lasted for several days after the May 20 and Aug. 29 floods.

There was no serious inundation from the Jun. 9th flood. The duration of rainfall was only one day and the water level of Nhue River had been very low (under EL. 2.5m) before it had begun raining.

New recording rain gauges supplied by JICA were fortunately installed before the rainy season in 1994. The hourly rainfall records during the May and Aug. floods at HSDC Headquarters were available as shown in Table C4.2 and Figure C4.1.

Daily Rainfall of Storms in 1994 (Lang Station)

unit : mm

May	17	13.5	June	9	159.3	Aug.	29	170.4
	18	39.5		total	159.3		30	130.6
	19	69.2					31	16.1
	20	179.6	July	7	16.0	Sep.	1	2.2
	21	7.2		8	161.5		total	319.3
	total	312.0		total	177.5			

4.2 Water Level of Nhue River

The water levels during the Sep. 1978, Nov. 1984 and Jun. 1989 floods at weirs on the Nhue River are shown in Table C4.3 and Figure C4.2. Dong Quann, Nhat Tuu and Luong Co weirs are located downstream of the Study Area. It is difficult to drain the flood water in the Study Area by gravity to the Nhue River during the flooding period, as the water level for the Thanh Liet floodgate closure is EL. 3.5m.

4.3 Relation between Rainfall and Water Level

The relation between rainfall and water levels during the Jun. 1989, May and Aug. 1994 floods are shown daily and hourly in Table C4.4 and Figure C4.3.

As shown in the figure, the water level of the Nhue River rose rapidly higher than EL.5m after intensive heavy rainfall and remained higher than EL. 3.5m for over ten (10) days. This causes the water level to rise in the To Lich river, flooding the Hanoi City area. This is a great constraint in discharging the flood water of the To Lich river basin by gravity to the Nhue River.

The flood discharge from the Jun. 1989 flood at the Thanh Liet floodgate was roughly estimated, as shown in Figure C4.4, using Honma's formula (a free-overflow weir formula) and the submerged orifice formula.

C5. LOW FLOW CONDITION

5.1 Low Flow Measurement

Low flow discharge measurements were carried out at six (6) points on the 15th and 16th December 1993, in collaboration with HSDC staff using a propeller type current meter. The measurement aims to investigate low flow conditions to be taken into account during drainage and wastewater disposal plannings.

The results of the measurements are shown in Tables C5.1 and C5.2. Locations of the measurement sites are shown in Figure C5.1. The results from June to August in Table C5.2 were carried out by HSDC in collaboration with FINNIDA.

5.2 Estimation of Natural Flow

It is considered that the low flow discharge at the Thanh Liet floodgate is 5 m^3/s throughout the year and the specific discharge is approximately 0.07 $m^3/s/km^2$. The amount of low flow discharge is quite large in comparison with that of the basin area. The low flow element is considered to be mainly wastewater flow.

Estimation of the natural flow element in the Study Area is required, however, it is impossible to measure it. In Japan, to measure maintenance flow, a regression formula figured out by many examples as shown below is used. The maintenance flow is generally decided based on its natural flow. It would be reasonable to use this formula to roughly estimate the natural flow.

$$Q = 0.0069\ A$$

where, Q : Maintenance flow (m^3/s)
A : Catchment area (km^2)

According to this formula, the natural flow of the To Lich river was estimated to be around 0.5m^3/s (0.0069*68.2=0.47).

C6. RAINFALL ANALYSIS

6.1 Duration of Design Rainfall

During the flooding period of the Study Area, it is nearly impossible to drain the flood water of the To Lich river basin using only gravity. All the flood water might be managed by the pumping station and storage facilities, therefore, it is important to evaluate not only the peak discharge but also the runoff volume and the effect of the storage facilities.

Therefore, it would be necessary to calculate the duration of the design rainfall carefully. One day and 2 days rainfall of major past floods amount to 73% and 91% of the total rainfall respectively, as shown in Table C4.1. Moreover, the hyetographs of major past floods stride across the boundary of daily rainfall (7:00PM) (See Figure C4.1).

It would be reasonably practical to apply 2 days rainfall as a typical design storm duration for drainage planning, also considering the coverage ratio to the total rainfall depth and duration of the high water level period of the Nhue River during the flooding period.

6.2 Design Rainfall Depth

Based on the Thiessen polygon coverage and data quality, it would be reasonable to adopt the probable rainfall at Lang station for drainage planning. According to the staff at Lang station, the rainfall at the station represents the rainfall of the whole Hanoi City area.

Annual maximum one day and 2 days rainfall at Lang station from 1955 to 1993 (39 years) are shown in Table C6.1. By using these data, probable one day and 2 days rainfall at the station were calculated by Gumbel's formula, Weibull-plot and Hazen plot, as presented in Table C6.2 and Figure C6.1.

Gumbel's formula was adopted for the following reasons. The figure obtained by using Gumbel's formula is safe among three (3) methods of drainage planning. Gumbel's formula has been widely applied to many rivers.

According to Gumbel's formula, 2 days rainfall of a 10-year return period (10%) was obtained as 310 mm. The design rainfall depth of 310 mm was adopted for the drainage planning.

One day rainfall of 230 mm with a 10-year return period was obtained by the same analysis. On the other hand, one day rainfall of 236 mm was calculated based on Gumbel's formula by the National Institute of Investigation and Design of MOWR. Both figures are similar.

