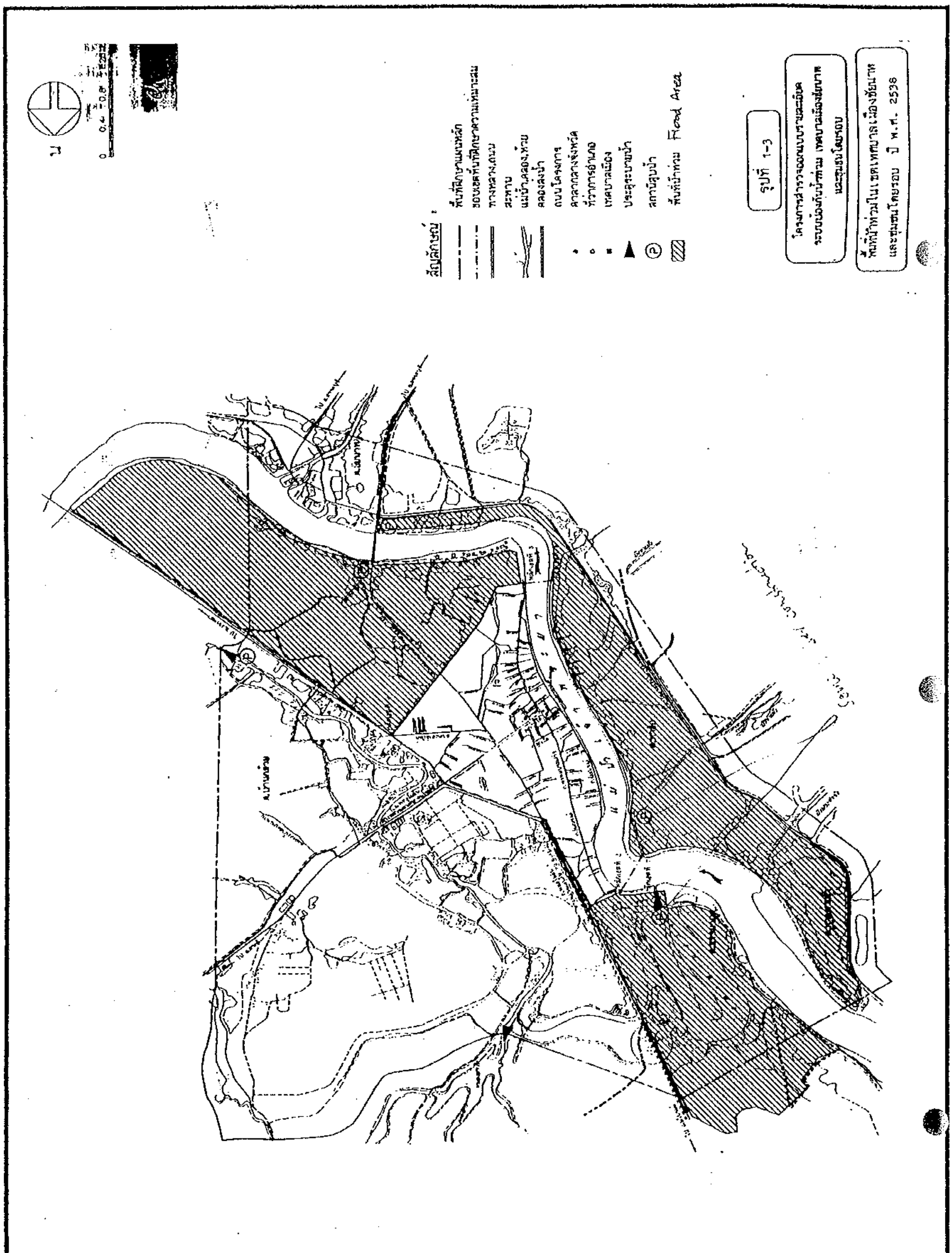
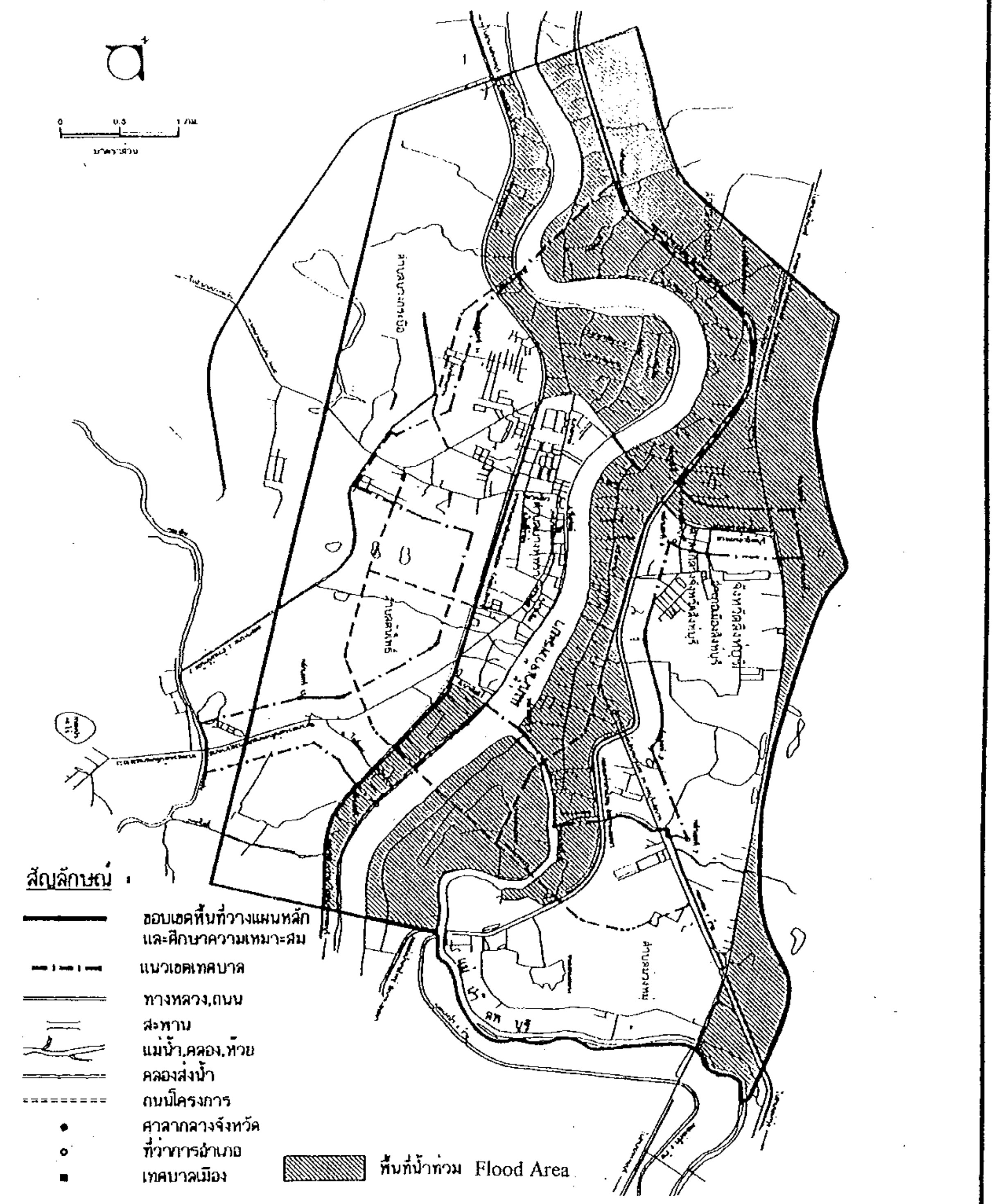
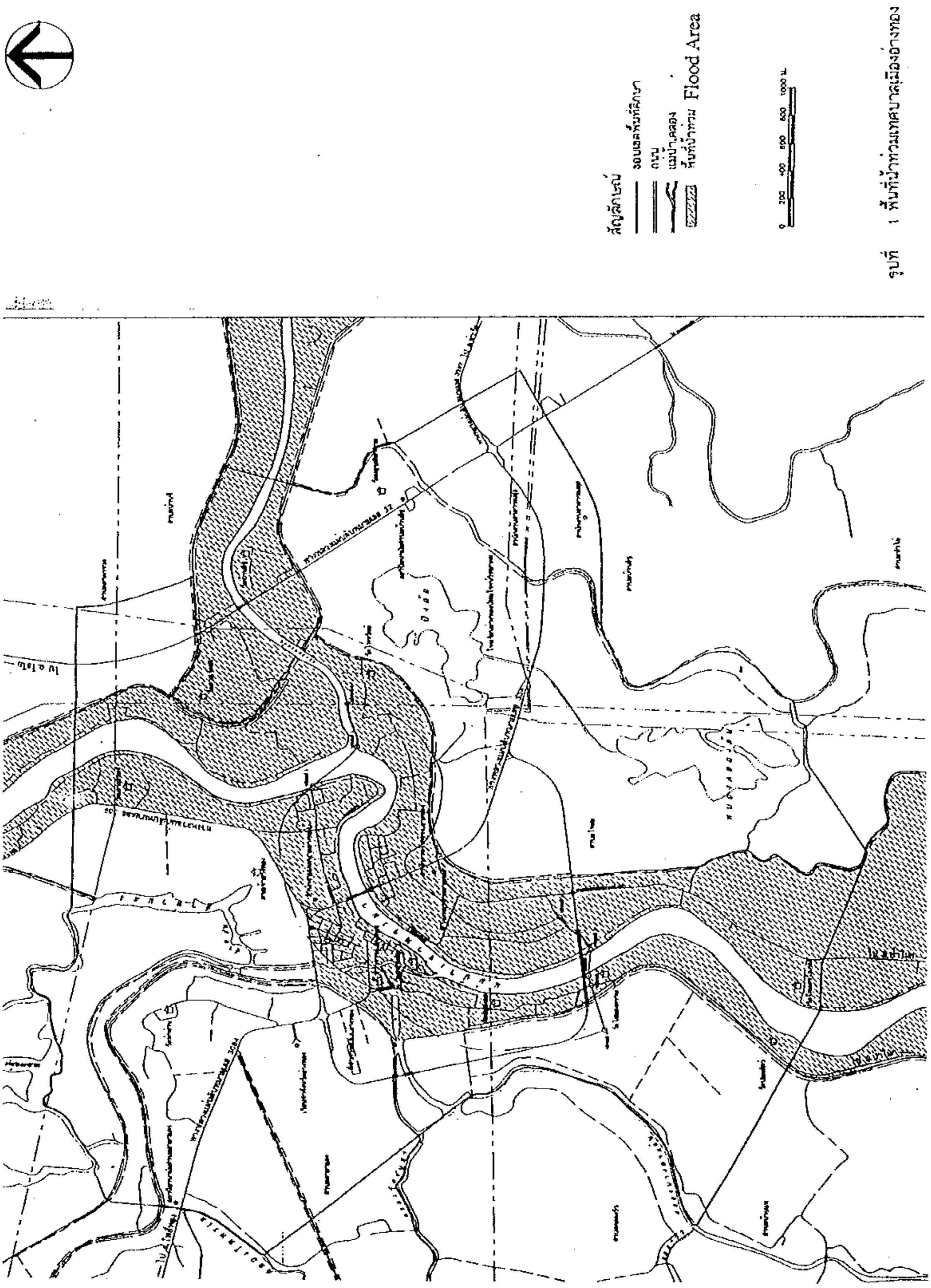