6.3 Relation between Probable Water Level and Rainfall

The water level of the Nhue River rises rapidly after heavy rainfall in the Study Area, because its basin adjoins the To Lich river basin and is not very wide.

The relation between the probable water level of the Nhue River and the probable 2 days rainfall was estimated as shown in Figure C6.2, assuming that the water level and the rainfall have a nearly one-to-one relationship.

The probable water level of Nhue River at the confluence with the To Lich river (19.9k) was estimated using the annual maximum water level for the past 37 years in Table C10.2.

6.4 Rainfall Intensity for Urban Drainage

A rainfall intensity formula for Hanoi city was developed by MOC as follows:

$$I = 0.36 \cdot \frac{5416(1 + 0.25 \cdot \log P \cdot t^{0.13})}{(t + 19)^{0.82}}$$

where,

I : Rainfall intensity (mm / hr) (36 mm/hr=100 l/s/ha)

P : Return period (year)

t : Time of flood concentration (minutes)

Another formula for Hanoi city was also developed in 1990 by the Hanoi Civil Engineering College as follows :

$$I = 0.36 \cdot \frac{5890(1 + 0.65 \cdot \log P)}{(t + 20P^{0.18})^{0.84}}$$

where,

I : Rainfall intensity (mm / hr) (36 mm/hr=100 l/s/ha)

P : Return period (year)

t : Time of flood concentration (minutes)

The curves and intensities are shown in Figure C6.3.

The annual maximum 10 and 60 minutes rainfall from 1957 to 1992 (36 years) at the Lang station are shown in Table C6.3. By using these data, probable 10 and 60 minutes rainfall were calculated to evaluate the curves as shown in Table C6.4 and Figure C6.4.

The obtained probable rainfall using Gumbel's formula coincide well with the curves as shown in the figure. It would be reasonable to apply the above stated formula for the study.

The formula by MOC was adopted for the wastewater disposal plan (refer to Appendix E), since it has been widely used in the planning and there is a slight difference between both curves.

Rainfall intensity formulas and curves of several countries are shown in Figure C6.5. The MOC curve of Hanoi retains an adequate position among these curves.

C7. FLOOD RUNOFF ANALYSIS

7.1 Methodology

7.1.1 General

A flood runoff analysis model was established to estimate the runoff hydrograph from hyetgraph, basin and channel conditions. The appropriate runoff calculation method must be selected according to the purpose of calculation and the conditions of hydrological data required.

The following methods are commonly used for the calculation of flood runoff.

1 Rational formula method

2 Unit hydrograph method

3 Storage function method

4 Tank model method

5 Equivalent roughness method

6 Runoff function method

Among the above, the storage function method was selected for the study for the following reasons :

(a) Rational, unit hydrograph, and runoff function methods are not suitable for the study since the rational method gives only the peak runoff and other two methods cannot simulate the non-linearity of runoff

(b) Storage function, tank model and equivalent roughness methods will give the runoff hydrograph in consideration of non-linearity of runoff. Above all, the storage function method is the most suitable for the Study Area, since the rainfall and runoff records are limited, the method is simple and standardized, to some extent, based on river work in Japan

(c) Constants of the storage function can be estimated using the empirical formula, which reflects land use condition, and length and slope of the basin, even if there is no observed discharge record for calibration.

(d) The storage function method has been applied to almost all important rivers in Japan when it is necessary to evaluate the effect of storage facilities and an hourly rainfall hyetgraph is available.

7.1.2 Basic Equation

The storage function method will be outlined as follows :

In order to express the nonlinear type characteristics of runoff phenomena, the storage function method can give the process of transformation from rainfall to runoff. This is on the assumption that there is a one-to-one functional relationship between the volume of storage and runoff.

Calculation of the runoff from rainfall is made using the volume of storage as a medium function. Through the use of this method, a relationship can be established between the volume of storage (S) of a basin or river course and the discharge (Q) from it. This relationship is expressed as

$$S_l = KQ_l^P \ (K, P: \text{Constants})$$

and then used as a substitution for the solution of the equation of motion. That is, this formula establishes that the runoff is proportional to the exponent of the volume of storage. This is equivalent to the thinking in which the phenomena of rainfall and runoff are considered to be similar to the runoff from a notch in a container filled up with water.

Runoff calculation is performed by the combination of this equation of motion with the following equation of continuity.

$$\frac{dS_l}{dt} = \frac{1}{3.6} f \cdot r_{ave} A - Q_l$$

where

f : Inflow coefficient

r_{ave} : Basin mean rainfall (mm / h)

A : Area of the basin (km^2)

$Q_l(t) = Q(t + T_l)$: Run - off volume from the basin under the consideration of lag time (excluding base flow , m^3 / s)

S_l : Apparent volume of storage in basin (m^3 / s)

T_l : Lag time (h)

The equation of continuity for the section of a river course is given by

$$\frac{dS_l}{dt} = \sum_{j=1}^{n} f_j I_j - Q_l$$

where

I_j : Inflow from basin, tributary or the upstream end of the river course to the river course being considered (m^3 / s)

f_j : Inflow coefficient

$Q_l(t) = Q(t + T_l)$: Discharge at the downstream end of basin unde the consideration of lag time (m^3 / s)

S_l : Apparent volume of storage of river cours

T_l : Lag time

7.2 Selection of Objective Storms

To select an objective storm for planning, it is necessary to evaluate the availability of relevant hydrological data, magnitude of storms, hyetograph patterns, and the degree of flood damage, synthetically as shown in Table C7.1. As a result, Jun. 1989 storm / flood type was employed as an objective flood.