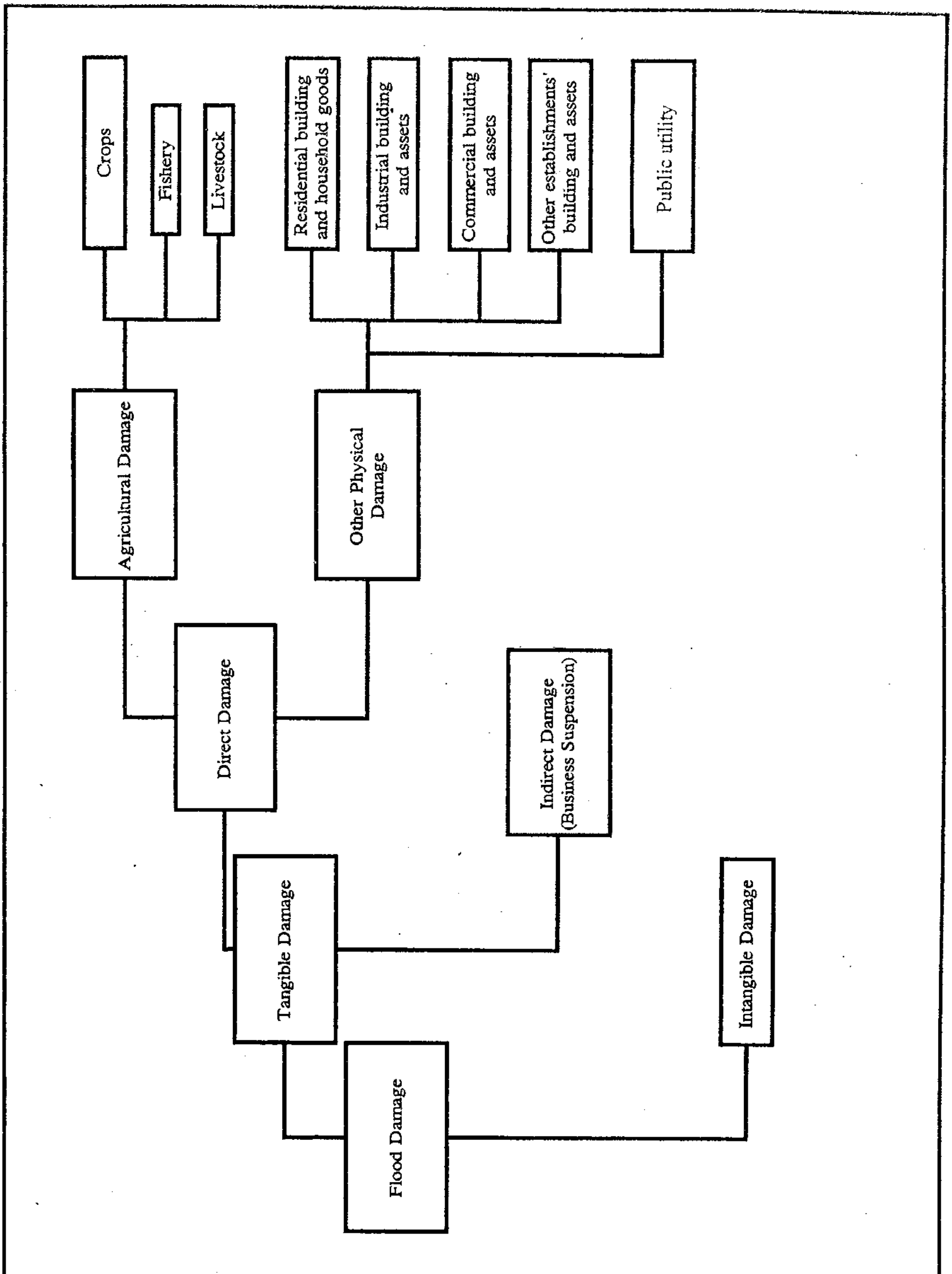
STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig.2.3.7 FLOODED AREA IN 1995 (CHAINAT)
CTI ENGINEERING CO., LTD. AND INA CORPORATION	



STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig.2.3.8 FLOODED AREA IN 1995 (SING BURI)
CTI ENGINEERING CO., LTD. AND INA CORPORATION	



STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig.2.3.9 FLOODED AREA IN 1995 (ANG THONG)
CTI ENGINEERING CO., LTD. AND INA CORPORATION	



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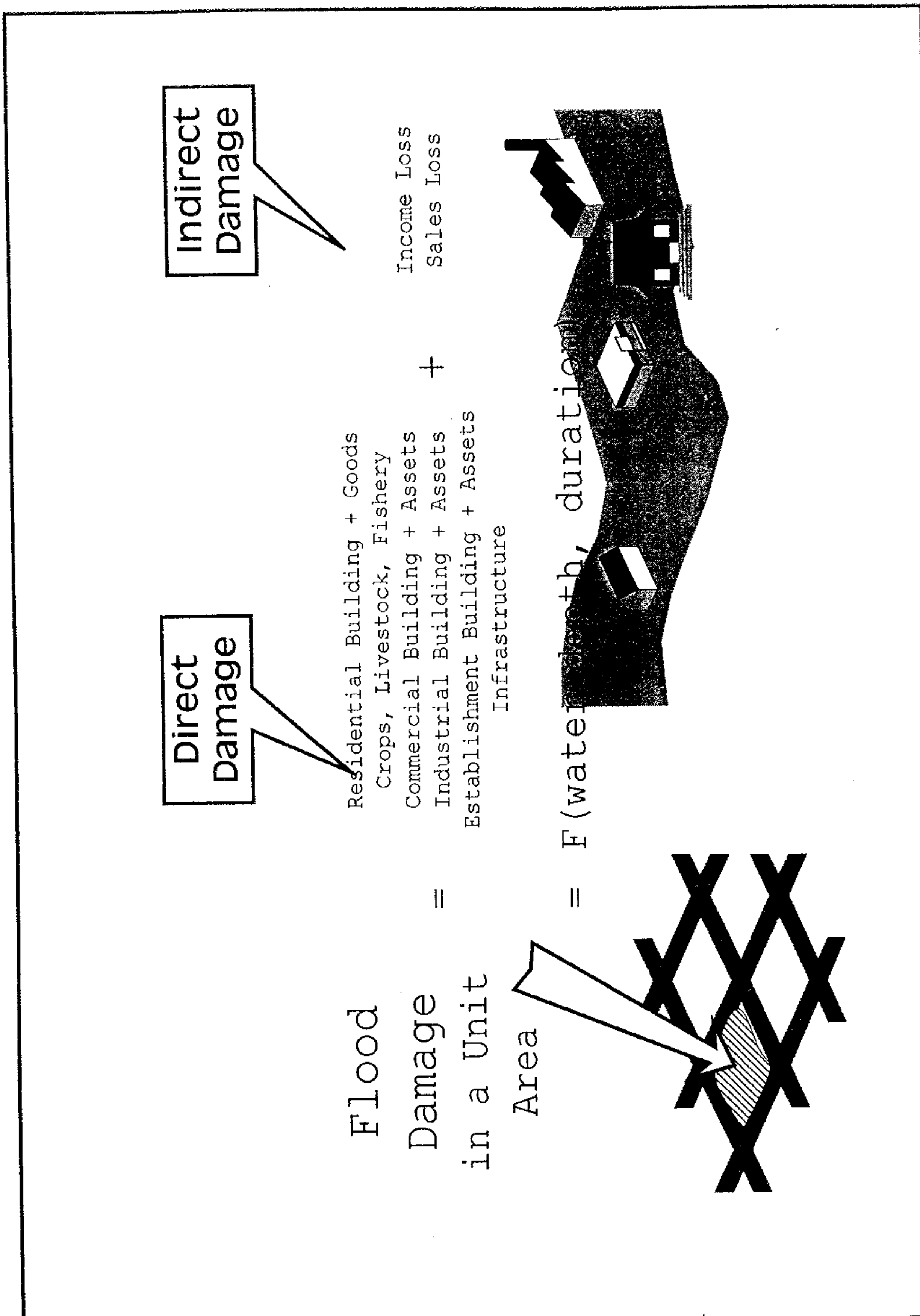
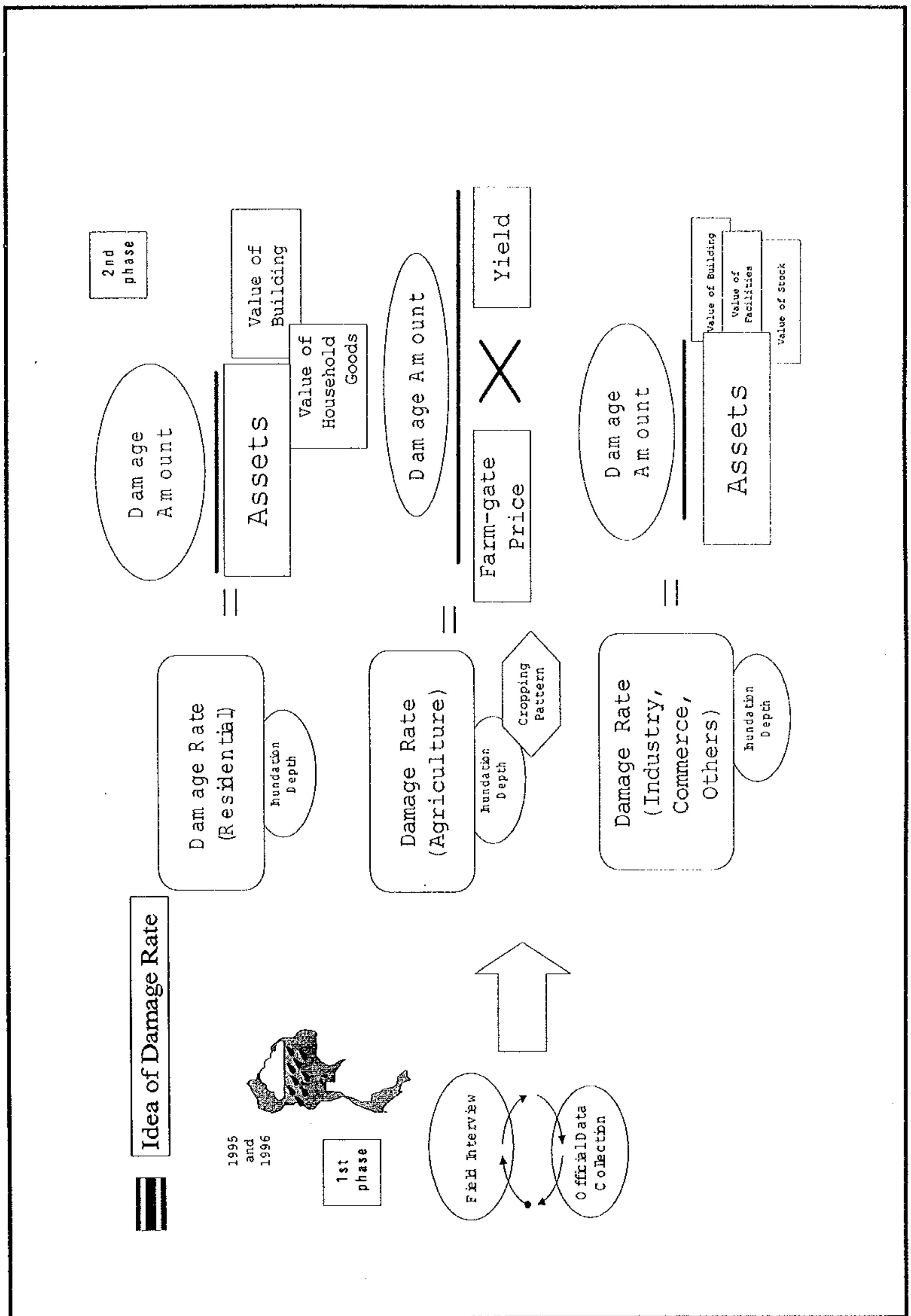
CTI ENGINEERING CO., LTD. AND INA CORPORATION	



STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig.3.1.2 FUNCTION OF FLOOD DAMAGE
CTI ENGINEERING CO., LTD. AND INA CORPORATION	



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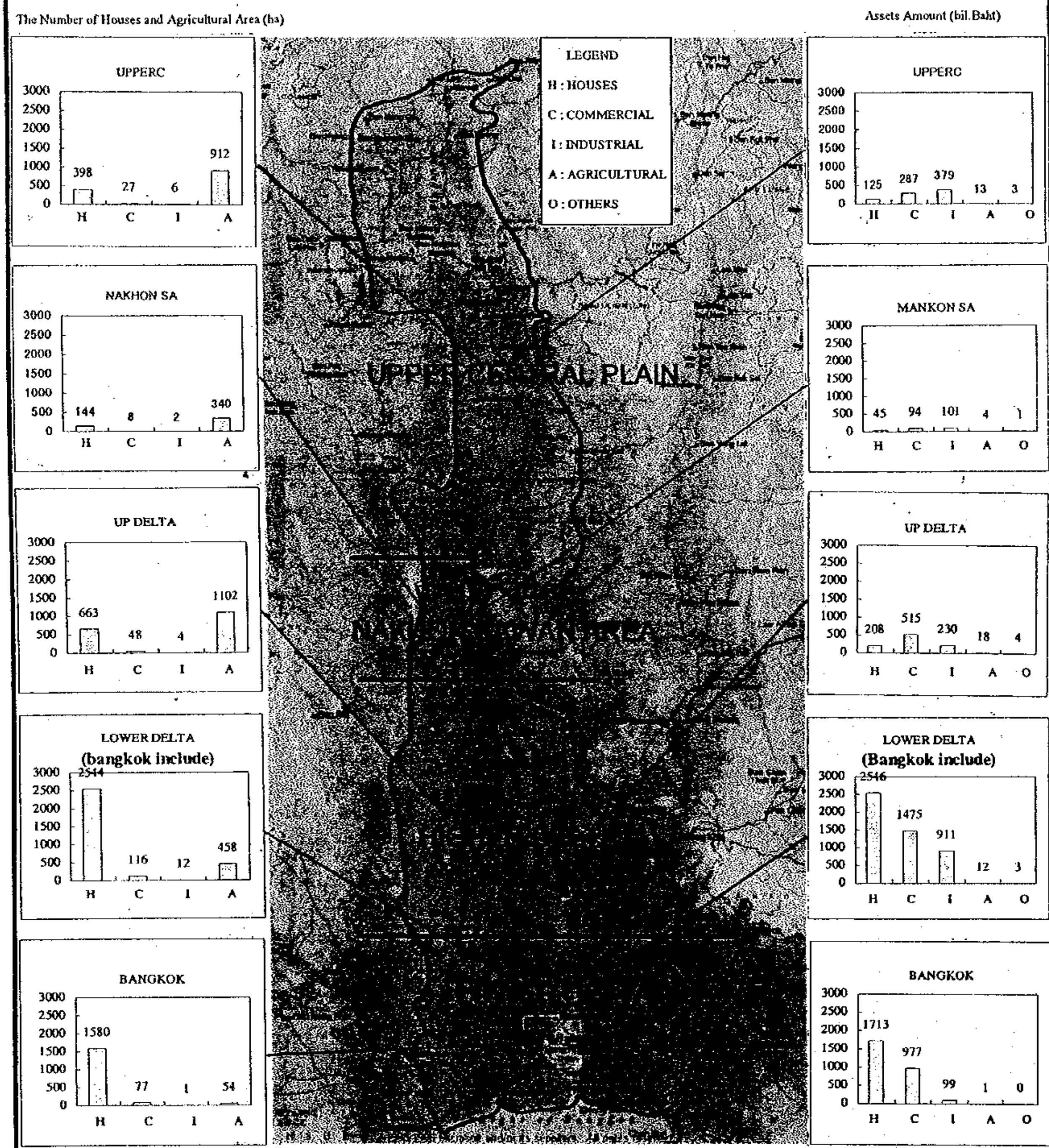
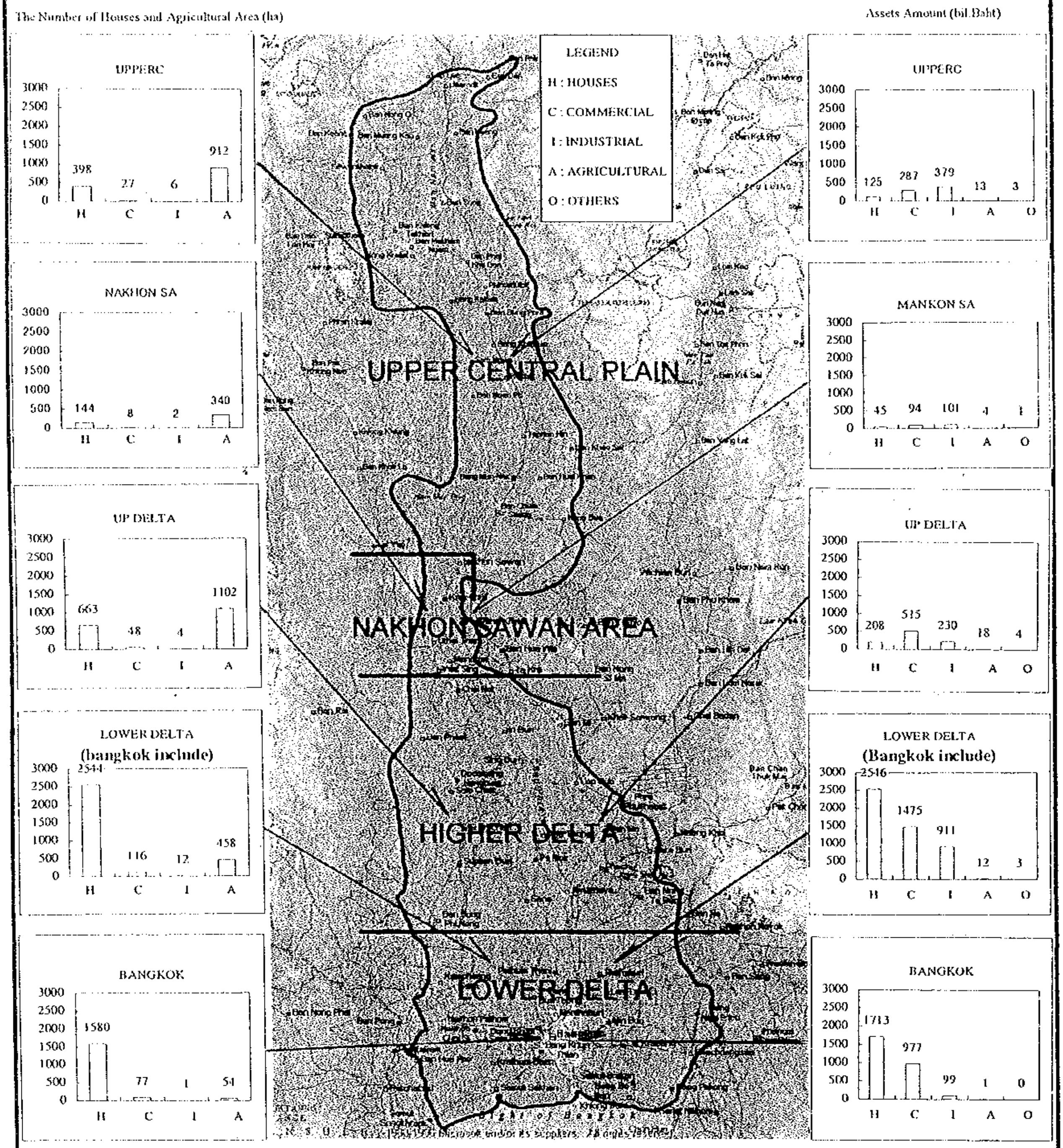


STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAOPHRAYA RIVER BASIN	Fig.3.1.4 WHOLES ASSETS VALUE IN THE STUDY AREA
CTI ENGINEERING CO., LTD & INA CORPORATION	



STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAOPHRAYA RIVER BASIN	Fig.3.1.4 WHOLES ASSETS VALUE IN THE STUDY AREA
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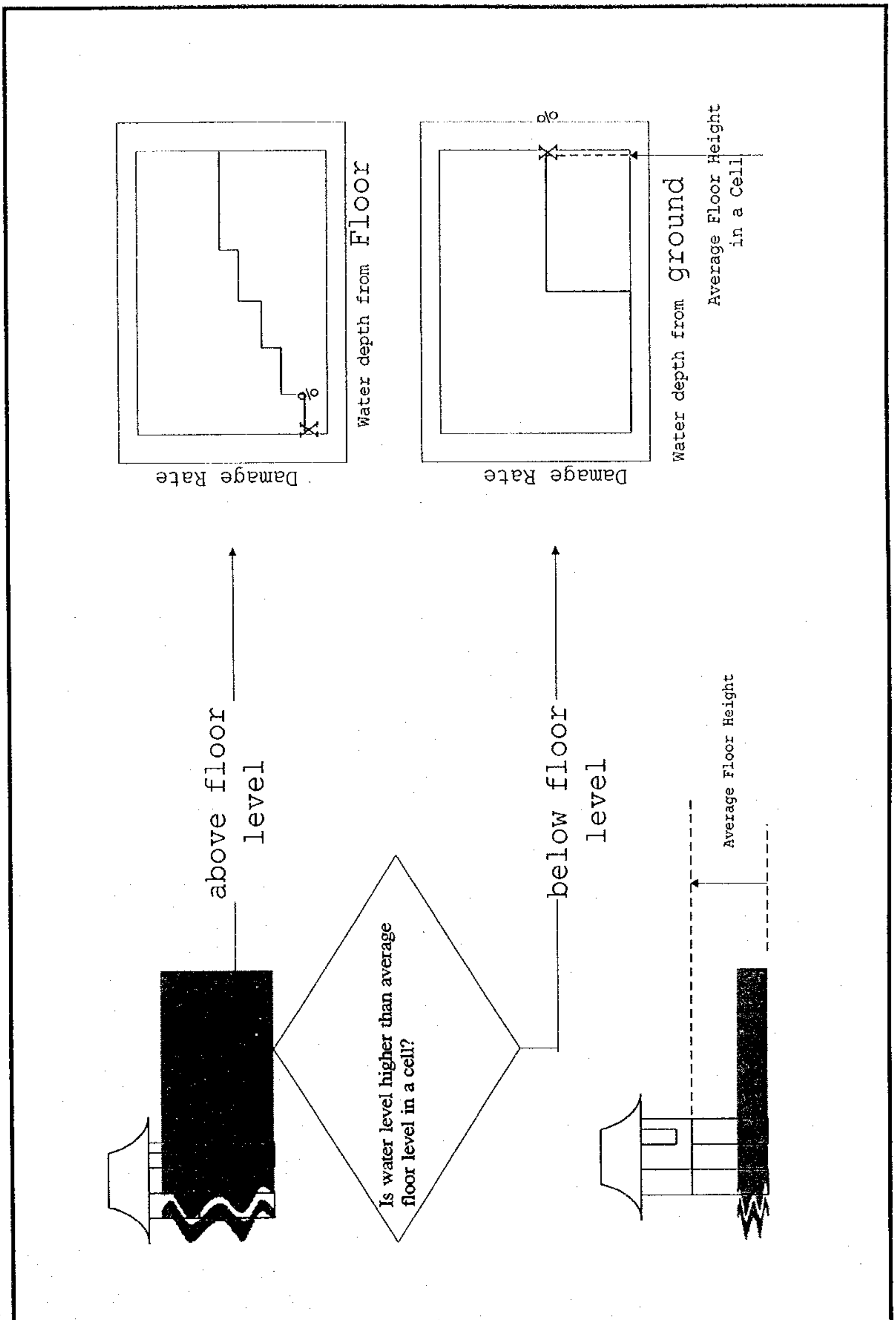
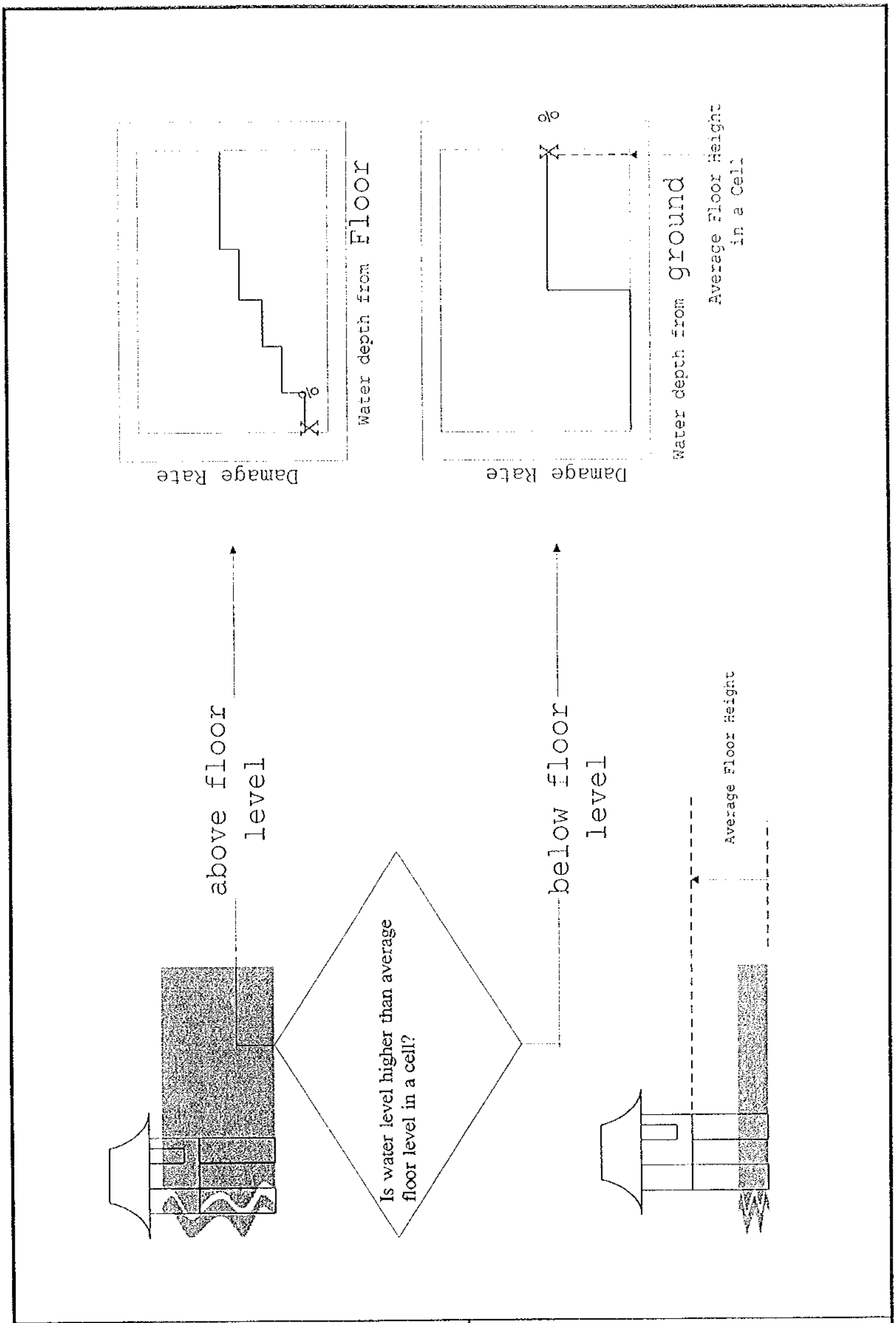


STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig.3.2.1 CONCEPT OF DAMAGE RATE
CTI ENGINEERING CO., LTD. AND INA CORPORATION	



STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig.3.2.1 CONCEPT OF DAMAGE RATE
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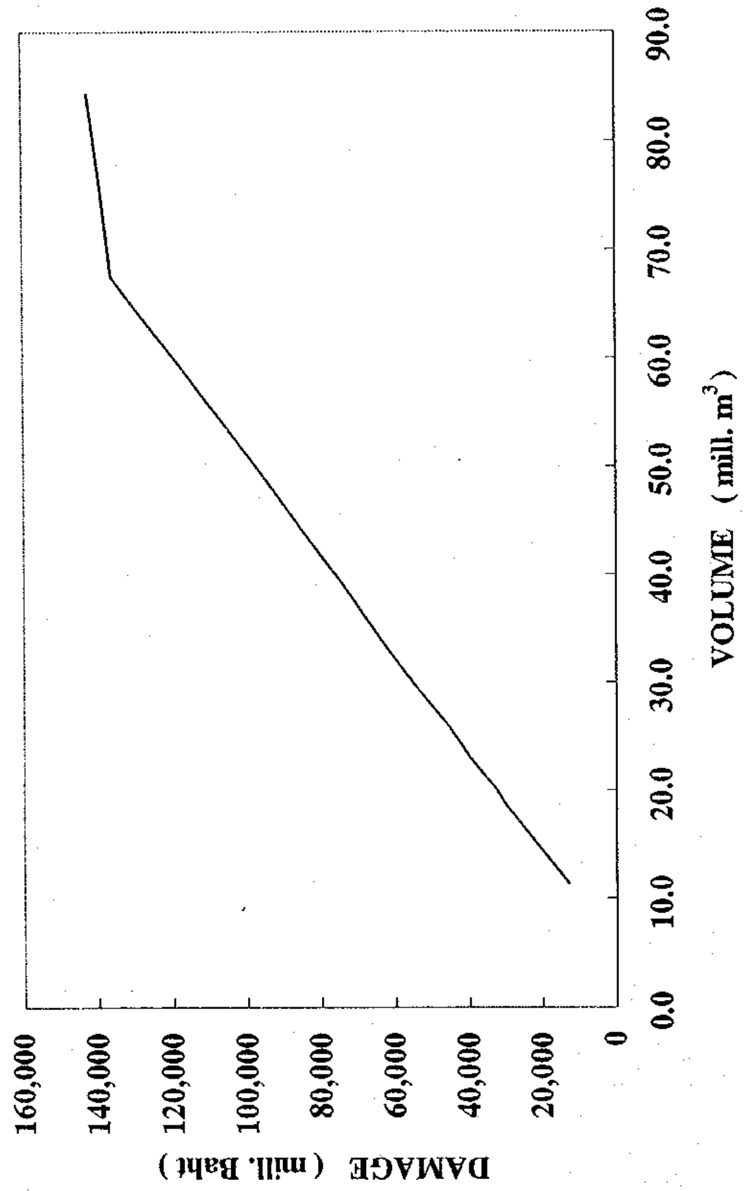
Fig.4.2.2 DAMAGE-VOLUME CURVE in BANGKOK