(a) The concept of an "enlarging factor" (adjustment of rainfall hyetgraph to a 10-year probability magnitude; i.e. 310 mm in 2 days rainfall) is introduced. The flood runoff discharge calculated are similar among the six (6) storm events listed in Table C7.1.

(b) 2 days rainfall amount (correspondingly flood runoff volume) of the Jun. 1989 storm approximately represents the probability of a once 10-year occurrence (cf. the Nov. 1984 flood was extremely large, and therefore should to be ruled out).

(c) Relevant hydrological data and information are available for the Jun. 1989 storm (cf. Some information is lacking in Aug. '72 and Sep. '78 storms).

(d) Judging from it's intensive hyetograph pattern, the Jun. 1989 pattern is considered to be more severe for river channels and regulating reservoirs than the Aug. 1994 pattern.

(e) The duration of flood concentration of the To Lich river is supposed to be around six (6) hours. The rainfall intensity of the Jun. 1989 flood within six (6) hours was 29mm/hr when the enlarging factor (1.081 (310mm/286.7mm)) was adopted. According to the rainfall intensity formula of MOC, the intensity of a 10-year in six (6) hours is 23mm/hr. Therefore, this enlarged design hyetgraph is reasonable not only for long term duration but also for short term duration. On the other hand, the rainfall intensity of Aug. 1994 flood within six (6) hours is 19mm/hr(enlarging factor ; 1.030).

7.3 Diagram for Analysis

On the basis of a division of sub-basins in the study on drainage plan (refer to Appendix D; Drainage Plan), the river systems of the To Lich and the Nhue River basins were modeled to investigate runoff / inundation analyses as shown in Figure C7.1. The system consists of sub-basins, river channels, lakes /ponds, regulating reservoir, pumping station and the drainage channel of sub-basins.

7.4 Determination of Constants

(1) Storage Function of Sub-basin

The storage functions of sub-basin are estimated from the empirical formula developed in the rivers of Japan. The estimated values are shown in Table C7.2. The K values were estimated by the synthesized equivalent roughness (N) based on the future land use (refer to Appendix B; City Development Plan) with the length and slope of sub-basin.

$$K = 1000/(3.6 \cdot 10^6)^{2/5} \cdot (L \cdot N / I^{1/2})^{3/5}$$

where

K : constants

L : Length of basin (m)

N : Equivalent roughness

High density urban area	0.010
General urban area	0.050
Park and green	0.100
Paddy field	1.000
Water surface	0.050

I : Slope of basin

The fixed P value of 0.6 is given when the above formula for K value is adopted. *Tl* (time lag) is decided to be 0.0hr since the sub-basin is very small.

(2) Primary Runoff Ratio (f1) and Saturation Rainfall (*Rsa*)

In the storage function method, a catchment is divided into two areas, an infiltration zone and a runoff zone. Effective rainfall, until the cumulative rainfall reaches *Rsa*, is assumed to be equal to the primary runoff rate multiplied by the rainfall intensity. The effective rainfall after reaching Rsa is assumed to be equal to the total rainfall, without reduction.

The empirical values of a primary runoff ratio of 0.9 and a saturation rainfall of 55mm for urbanized river basins in Japan were correspondingly introduced.

(3) Base Flow

The base flow of the To Lich river is assumed to be $5m^3/s$ at the Thanh Liet floodgate, obtained from the low flow measurement (refer to C5). Base flows of the Nhue River basin were also estimated by using the same specific discharge of the To Lich river.

The initial values (*K,P,f1,Rsa*) were used for the planning, unchanged, as the observed hourly water level/discharge records during floods do not exist for the calibration of constants.

(4) Storage Function of Channel

The storage function of the channels (K and P) was estimated, as shown in Table C7.3, in terms of the storage volume (S) and the discharge (Q) relationship, based on the uniform flow calculation of the design channel. *Tl* (time lag) is decided by using the empirical formula. It is considered that the channels in the Nhue River Basin have practically no storage function due to their narrow width.

7.5 Calculation of Design Hydrograph

For the drainage planning, the design discharge hydrographs at the Yen So site corresponding to several alternatives (10-years) were calculated. The hydrographs are delineated in Figure C7.2. Design hydrographs of the Alternative 6, (10-years and 2-years) at Yen So and the lower end of the main rivers in the To Lich river basin are shown in Table C7.4 and Figure C7.3. Design hydrographs of the four (4) drainage basins in the Nhue River basin (10-years, Alternative 1) are also shown in

Figure C7.4. The specific discharges of sub-basins obtained are plotted in Figure C7.5.