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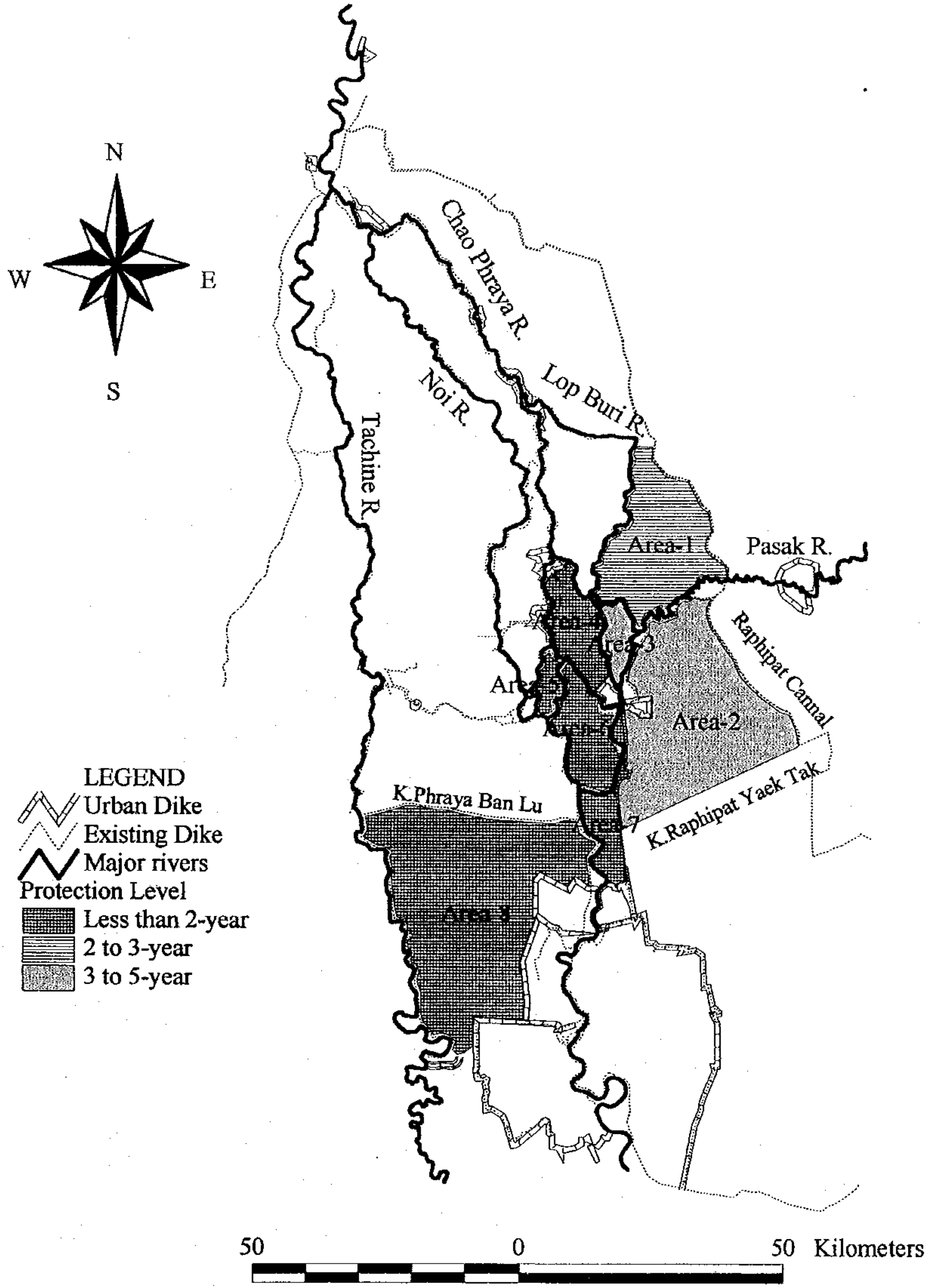
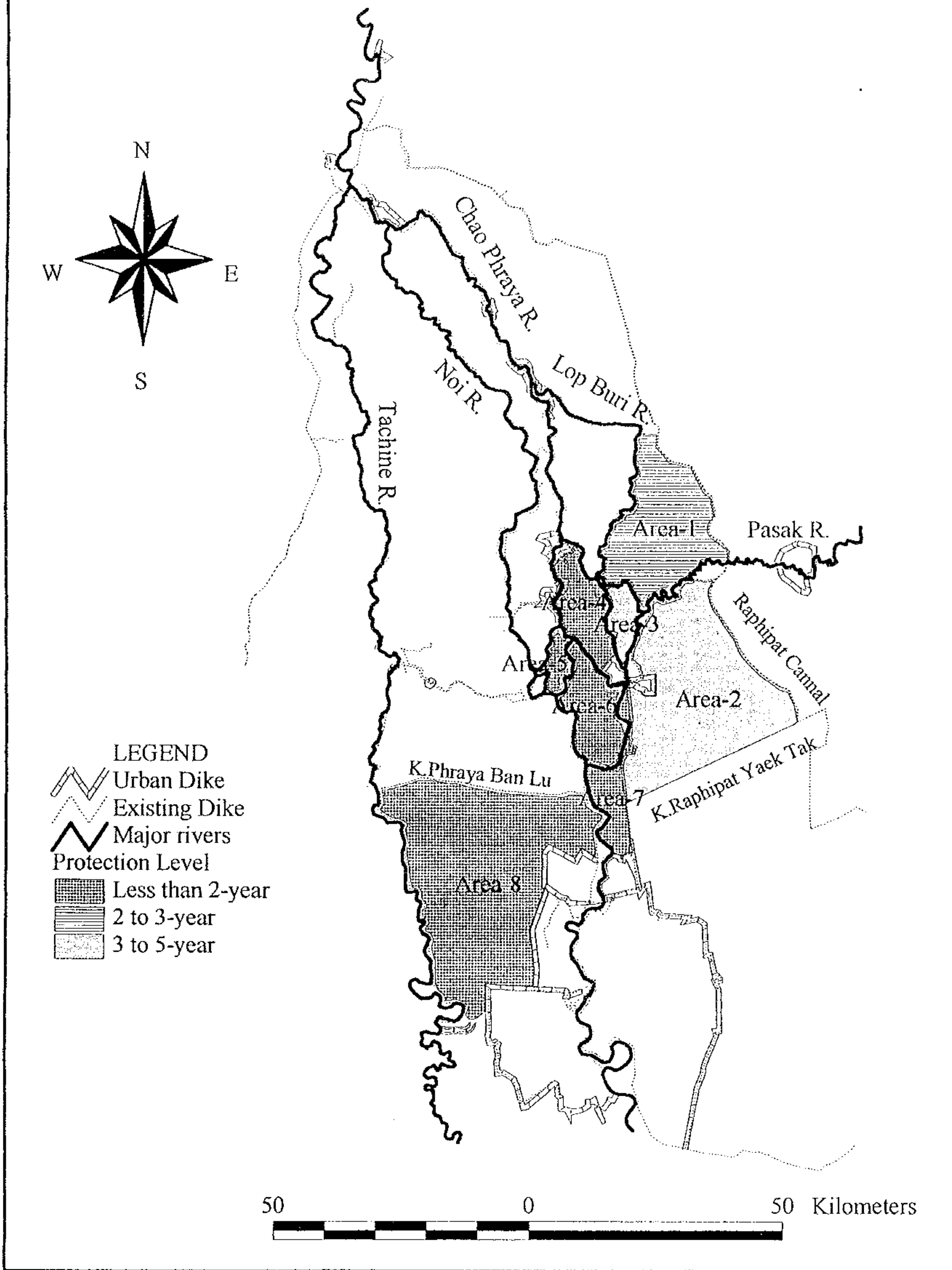


STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig.3.2.3
CTI ENGINEERING CO LTD., & INA CORPORATION	PROBLEM AREA DIVISION



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SECTOR VI

FLOOD MITIGATION PLAN

SECTOR VI
FLOOD MITIGATION PLAN

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1. INTRODUCTION

1.1 Objectives of the Study

This Supporting Report VI, Flood Mitigation Plan, presents the Master Plan formulation considering the present and future flood damage condition as well as the features of flood in the Chao Phraya River Basin. As to the feasibility study for project components selected from the Master Plan, discussion is made individually in the Sectors concerned.

1.2 Study Area

The study area is the whole Chao Phraya River Basin of 163,000 km^2 (see General Map). The Chao Phraya Delta and the lower reaches of the Nan and Yom rivers are the target areas for flood mitigation giving high priority to the Chao Phraya Delta, and including the Bangkok metropolitan area because of its social and economic significance.

1.3 Flood and Damage

1.3.1 Historical Changes in the Basin

Inhabitants of the Chao Phraya River Basin had been experiencing floods which, on one hand, brought abundant water and fertile soil to agricultural lands. However, at present, such benefits of abundant water are no longer available because of the social and economic development all over the basin.

In the agricultural lands, the intensified agricultural practice that gives emphasis on replacement of traditional local varieties like floating rice to the high yield varieties vulnerable to flooding has resulted in the enhancement of flood damage potential. Furthermore, cultivated areas, mostly with irrigation works, have increased from 7,000 km^2 before the 1950's to 35,000 km^2 in the 1990's.

On the other hand, urbanization in the basin has progressed and the Bangkok metropolitan area of 51 km^2 before the 1950's has grown to 528 km^2 at present. Consequently, the flood damage potential has not only expanded due to the increased population and assets, but flood discharge due to the decrease of runoff detention capacity has also become more serious.