The conditions for the calculation are summarized as follows :

- Objective area : To Lich river basin ($A=68.2km^2$) (excluding West Lake basin)
: Nhue River basin; four(4) drainage basins

Co Nhue drainage basin	($A=19.7km^2$)
My Dinh drainage basin	($A=13.6km^2$)
Me Tri drainage basin	($A=14.7km^2$)
Ba Xa drainage basin	($A= 9.9km^2$)

- Design control point : Yen So pumping station site (To Lich river basin)
: Confluence with Nhue River (Nhue River basin)

- Method of calculation : Storage function method

- Design scale : 10-year (10%) : once in 10 year probability

- Duration of design rainfall : 2 days

- Design rainfall depth : 310 mm (2 days)

(Cf. Nov. 1984 flood 2 days rainfall : 560.4mm
Return period : less than 200-years)

- Design hourly hyetgraph : Jun. 1989 flood type
(Observed 2 days rainfall is 286.7mm)

- Enlarging factor for making design hourly hyetgraph of 10-year
: 1.081 (310mm / 286.7mm)

The total hourly rainfall (2 days; 278.7mm) was adjusted to the 2 days rainfall (286.7mm) before enlarging.

- Case of calculation

  - To Lich river basin : Alternative 0 - 6
  - Nhue River basin : Alternative 1

Case of Calculation

Alternatives	18 Major Lakes in City Area	Use of Linh Dam Lake		Use of Dinh Cong Lake	
		Channel to Yen So Site	Linh Dam Lake	Channel to Linh Dam Lake	Dinh Cong Lake
0	No lakes	-	-	-	-
1	As they are	-	As they are	-	As they are
2	Dredged	-	- do -	-	- do -
3	- do -	Provided	- do -	-	- do -
4	- do -	- do -	Dredged	-	- do -
5	- do -	- do -	As they are	Provided	- do -
6	- do -	- do -	Dredged	- do -	Dredged

note : For the details of alternatives, refer to Appendix D; Drainage Plan

- Regulation at lakes /ponds : Natural control method (No gate discharging)

In actual calculation, the constant discharging method with draining after floods was applied. To approximately express the hydrograph of the natural control method, the *Qs* (flood control starting discharge) of the constant discharging method was decided by half of the flood control volume. The flood control volume of lakes is tabulated in Table C7.5.

At Linh Dam and Dinh Cong lakes, the channels to the downstream lake are planned to be constructed in order to complement the regulation function of the Yen So reservoir (Linh Dam : Alternative 3-6, Ding Cong : Alternative 5-6). In this regard, 100% of the flood regulating efficiency of the two (2) lakes is to be ensured, so that the *Qs* is decided by the total volume. (For the details, refer to Appendix D; Drainage Plan)

7.6 Flood Control Volume of Regulating Reservoir

7.6.1 Yen So Regulating Reservoir

The required flood control volume of the Yen So regulating reservoir which corresponds to each of the alternatives and the pump capacities, was calculated by the obtained hydrographs.

Required Flood Control Volume of the Yen So Regulating Reservoir

unit : $10^6 m^3$

Pump Capacity (m3/s)	Case						
	Alt. 0	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5	Alt. 6
30	13.90	12.43	12.39	11.92	11.38	12.43	11.35
60	10.22	8.44	7.86	7.57	7.24	7.54	6.83
90	7.49	5.51	4.73	4.51	4.25	4.38	3.87
120	5.23	3.23	2.42	2.26	2.08	2.12	1.75
150	3.41	1.48	0.78	0.68	0.56	0.54	0.32
Qp(m^3/s)	256	203	187	184	181	180	174

7.6.2 Nhue River Basin

A regulating reservoir of four (4) drainage basins is planned at the confluence with the Nhue River. The required flood control volume of the regulating reservoir in Alternative 1 was calculated as shown below. The pump capacity was decided by adopting a specific discharge for planning by MOWR ($0.6m^3/s/km^2$) (refer to Appendix D ; Drainage Plan).

Required Flood Control Volume of Regulating Reservoir

Drainage Basin	Pump* Capacity (m^3/s)	Required Volume (106m^3)	Peak Discharge (m^3/s)
Co Nhue	12	3.02	55
My Dinh	8	1.59	26
Me Tri	9	1.60	31
Ba Xa	6	1.07	14

7.7 Comparative Study of Runoff Calculations

The differences of methodology on runoff calculation between the JICA study (Alternative 2 as an example) and the existing Vietnamese plan were studied. The result is compiled in Table C7.6. The hydrographs and the concept of flood regulation of both studies are shown schematically in Figure C7.6.

The remarkable difference of flood control volume of the Yen So regulating reservoir is caused mainly by the differences of design rainfall depth and runoff ratio.

7.8 Assessment of Floods Occurring in 1994

The hydrographs of the two (2) latest big floods, on May 20 (3.6-year) and Aug. 29 (9-year) in 1994, were estimated by using the established runoff model (Alternative 6). The results are delineated in Figure C7.7.

As can be seen in the figure, the volume (over 90 m^3/s) and discharge of the two (2) floods are less than that of the design hydrograph of a 10-year return period. Therefore, these floods will be safely managed by the drainage plan of the JICA Study. The regulating volume by the Yen So reservoir with a pump of 90m^3/s was estimated to be 1.93 million m^3 (May 20 flood) and 1.76 million m^3 (Aug. 29 flood) respectively, whereas the flood control volume of the reservoir was 3.87 million m^3.

C8. CHANNEL CHARACTERISTICS ANALYSIS

8.1 Fundamental Formula of Non-uniform Flow

The fundamental formula of non-uniform flow calculation is given as follows.

$$H_i = H_{i-1} + \frac{\alpha Q^2}{2g} \cdot \left[\frac{1}{A_{i-1}^2} - \frac{1}{A_i^2}\right] + \frac{Q^2}{2}\left[\frac{n_{i-1}^2}{R_{i-1}^{4/3} \cdot A_{i-1}^2} + \frac{n_i^2}{R_{i-1}^{4/3} \cdot A_i^2}\right] \cdot \Delta X$$

where,

H : Elevation of water level (m)
g : Acceleration of gravity (m^3/sec^2)
Q : Discharge (m^3/sec)
A : Water area (m^2)
ΔX: : Distance between two cross-sections (m)
n : Manning's coefficient of roughness
R : Hydraulic radius (m)
∝ : Correction coefficient for vertical distribution of velocity

Suffix denotes number of a cross-section, from downstream to upstream.

8.2 Present Channel Capacity

8.2.1 Water Levels by Non-uniform Flow

The water levels of the present channels of the main rivers in the city area were obtained by a non-uniform flow calculation as shown in Figure C8.1.

The conditions for the calculation are as follows:

- Objective River : To Lich, Kim Nguu, Lu and Set Rivers
- Cross Section : Present cross sections measured by the Study Team
- Distance between two cross-sections : by present longitudinal profiles measured by the Study Team
- Manning's coefficient of roughness : 0.030
- Water levels for the lowest section (0.0k on To Lich river) and discharge

The water levels of each magnitude downstream, were decided by using the result of Chapter C6 (See Figure C6.2). The discharges of each magnitude were calculated by using the runoff model established in Chapter C7.

Return Period (year)	Water Level at 0.0k (m, MSL)	2 days Rainfall (mm)	Enlarging Factor of Rainfall (Jun. 1989 286.7mm)	Discharge at 0.0k (Alt.1) (m3/s)
1.2	4.2	103	0.359	58
2	4.5	173	0.603	109
5	4.9	255	0.889	172
10	5.2	310	1.081	203
20	5.4	363	1.266	250
50	5.7	430	1.500	342

- Distribution of discharge: Based on the discharge distribution for drainage plan.

8.2.2 Channel Capacity

The present bankful channel capacity was calculated using the result of a non-uniform flow calculation as shown in Figure C8.2.

The capacity of the To Lich river is about 50m^3/s. The capacity of the Kim Nguu River is about 40m^3/s in the lower reaches and 20m^3/s in the upper reaches. The capacity of the Lu River is about 15m^3/s and the Set River is about 10m^3/s. The present bankful capacities of the four (4) main rivers were assessed to correspond roughly to a 1.2-year flood discharge.

8.3 Influence of Backwater under Design Section

The design's highest high water level of the Yen So regulating reservoir is EL. 4.5m, in order to tentatively store floodwater in the receding period of floods. The discharge is around 90 m^3/s when the water level reaches the level of EL. 4.5m (refer to Appendix D ; Drainage Plan).

The influence of a backwater in the above mentioned condition (water level ; EL. 4.5m and discharge ; 90m^3/s) was studied by a non-uniform flow calculation by design cross-sections.

The influence of the water level of EL4.5m does not affect the upper reaches as shown in Figure C8.3.

C9. INUNDATION ANALYSIS

9.1 Methodology

The inundation (landside water) analysis of the Study Area aims to obtain the landside water levels corresponding to several magnitudes of flood and alternatives for the drainage plan.

The inundation analysis of the Study Area was performed using a pond model on the basis of 1) hydrograph of a sub-basin, 2) drainage channel capacity of a sub-basin and 3) Elevation-Volume relationship of a sub-basin.

In other words, the hydrograph of the sub-basin is calculated by the runoff model. The outflow from the sub-basin is limited by the outlet channel capacity and the discharge over the channel capacity is stagnated in the sub-basin. Consequently, the inundated volume is translated into water level by the Elevation-Volume relationship of the sub-basin.

This method is reasonable as the inundation in the Study Area occurs from the shortage of the drainage channel capacity. The inundation is not derived from the overflow at the main rivers such as the To Lich river. For drainage planning, the inundation of the sub-basins is managed independently, and the flow between the two adjoined basins is not considered.

9.2 Calculation of Landside Water Level

9.2.1 To Lich River Basin

The inundation analysis of the To Lich river basin was performed in accordance with the above mentioned procedure. The landside water levels obtained are shown in Table C9.1 and the Elevation-Volume relationships of sub-basins are shown in Table C9.2.

The conditions for the analysis are as follows:

- Alternatives : Case 1; Present Condition (Pond ; Alternative 1)
  : Case 2; Future Condition (Alternative 6)

- Magnitude of flood : 1.2,2,5,10,20,30 and 50-years for Case 1
  : 20,30 and 50-years for Case 2
  (Jun. 12 1989 flood type)

- Drainage channel capacity of sub-basin : refer to Appendix D

As there is no planned dike under the present conditions, the probable water level of the Nhue River (See. Figure C6.2) was adopted instead of the calculated water level when the probable water level was higher than the calculated level.

The calculation of a 10-year under the present conditions closely resembles the actual Jun. 1989 flood. The result coincides well with the observed water level (for the details, refer to Appendix D) and proves the propriety of the model.