Moreover, the forest area has diminished to give way to various types of development from 166,000 km^2 before the 1950's to 92,000 km^2 in the 1990's, which also resulted in the increase of flood discharge of the rivers. Such changes in the basin that possibly heightened the flood damage and enhanced the importance of flood mitigation works are summarized in Table 1.3.1.

1.3.2 Major Flood Events

As far as people in Thailand could remember, the biggest flood was the 1942 flood. In this flood, the highest water level marked at the Memorial Bridge in Bangkok was 2.27 m MSL (refer to the Table 1.3.2), and the entire area of Bangkok City suffered catastrophic damage.

In the last two decades when data and information have become more available, the years 1978, 1980, 1983, 1995 and 1996 have been rated as flood years and the 1983 and 1995 floods were most serious. Spatial distribution of 5 months rainfall from July to December and flood inundation areas in these years are given in Figs. 1.3.1 and 1.3.2. The following are descriptions of the respective flood events listed in the above table.

(1) 1942 Flood

Although the official record was not good in quality and the inundation map was not available, the river flood in 1942 may have caused one of the largest inundation in the Chao Phraya River Basin. The peak water level at Nakhon Sawan (C.2) was estimated to be 1.5 m higher than that recorded in 1995. The water level at Memorial Bridge reached 2.27 m MSL, which was the highest on record in the observation period. Flood control measures in the basin were almost non-existing, and natural habitation on its flood plain was much smaller than at present.

(2) 1978 Flood

Heavy rainfall took place in the Nam, Yom, Ping and Pasak river basins, resulting in swelling of the Chao Phraya River in October 1978. At Nakhon Sawan (C.2) and Chainat (C.13), maximum flood discharges of 3,500 m^3/s and 3,800 m^3/s were recorded, respectively. Floodwaters overtopped the riverbanks at many locations and spread into klongs between Chainat and Ayutthaya, resulting in extensive flood inundation in the adjacent flood plains, as shown in Fig. 1.3.2(1/5). At Ang Thong, the river discharge decreased to 2,900 m^3/s.

Local rainfall also caused inundation along the Chainat-Pasak Canal and the Lop Buri River. The damage to Bangkok was reported as a normal one.

(3) 1980 Flood

Inundation by local rainfall, as well as spilling and distribution from rivers, took place at several places. Flood discharges of 4,400 and 3,800 m^3/s were observed at Nakhon Sawan and Chainat, respectively. Serious inundation occurred on both sides of the Chao Phraya River between Chainat and Ayutthaya as shown in Fig. 1.3.2(2/5), inflicting tremendous damage to the agricultural areas. In addition, urban areas along the Chao Phraya River including Nakhon Sawan, Chainat, Sing Buri, Ang Thong and Ayutthaya were also exposed to the floodwaters.

(4) 1983 Flood

The flood in 1983 was well known by its considerable damage, primarily in Bangkok, and this has lead to the present flood protection facilities. Exceptionally large rainfalls were recorded in the upper reaches of the Chao Phraya River from September to November. The discharge at Chainat reached 3,400 m^3/s in October and November, adding the flood discharge from the Sakae Krang tributary to the 2,300 m^3/s at Nakhon Sawan.

In the lower basin, heavy rainfall in August (434 mm compared to 170 mm on the average) caused local flooding. After that, the total rainfall from September to November was recorded at 405 mm (215 mm on the average), which resulted in the peak water level of 2.04 m at Memorial Bridge in November and extensive inundation in and around Bangkok, as shown in Fig. 1.3.2(3/5).

(5) 1995 Flood

The flood in 1995 caused inundation to an extensive area of nearly 15,000 km^2 from the Nan and Yom upper to lower reaches, as shown in Fig. 1.3.2(4/5). The difference with the other cases of flooding was that Bangkok was practically free from floodwaters, and hence did not suffer much damage in contrast with the heavy damage outside of the city. The infrastructure damage inflicted by the flood was estimated at about 6.4 billion Baht on the assumption that the damage equals the repairing cost for damaged roads, bridges, riparian structures and other infrastructures recorded at the 21 provincial offices in the study area. No statistical data on the damage to houses, crops, industrial activities, etc., was available.

The cause of heavy rainfall was a sequence of tropical storms from the end of July to early September. The August's rainfall in the Nan and Pasak catchment areas was recorded at 450 mm and 345 mm, respectively. The discharge at Nakhon Sawan reached 4,800 m^3/s. A substantial volume of water was released into the floating rice area and some sections of the left bank between Chainat and Ayutthaya were breached, attenuating the flood discharge of 4,500 m^3/s at Chainat into the 2,700 m^3/s at Ang Thong.

The Sirikit Dam's huge reservoir, the water level in which was near the upper rule curve at the end of July due to large quantity of inflow in 1994, was filled with inflow from the upstream catchment in August and September. Then the spillway came into operation in September for the second time following 1972, resulting in local flooding in downstream reaches.

In spite of the spillage, the Sirikit Dam was able to store 3 billion m^3. The Bhumibol Dam Reservoir, the water level in which was below the lower rule curve at the end of July, was free from spillage and stored 4.5 billion m^3 from August to October. Had it not been for these reservoirs' capacities, the peak discharge at Nakhon Sawan could have reached 6,000 m^3/s according to the Flood Review by the World Bank (1996).

(6) 1996 Flood

A big flood occurred in 1996 consecutively with extensive flood inundation by local rainfall, as well as spilling and distribution from the rivers, as shown in Fig. 1.3.2(5/5). The flood magnitude was rather smaller than that of the 1995 flood, but discharge of over 3,000 m^3/s was observed at Nakhon Sawan and Chainat. The two huge dam reservoirs, Bhumipol and Sirikit stored 3.4 and 2.7 billion m^3 of floodwater, respectively, without any spillage. Heavy local rainfall in the west of Tha Chin River filled the Krasieo Dam Reservoir and spilled water caused inundation along the river in Supan Buri Province.

The damage to infrastructure was estimated at about 1.5 billion Baht on the same assumption as above.

1.3.3 Features of Flood Damage

Based on the previous flood records especially those in 1983, 1995 and 1996, the characteristic features of flood damage in the Chao Phraya River basin are summarized as follows:

(1) Upper Central Plain (Upstream of Nakhon Sawan)

In the upstream of Nakhon Sawan, the geographic features are characterized by valley plain between hilly areas with gentle slope in the east and west sides. In this area, inundation caused by overtopping of the Yom and Nam rivers widely spread along these river course.

The total inundation area was about 7,000 km^2 in the 1995 flood. The inundation period lasted for as long as 2 to 3 months, and in some depressed areas inundation continued for more than 3 months up to January the following year.

Although the inundation depth was between 0.5 m and 3 m, areas with inundation depths greater than 1 m were dominant. Some of the inundation water got detained for a long time and gradually drained into the river when the river water level went down. Some of it went downstream as overland flow.

In the area, the major flood damage was brought to the agricultural area where paddy fields with traditional varieties such as floating rice, deep-water rice and others were dominant. High yield rice varieties were observed in a certain irrigation area protected by dike, and 50% of the area was spared from flood damage. The other areas including the traditional variety area were damaged.

The urban areas such as Sukoh Thai, Phitsanulok and Phichit, as well as public facilities such as roads, irrigation facilities and canal embankments, also suffered from serious flood damage.

(2) Nakhon Sawan Area between Nakhon Sawan and Chainat

In the Nakhon Sawan area between Nakhon Sawan and Chainat, the geographic condition is characterized as a narrow valley plain with a number of isolated mountains. In this area, inundation water is caused by overland flow from upstream and overtopping from the Chao Phraya River. The inundation water widely spreads, and some of the water is detained in the area and some flow downstream as overland flow.

The inundation area was about 500 km^2 in the 1995 flood. The inundation period did not last as long as 1 to 2 months compared with the other areas and the inundation depth was between 0.5 m and 3 m.

In the area, major flood damage was brought to both agricultural and urban areas. In the agricultural areas, 30,000 ha of paddy fields where the traditional rice variety was dominant were damaged. The urban areas such as Nakhon

Sawan and Uthai Thani, as well as public facilities such as roads, irrigation facilities and canal embankments, also suffered from serious flood damage.

(3) Higher Delta in Lower Central Plain (between Chainat and Ayuthaya)

In the higher delta in the lower central plain between Chainat and Ayuthaya, the geographic condition is characterized with natural levees and back marshes. In this area, the inundation water is caused by overland flow from upstream and overtopping and breaches along the Chao Phraya River, Lopburi River, Tha Chin River and so on. The inundation water widely spreads, and some of the water is detained in the area and some flow downstream as overland flow.

The inundation area was about 6,000 km^2 in the 1995 flood. The inundation period also lasted as long as 2 to 3 months, and in some depressed areas, inundation continued for more than 3 months up to January the following year. The inundation depth was between 0.5 m and 4 m.

In the area, major flood damage was brought to both agricultural and urban areas. In the agricultural areas, paddy fields with high yield rice varieties were dominant, but floating rice and deep-water rice were planted in the habitual inundation area.

The urban areas such as Chainat, Sin Buri, Angthong, Ayuthaya and Supan Buri, as well as public facilities such as roads, irrigation facilities and canal embankments, suffered from serious flood damage.

(4) Lower Delta in Lower Central Plain (downstream of Ayuthaya)

In the lower delta in the lower central plain (downstream of Ayuthaya), the geographic condition is characterized as very flat lowland. In this area, the inundation water is caused by overland flow from upstream and overtopping and breaches along the Chao Phraya and Tha Chin rivers. The inundation water widely spreads and most of the water is detained for 2 to 3 months and naturally or artificially drains into the river or the sea.

The inundation area was about 6,500 km^2 in the 1995 flood. The inundation depth was between 0.5 m and 2 m.

In the area, major flood damage was brought to both agricultural and urban areas. In the agricultural areas, paddy fields with high yield rice varieties were dominant.

The urban areas such as Pathum Thani and Nonthaburi, as well as public facilities such as roads, irrigation facilities and canal embankments, suffered from serious flood damage. In the 1995 flood, the Bangkok metropolitan area was spared from severe flood damage.

The features of flood damage are summarized in Table 1.3.3.