9.2.2 Nhue River Basin

The inundation analysis of the Nhue River basin was performed in accordance with the above mentioned procedure. The landside water levels obtained are shown in Table C9.3 and the Elevation-Volume relationships of the sub-basins are shown in Table C9.4. Each of the four (4) drainage basins were treated as one sub-basin.

The conditions for the analysis are as follows:

- Alternatives : Future Condition (Alternative 1)

- Magnitude of flood : 20, 30 and 50-years (Jun. 12 1989 flood type)

- Capacity of pumping station and volume of regulating reservoir

Drainage Basin	Pump Capacity (m^3/s)	Volume of Regulating Reservoir (106m3)
Co Nhue	12	302
My Dinh	8	159
Me Tri	9	160
Ba Xa	6	107

C10 FLOW REGIME ANALYSIS

10.1 Flow Regime

This analysis aims to supply basic information for a feasibility study on the drainage plan (for planning of a design pump head at Yen So pumping station, and the discharge condition from the Thanh Liet floodgate to the Nhue River, etc.).

10.1.1 Nhue River

The flow regimes downstream from the Ha Dong weir and upstream from the Dong Quan weir on the Nhue River were studied by using daily water level records for the past 5 years (1989-1993). The results are shown in Table C10.1 and Figure C10.1.

The flow regime at the Thanh Liet floodgate in the table was estimated using the interpolation calculation. The discharges at the gate were also estimated by the discharge rating curve shown in Figure C10.2, which was obtained from the uniform flow calculation using cross sections measured by the Study Team.

10.1.2 Red River

The average flow regime of the Red River at Hanoi station (on Long Bien bridge) was studied by using the daily water level records for the past 5 years (1989-1993). The results are shown in Table C10.1 and Figure 10.2.

Hanoi station is located about 100km from the sea and the Yen So site is located approximately 7km south from Hanoi station. The water level at the Yen So site in the table was estimated using the interpolation calculation with the distance from the sea.

The Study Team surveyed the water level of the Red River at the Yen So site at 9:00AM on August 2. The level at that time at the Hanoi station is presented below. As the results show, the above mentioned process of estimation is considered reasonable.

<u>Observed Water Level of the Red River at 9:00AM on Aug. 2 1994</u>

- Hanoi station (Long Bien bridge) : 10.00m, MSL
  <monitored by Lang meteorological station>
- Yen So site : 9.29m, MSL
  <measured by the Study Team>

Difference <u>0.71m</u>

10.1.3 Water Level of the Nhue River and Discharge of the To Lich River

The relationship between the water level of the Nhue River at the Thanh Liet floodgate and the discharge of the To Lich river (Alternative 6) was investigated annually as shown in Figure C10.3. The 1989 year pattern was adopted as a typical case in terms of annual rainfall amount and storm pattern.

This analysis aims to supply the basic information to estimate the annual pump operating period at the Yen So site in the feasibility study on the drainage project.

The water levels under future conditions were roughly estimated by the following procedure.

1) The discharges of the To Lich river (Q-t) in the figure are estimated from 2 days rainfall at Lang station, using the relationship between rainfall and peak discharge by Alternative 6, as shown in Figure 10.4.

2) The water levels of the Nhue River under present conditions are estimated on the observed levels at the Ha Dong and Dong Quan weirs. The estimated water level is converted into discharge by the discharge rating curve shown in Figure C10.2.

3) About 73% of the above converted discharge is regarded as the Nhue River's element(Q-n), on the assumption that both rivers have almost the same specific discharge under present conditions (Nhue R.-188km^2, To Lich R. 68.2km^2).

4) The total of Q-t and Q-n (Q-t+n) is considered to be the discharge under future conditions.

5) The discharge (Q-t+n) is converted into water level again by the same discharge rating curve.

10.2 Probable Maximum Water Level

10.2.1 Nhue River

The probable maximum water levels downstream from the Ha Dong weir and upstream from the Dong Quan weir on the Nhue River were calculated using the annual maximum water levels for the past 37 years (1957-1993) (See Table C10.2). The results based on Gumbel's formula are shown in Table C10.4 and Figure C10.5.

The water levels and discharges at the Thanh Liet floodgate in the table were estimated using the same method mentioned in 10.1.

10.2.2 Red River

The probable maximum water levels of the Red River at Hanoi station (on Long Bien bridge) were calculated using the long term annual maximum water levels for the past 92 years (1902-1993) (See Table C10.3). The result based on Gumbel's formula is shown in Table C10.4 and Figure 10.5.

The levels at the Yen So site were estimated using the same method mentioned in C10.1.

C11. INSTALLATION OF WATER GAUGE AND RAIN GAUGE

To obtain accurate hourly hydrological information, two (2) recording rain gauges and five (5) automatic water gauges are planned to be installed. The equipment is also expected to be used for flood forecasting and warning in the future.

11.1 Recording Rain Gauge

(1) General

Since 1957, hourly rainfall has been recorded continuously in the Study Area at only the Lang Meteorological station. In order to observe hourly rainfall records in the Study Area in detail (especially in the To Lich river basin), two (2) rain gauges were installed. The equipment was supplied by JICA, and installation work was carried out by HSDC. The observation started from May 1994.

(2) Proposed Installation Sites

The proposed installation sites are the Thanh Liet Floodgate and the HSDC Headquarters. The locations and the Thiessen polygon coverage by these stations including the existing Lang station, are shown in Figure C11.1.

1. Thanh Liet Floodgate

   This place is suitable in regard to management and security of the rain gauge, because the weir is being continuously managed by HSDC staff.

2. HSDC Headquarters

   In regard to special distribution, the HSDC headquarters is suitable for the installation of a new gauge. The station will be well managed by HSDC ensuring adequate security.

(3) Specification of Equipment

The specifications of the recording rain gauge (Model B-432, Yokogawa Weathac Co., LTD.) are as follows :

1)	Detection method	: Tipping-bucket type
2)	Rain inlet	: 200 mm diameter
3)	Rainfall per inversion	: 0.5 mm rainfall per inversion (tipping) of the tipping-bucket
4)	Accuracy	: Within ± 3% when at continuous rainfall of 100mm/h or less
5)	Recording method	: Arc-tracing system
6)	Recording chart	: Roll-type, effective recording width of 50 mm
7)	Chart speed	: 6 mm/hr
8)	Chart drive	: Quartz clock
9)	Recording term	: 3 months
10)	Power supply	: 1.5V DC for the quartz clock (one C-Cell dry cell battery)
11)	Battery term	: Approximately 1 year per battery

12) Ambient conditions	:	Temperature .... -10 +50°C Humidity................ 0 ~ 90%
13) Outer dimensions	:	Approximately Ø 330 x 700(H)mm
14) Weight	:	Approximately 18 kg

11.2 Automatic Water Gauge

(1) General

Several water level gauges exist on the To Lich, Lu, Set, Kim Nguu Rivers and the main lakes. The water level is observed daily at these gauges. To obtain more accurate hourly hydrological information, five(5) automatic water gauges are planned to be installed. The equipment was supplied by JICA. The installation work and subsequent observation are to be carried out by HSDC.

(2) Proposed Installation Sites

On the basis of review of the present water level gauging station network, the following five (5) sites were selected as shown in Figure C11.1 for the reasons mentioned below.

1. Downstream Reaches of the Thanh Liet Floodgate (To Lich River)

   The Thanh Liet Floodgate is the most important water level control point for the drainage plan of the To Lich river basin. A gauge is required to observe the hourly water level downstream of the gate.

2. Upstream Reaches of the Thanh Liet Floodgate (To Lich River)

   A gauge is required to observe the hourly water level upstream of the gate.

3. Cau Moi Bridge (To Lich River)

   A gauge is required upstream of the confluence with the Lu River. Cau Moi bridge is suitable for observation.

4. Mai Dong Bridge (Kim Nguu River) (Tentative)

   The Mai Dong bridge site was selected in order to evaluate the runoff of the Kim Nguu River. The Yen Duyen bridge downstream from the Mai Dong bridge was not selected because this old bridge might be replaced in the near future.

   This station might be tentatively installed. After the Yen So regulation reservoir is constructed, the equipment is recommended to be re-installed for the station at the regulating reservoir.

5. Tran Quoc Pagoda (West Lake)

   West Lake is the biggest lake in the Study Area. A gauge is required to continuously observe water levels. In regard to management and security of the gauge, Tran Quoc Pagoda site was selected.

(3) Specification of Equipment

The specifications of the automatic water gauge (Model LR-1021, Ogasawara Keiki CO., LTD.) are as follows :

1) Dimensions	:	250 mm deep 360 mm wide 290 mm high (excluding pulley shaft)
2) Pulley	:	Effective one turn / m
3) Float	:	100 mm in diameter
4) Counterweight	:	About 3.3kg
5) Wire	:	0.63 mm dia. stainless steel twisted wire
6) Clock	:	Crystal clock
7) Take-up device	:	Drive type by connecting clock and gears
	:	with each other
8) Chart days	:	Effective 20 cm x 15 m in total length for 90
9) Chart speed	:	6mm/h
10) Recording System	:	Dirtless two-pen system Continuous 1800 m recording Ambient temperature -25 +50C
11) Measuring range	:	0 ~ 10 m
12) Accuracy	:	Better than ± 1cm Follow-up error: Less than 5 mm at water level Inversion error : Within 1 mm on chart Check error : Within ± 2 min

C12. PROPOSAL FOR FLOOD FORECASTING AND WARNING

Flooding occurs within several hours of the beginning of intensive rainfall in the To Lich river basin, especially in the urbanized area of the upper reaches. Even at the Yen So site, flood concentration is supposed to be around six (6) hours. Judging from the required time for warning and evacuation, flood forecasting and warning is inadequate for flood runoff in the urbanized area.

On the other hand, it might be effective to forecast the future hydrograph (one (1) to three(3) hours after) at the Yen So pumping station. The newly installed equipment could be used for that purpose. The basic concept of flood forecasting and warning is as follows:

(1) Rainfall Forecasting

It is necessary to forecast an hourly rainfall hyetgraph pattern to calculate the future flood runoff. There are two (2) forecasting methods described below:

- Using the accumulative rainfall curve prepared through the analysis of past flood's hourly hyetograph pattern

- Based on the assumption that the average rainfall intensity of past n-hours (3 hours is used in many cases in Japan) will continue for the coming n-hours.

Further study is required to decide which method should be adopted in the To Lich river basin.