1.4 Flood Mitigation and Drainage Works

1.4.1 Previous Plans

To cope with the repeated flooding as presented in Section 3.2, the agencies responsible for flood mitigation and drainage works have made every effort to prepare several plans as listed in Table 1.4.1 whose major features are shown in Table 1.4.2. As can be seen in the table, the first study was in 1960 for the protection of Bangkok, and most of the plans also focused on the protection of the Bangkok metropolitan area and the adjacent flood plain. These plans, in general, proposed the following measures:

(1) Polder system together with the improvement of drainage system including pump facilities;

(2) Dikes along the river course; and

(3) Diversion channel.

Of these plans, a polder system with drainage system improvement covering the Bangkok metropolitan area has been developed, and diking has progressed continuously along the Chao Phraya River even in rural areas.

1.4.2 Works in Urban Areas

(1) General

The flood protection and drainage facilities provided for typical urban areas such as Bangkok Metropolis and provincial cities in the Chao Phraya River Basin have not been well installed. After the 1995 flood, however, substantial improvement works were made or are being designed for many of such cities as briefly described below. Regular improvement and maintenance works not described herein are carried out by the related agencies.

(2) Bangkok Metropolis

Based on the various studies as listed in Table 1.4.1, BMA has continuously made vital efforts to protect the metropolis from flood and to improve the drainage condition. Such efforts have concentrated on the construction of (a) polder dikes along the periphery of the urban areas of both right and left banks of the Chao Phraya River; (b) flood barriers along both banks; (c) drainage pumping stations with flood forecasting center; and (d) improvement drainage channel. Fig. 1.4.1 shows the location of polder dikes, flood barriers and pumping stations.

At present, BMA is constructing a flood barrier along both banks to protect the urban area of about 890 km^2 (650 km^2 on the left bank and 240 km^2 on the right bank) as shown in Table 1.4.3. The location is as presented in Fig. 1.4.2.

The crest elevation (EL. 2.75 - 3.00m) was determined in consideration of the probable high water level of 100-year return period (EL. 1.90 - 2.50 m), freeboard (0.50 m) considering estimated land subsidence (20 cm in 2006), and public opinion with respect to convenience and aesthetic condition.

As shown in the same table and figure, the total capacity of the drainage pumps of BMA is 692 m^3/s in total, i.e., 452 m^3/s for the left bank and 240 m^3/s for the right bank, most of which are directly discharged into the Chao Phraya River.

On the other hand, RID has a plan to increase the flow capacity of the Chao Phraya River at Bangkok Port by loop-cut. (Refer to Fig. 1.4.3.)

(3) Provincial Urban Areas Located Downstream of Bangkok

Samut Prakan Province, which is located between the southern part of Bangkok metropolitan area and the Gulf of Thailand, is divided by the Chao Phraya River into East and West. The ground level of the province is generally low and the area is always affected by flood mainly caused by high tide in the rainy season.

The PWD is presently carrying out the flood protection works along the Chao Phraya River, 236 km^2 in the East and 124 km^2 in the West. A polder system together with gates and pumps has been adopted to protect the area. The design criteria, together with the designed crest level of the dikes, are as follows (see Fig. 1.4.4):

High water level in 100-year return period	+1.900 m (MSL)
Dikes along the Chao Phraya River	+2.500 m (MSL)
Inside the dikes	+2.200 m (MSL)
Design rainfall for pumping station and discharge structure	5-year return period
The budget	2,844.35 million Baht (1986~1996)

(4) Provincial Urban Areas Located Upstream of Bangkok

After the serious damage in major urban areas in the study area, PWD is presently carrying out some remedial measures for flood protection in some provincial capitals along the Chao Phraya River. On the other hand, PWD had selected seven (7) provinces; namely, Nakhon Sawan, Chainat, Sing Buri, Ang Thong, Ayuthaya, Pathum Thani and Nonthaburi, for feasibility study and detailed design works which were generally completed by November 1997.

In the study mentioned above, the urban areas to be protected were generally selected through the screening of urban areas in each province in due consideration of the importance of the urban areas, the amount of damage from floods, the number of population, quantity of work for countermeasures, etc. Thus, provincial capitals, several municipalities and sanitary districts were chosen for the feasibility study as shown in Table 1.4.4 and Fig. 1.4.5. The expansion of urban areas, one of the factors affecting the flood condition, was taken into account, especially in the provincial capitals.

PWD/AIT also conducted a master plan study for 67 provinces in the country (except Samut Prakan, Bangkok and the 7 provinces mentioned above). The final report was expected to be available in January or February of 1998, with higher priority placed on some provinces in the study area such as Sukhothai, Pitsanulok and Phichit.

1.4.3 Works in Rural Areas

(1) Present Situation

The present flood prone areas are the lowlands of the Chao Phraya Delta and the Yom-Nan basin where one paddy cropping per year is predominant. Once these areas are flooded, the farmers lose the total income of one crop-year. To protect these areas, RID had established the following three (3) regional offices in the study area to execute the protection works and water management for major irrigation facilities (refer to Figs. 1.4.6 and 1.4.7):

- Regional Office 7 which consists of 17 project offices at the right bank of the Chao Phraya River.
- Regional Office 8 which consists of 12 project offices at the left bank of the Chao Phraya River.
- Regional Office 3 which consists of 4 project offices under the Pitsanulok Irrigation Project.

Provincial irrigation offices have been established also for each province to carry out construction and maintenance works that are not covered by the above project offices. The provincial irrigation offices function under the RID Regional Office and work for the province under the Provincial Governor. The main budget is allocated by the RID Regional Office and is supplemented by one from the provincial office.

Amounts disbursed by RID for flood protection and drainage improvement for Fiscal Year 1995 and 1996 are given in Table 1.4.5. According to RID, the disbursements for the Chao Phraya River Basin in 1995 and 1996 were far larger than normal years which required limited disbursements for regular works. The regular works consist of regular maintenance work (a half) and rehabilitation of damage by the 1995 flood.

(2) Monkey Cheek on the West Bank and the East Bank

The west and east banks on Bangkok Metropolis which extend over 2,000 km^2 between the Chao Phraya and Tha Chin rivers and 2,000 km^2 between the Chao Phraya and Bang Pakon rivers, respectively, are called water conservation areas. These areas have long played a vital role to protect Bangkok during extreme floods (Takaya, 1982).

However, the recent rapid changes in land use and lifestyle of inhabitants have made it difficult to expect such a role in some areas. RID, thus, commenced the detailed design for the regional drainage project for each bank, named the Monkey Cheek by His Majesty King Bhumibol, focusing particularly on flood control and drainage improvement in these regions.

The present major drainage canals and the location of pumping stations and regulators are presented in Fig. 1.4.8. The total capacities of the RID pumps in the West Bank and the East Bank are, thus, estimated at 126 m^3/s along Tha Chin River, 405 m^3/s in the East Bank and 130 m^3/s along Chao Phraya River.

(a) Monkey Cheek Project in the West Bank

The project was conceived in accordance with His Majesty King Bhumibol's suggestion at Mahachai-Senamchai Khlong in the 1995 flood as shown in Fig. 1.4.9. The suggestion is summarized as follows:

- Flood control and drainage improvement, at first by regulators, then pumps, or effective combination of them. Retarding will enhance the flood mitigation effect.
- Dams are effective for flood control. Flood diversion is also possible by a new route or expansion of the existing facilities.
- Land use in the vicinity of Bangkok is changing and urbanized which should be provided with flood protection and drainage improvement. Land raising as well as soil improvement is to be considered.
- Environmental consideration particularly for improvement of water quality through provision of regulators and effective operation thereof.

These guidelines or policies have been observed by RID for application to the ongoing projects discussed below.

(i) Mahachai-Senamchai Project

This project aims to prevent floods and to improve drainage conditions in an area of 46 km^2 downstream of the West Bank, as shown in Fig. 1.4.10, by the provision of 13 regulators and 6 pumping stations with a total capacity of 138 m^3/s. Fig. 1.4.11 shows the typical layout. This project is expected to improve the water quality through flushing deteriorated water by tidal phenomena.

(ii) Upper Tha Chin and Lower Tha Chin Project

The West Bank with an area of 2,400 km^2 (80 km N-S and 30 km wide as shown in Fig. 1.4.12) have long played the role of retarding basin to protect Bangkok from floods. However, urbanization is recently encroaching into the area from the southern end. The Upper Tha Chin Regulator and the Lower Tha Chin Tidal Barrage projects (location and plan are shown in Figs. 1.4.10 to 1.4.12) have been designed with water use as primary objectives. The Upper Tha Chin project is ready to be constructed, and the Lower Tha Chin project is at its final stage of detailed design (refer to Figs. 1.4.13 and 1.4.14.) A preliminary study has been made for the stream flow of the canal network in this area, as presented in Fig. 1.4.15.

(b) Monkey Check Project in the East Bank

(i) Cholahan Phichit 2 Drainage Pump Project

The project aims at improvement of drainage condition of the eastern suburban area adjoining the BMA territory for an approximate area of 2,500 km^2. This area is bounded on the West by the King's Dike, on the East by the Bang Pakong River, on the North by the Rangsit Canal and on the South by the Gulf of Thailand (refer to Fig. 1.4.16). The existing main drainage canals are Khlong Phalonk Chaiyanuchit and Khlong Bang Chalok, with widths of 40-60 m. Both canals originate from Rangsit Canal and flow toward south to the sea, being used for drainage and navigation. Excessive water during the flood season is drained out to the sea by nine (9) pumping stations equipped with 101 pumps in total or a capacity of 303 m^3/s installed along National Road No. 3. The existing Cholà Han Phichit Drainage Pump Station is among these stations. On the other hand, along the Bang Pakong River, there are six (6) pumping stations equipped with 34 pumps in total or a capacity of about 102 m^3/s, which drain water to the Bang Pakong River.

The Project aims at drainage improvement by provision of main drainage canal with a bottom width of 100m and a length of 63km from Rangsit to the sea, and construction of a new and large pumping station named Chola Han Phichit 2 Pumping Station with a total capacity of 200 m^3/s for five (5) vertical axial flow pumps. The layout plan of the station is presented in Fig. 1.4.17.

(ii) Eastern Bangkok Drainage System Study

In response to the implementation of the Second Bangkok International Airport, RID is planning a scheme for the Eastern Bangkok Drainage System Study which covers a wider area than studied by the above Cholahan Phichit 2 Project at master plan and feasibility study levels.