The hourly rainfall data of the newly installed gauge at the HSDC headquarters will be used for forecasting. There seems to be no need to collect data from other stations, since the data at HSDC represents the rainfall in the Study Area. For flood forecasting, the ideal coverage of one station is said to be around $50km^2$, whereas the actual coverage of the forecasting system is quite wider in many areas of Japan. The rain gauge at the Thanh Liet floodgate could be used as a backup.

It is recommended to connect the rain gauge at HSDC to the personal computer (IBM compatible) provided by JICA, to collect the data automatically for flood runoff forecasting.

(2) Runoff Forecasting

Future runoff (one (1) to three (3) hours) can be calculated using the predicted hourly rainfall through the flood runoff model by the storage function method established in Chapter C7. The interval of forecasting is one (1) hour. To make the result more accurate, the feedback system will be introduced. That is, the present calculated hydrograph can be adjusted using the observed hydrograph.

For the actual operation, it is necessary to establish a flood runoff forecasting system for the personal computer using easy man-machine interface.

(3) Control System for Drainage

It is required to establish a control system for drainage which connects the HSDC headquarters, the Yen So pumping station and other facilities, as shown in Figure C12.1. The system aims to transmit the data/information, including rainfall and water levels, and to transmit direction. The HSDC headquarters is in charge of the overall direction of the whole system, and direction for the emergency activities. The communication system consists of a telemetering network and a wireless telephone network, and also vehicle or motorcycle communication.

(4) Required Cost

The required cost for flood forecasting and warning in the To Lich River basin is estimated to be around US$ 300,000, as follows.

- Telemetering network, 4 sites : US$200,000 (US$50,000 for each unit)
  (HSDC Headquarters, Yen So pumping station, Thanh Liet floodgate and West Lake control gate)

- Runoff forecasting system : US$100,000

C13. WATER BALANCE OF THE WEST LAKE

The possibility of water supply for flushing from the West Lake to the To Lich river basin in the dry season was roughly studied using existing hydrological data.

As mentioned in Chapter C3, the water level of the West Lake has practically no relation to the Red River (See Figure C3.5). The seepage from the Red River to the lake is practically nil. The water level fluctuations of the lake seem to synchronize only with rainfall and evaporation.

The water level records of the West Lake since 1987, exist only for the rainy season (Apr. or May to Nov.). Judging from the meteorological data, the annual lowest water level appears at the end of the dry season in April, since evaporation exceeds rainfall from December to March (See Figure C3.1). The surplus amount of evaporation in the dry season is 181mm in average (rainfall:178mm, evaporation: 359mm, See Table C3.1). The lowest level is assumed to be around EL. 5.6m (See Figure C3.5).

Rainfall exceeds evaporation in the rainy season from April to October and the average surplus is 871mm (rainfall:1496mm, evaporation:625mm). Therefore, by closing the gate, the water level theoretically can reach up to around EL.7.0m (5.60m+1.43m (0.87m*930ha/567ha)) at the end of rainy season.

On the other hand, according to the drainage plan, the high water level of the West Lake is EL.6.5m and the design rainfall depth is 310mm (10-year, 2 days). During the flooding, the control gates of the lake are completely closed. The water level should keep to under EL.6.00m (6.50m-0.50m(0.31m*(930ha/567ha)) to retain flood control volume.

Based on environmental reports and existing data, the lowest level should be maintained at EL.5.6m.

Therefore, the maximum available volume for flushing was calculated as follows:

$$V=567ha * (6.00m-5.60m-0.18m)=1,240,000m^3$$

(0.18m : evaporation in dry season)

The possible flushing discharge for the dry season from December to March was estimated as follows:

$$Q=1,240,000m^3 / (60sec*60min*24hr*120days)=0.12m^3/s$$

The discharge is not sufficient for flushing. It is practically impossible to supply enough flushing water from the West Lake to the To Lich river basin.

C14. RECOMMENDATIONS FOR HYDROLOGICAL OBSERVATION

(1) Rainfall Observation

Two (2) new automatic rain gauges supplied by JICA have already been installed at the HSDC headquarters and the Thanh Liet floodgate. The installation work was carried out by the HSDC. The hourly rainfall observation started from May 1994. These gauges were quite useful for the Study, because the Study Team could immediately obtain the hourly hyetgraph patterns of May 20 and August 29, 1994 floods .

The observed result is recommended as follows.

(a) Hourly rainfall table (especially in flooding period)

(b) Daily rainfall table (note that the daily rainfall means the rainfall from 7:00PM to 7:00PM at Lang Station and other stations of MOWR.)

(c) Annual maximum n-minute (10,20,30,40,60 minutes) rainfall and n-hour (2,3,4,5,6 hours) rainfall table

(2) Water Level Observation

Since 1987, daily water levels have been observed by the HSDC along the To Lich, Lu, Set, and Kim Nguu rivers and on the main lakes in the Study Area. For the present, observations have been carried out only in the rainy season (Apr. (or May) - Oct. (or Nov.)) excluding Sundays.

It is recommended this observation be continued throughout the year. The water levels in the dry season are important in assessing the low flow condition of the Study Area.

(3) Management of Observed Result

A computer spreadsheet program (Lotus 1-2-3, Microsoft Excel, etc.) is quite suitable for the management and tabulation of the observed results. Many kinds of hydrological analyses could be assessed by utilizing spreadsheet data.