(3) Flood Protection Dike Proposed by RID

RID has planned reconstruction of existing dikes, whose elevation is from 2.0 m to 4.0 m (MSL), between Ayutthaya and Pathum Thani along the Chao Pharaya River. The design crest elevation of these dikes is 4.0 m (MSL). These dikes will be completed in near future based on the results of the present Study.

(4) Projects which Relate with Flood Mitigation

The Harbor Department has planned a project for construction of two barrages in Chao Phraya River reaches. The main objective of the project is to increase the least available depth, LAD, for navigation so that the size of cargo ships and their tonnage can be increased. The general features of the two barrages are as tabulated below. The locations of the two barrages are as shown in Fig. 1.4.18.

Barrage at Km. 205	The barrage will be located at Km. 205, along the Chao Phraya River from the river mouth in Amphoe Phrom Buri, Changwat Sing Buri. (See Fig. 1.4.19 and refer to Table 1.4.6 for more details.)
Barrage at Km. 345	The barrage will be located at Km. 345, along the Chao Phraya River from the river mouth in Amphoe Phayuha Khiri, Changwat Nakhon Sawan. (See Fig. 1.4.20 and refer to Table 1.4.6 for more details.)

1.5 Water Resources Projects

1.5.1 Dams

In the Chao Phraya River Basin, sixteen (16) dams have been constructed and twenty-nine (29) construction plans are being implemented. Among the constructed dams, there are seven (7) large reservoirs whose effective volume exceeds 100 MCM and the others have less than 100 MCM.

Among the twenty-nine (29) planned dams, seven (7) including one under construction (Pasak Dam) have large reservoirs and the remaining twenty-two (22) dams are classified as small ones. The general features of these dams are shown in Table 1.5.1 and the principal features and locations of the large scale dams are shown in Table 1.5.2 and Fig. 1.5.1, respectively.

The purposes of these large-scale dams are irrigation, power generation, and flood control. However, none of the dam reservoirs have an exclusive volume for flood regulation, and flood control has not been given priority in the determination of release and reservoir operations.

The two giant dam reservoirs, Bhumibol and Shirikit, however, can regulate flood runoff by using the vacant volume above the upper rule curve for reservoir operation which was established to maximize power generation. The other dam reservoirs may also regulate flood runoff to some extent as a result of impounding water. Figs. 1.5.2 and 1.5.3 show the upper rule curves and results of reservoir operation of the Bhumibol and Sirikit reservoirs, respectively.

The flood regulation effects of these dam reservoirs depend upon the reservoir volume used for flood regulation, namely, the vacant volume of the reservoir at the beginning of the flood season (at the end of the dry season). The reservoir volumes of dams in the Chao Phraya River Basin are given in Table 1.5.3.

1.5.2 Trans-basin Water Diversion Plans

To fulfill the possible future water demand, NESDB/RID/JICA is conducting a feasibility study for the Kok-In-Nan Water Diversion Project. This project has been selected from other trans-basin plans such as Salawin River to Bhumibol diversion and Mekong River to Sirikit and Upper Pasak diversion (see General Map and refer to Table 1.5.4). A conceptual planning report was submitted in March 1997. The report is briefly summarized as follows:

(1) Background

The total inflow of the Sirikit Reservoir, operated since 1974, is 5 billion m^3 in normal years and 3.4 billion m^3 in drought years against the active storage of 6.7 billion m^3. However, the water actually released from the reservoir for water use in the downstream in dry season is as low as 2.7 billion m^3, and 1.6 billion m^3 in normal and drought years. This is mainly due to the inevitable carrying over storage of 2 to 3 billion m^3 to cope with the demand in the possible succeeding drought year. Improvement of this condition of the reservoir operation has long been expected by the agency concerned.

(2) Proposed Plan

The proposed plan aims to increase the released water to 5.7 billion m^3 as follows:

- To reestablish the carrying over storage at 1 billion m^3;
- To divert water of the Sirikit Reservoir of a maximum of 2 billion m^3 (175 m^3/s) in flood season from the Kok and Ing rivers to the upstream tributary (Yao River); and
- To store at least 3.7 billion m^3 inflow from the Nan River Basin.

(3) Major Components of the Project

The major components of the project are:

- Kok Diversion Dam (125 m^3/s) and Kok-Ing Diversion Channel (20 km);
- Ing Diversion Dam (175 m^3/s), Lao Diversion Canal (12.4 km) and Ing-Yot Tunnel (50 km); and
- Yao Flood Control Dam (28 MCM) and Yao River Improvement (40 km).

(4) Flood Control Effect

The report states that the project will bring an increase in flood control effect by reducing the carrying over storage from 2 billion m^3 to 1 billion m^3 which, in turn, increases the flood control storage. In addition, 2 billion m^3 of the diverted water may be regulated in case a flood damage is forecast in the downstream of the dam.

2. STRATEGY OF FORMULATION OF THE MASTER PLAN

2.1 Basic Concept of Formulation of the Master Plan

The primary purpose of the Master Plan is to mitigate flood damage in flood prone areas of the Chao Phraya River Basin. The Master Plan has to consider technical and environmental soundness, social acceptability and ease of operation, and economic efficiency is one of the important indices for the selection of the optimum measure among the conceivable options.

Hence, in consideration of the characteristics of flood damage caused by previous floods as discussed in Section 2.5 of Chapter 2 of the main report, the Master Plan is formulated in the following concept:

- According to the past flood occurrence, flood conditions in the Chao Phraya River Basin is featured with the existence of inherent natural retarding area, which plays an important role to retain flood discharge flowing into the Chao Phraya River, resulting in the mitigation of flood damage in the downstream. In this connection, the flood mitigation plan is formulated, putting emphasis on preservation of the natural retarding effect which is the concept of "monkey cheek" practiced in Thailand and also a global concept for flood mitigation through the provision of nonstructural measures.
- On the other hand, the Chao Phraya River basin, especially Chao Phraya Delta tends to be developed continuously in the future, even in such natural retarding area, which results in the decrease of retarding effect causing the increase of flood discharge to the downstream. To minimize the influence due to decrease of retarding effect, suitable measures for comprehensive flood mitigation including structural and nonstructural measures are introduced. The river basin broadly divided into four (4); namely, Upper Central Plain, Nakhon Sawan Area, Higher Delta in Lower Central Plain and Lower Delta in Lower Central Plain, in consideration of the flood damage characteristics in each area.
- Flood mitigation measures are also classified according to the extent of flood, i.e., basin-wide flood or local inland water. In this study, the Master Plan is formulated by putting emphasis on flood mitigation measures for basin-wide flood. As for local inland water, the conceivable measures for drainage system improvement is examined for agricultural areas as well as the prioritization for implementation of improvement works.
- The flood prone areas in the basin are mainly composed of urban and agricultural areas. Among them, the urban areas will take priority for flood protection because their social and economic impacts are considerably much higher than the agricultural areas. Urban areas like Bangkok, Ayuthaya, Nakhon Sawan and others are to be protected by effective measures against bigger scale floods.
- The agricultural areas play an important role as retarding area during big scale floods, and this role should be preserved. On the other hand, for small-scale floods, the present flood damage condition should be improved, providing suitable measures within the allowable extent, in which measures will not cause any adverse influence to the other areas.
- Flood damage conditions are influenced by nonstructural measures such as control of land use and groundwater extraction, and such influence would finally affect the effectiveness of structural measures. In this connection, the selection of optimum measure is made through a comparative study of alternatives, considering the most effective combination of structural and nonstructural measures.
- In general, higher priority of flood damage mitigation is given to the downstream reaches to minimize the adverse influence of flood mitigation measures adopted in the upstream. Thus, the project scale in the downstream is set higher than the upstream.

- Although the primary purpose of the Master Plan is flood mitigation, it is also important to consider the shortage of municipal water supply in the dry season. The multipurpose use of the proposed flood mitigation measures is thus examined, especially for irrigation and municipal water supply.

2.2 Basic Conditions for the Formulation of Master Plan

Based on the above concept, the following conditions are applied for the formulation of the Master Plan.

2.2.1 Target Project Completion Year

The year 2018, which is 20 years after the completion of this study, is applied as the target year, considering the target years for related development projects as shown in Table 2.2.1.

2.2.2 Project Scale

(1) Project Scale for the Protection of Major Urban Areas

In the previous studies and plans, the proposed protection works for major urban areas such as Bangkok metropolitan area and the provincial capitals adopted the project scale of 100-year return period. Among these works, the flood barrier along the Bangkok core area is under construction, while the flood protection works for the other urban areas such as provincial capitals and several municipalities are under detailed design, master planning or feasibility study.

Therefore, to be consistent with these previous plans, it is desirable to apply the same project scale for the protection of major urban areas along the Chao Phraya River. The project scale of 100-year return period is thus applied for the protection of urban areas.

(2) Project Scale for the Protection of Agricultural Land

For the protection of agricultural land, the project scale is not clear in the previous studies. However, according to the interview survey with the agencies concerned, RID has been promoting protection works with the project scale of 25-year return period. Thus the project scale of between 5 and 25-year return period currently protect most of the agricultural lands.

In this study, the appropriate project scale for the Master Plan has been decided, considering the economical and social aspects as well as the current flood control plan.

2.2.3 Expected Future River Basin Condition

River basin conditions are rapidly changing and some of the changes may seriously affect the flooding condition. The following factors that coincide with the target project completion year of the Master Plan are considered to be contributory to the future flooding condition (refer to Fig. 2.2.1).

(1) Ring Levee with Drainage System Improvement for the Protection of Urban Areas

The construction of a ring levee with drainage system improvement for urban areas is considered as one of the factors that could seriously affect the flooding condition in the future. The project will result in the increase of flood discharge to the Chao Phraya River.

In this connection, it is expected that urban areas suffering directly from the damage caused by floods of the Chao Phraya River are to be protected by the construction of a ring levee together with drainage system improvement. These areas are:

- Bangkok Metropolitan Area
- Fourteen (14) provincial capitals (Sukhothai, Phitsanulok, Phichit, Nakon Sawan, Chainat, Sing Buri, Ang Thong, Ayuthaya, Pathum Thani, Nonthaburi, Samut Prakan, Supanburi, Samutsakon and Saraburi)
- Eighteen (18) municipalities (Sawankalok, Ban Mun Nak, Taphan Hin, Chumsaeng, Krok Phra, Phayuha Khiri, Watsing, In Buri, Phrom Buri, Pamok, Bang Luang, Bang Pho Thai, Katumban, Aomnoy, Phapntabat, Nongkhea, Keangkoy and Songpeenong)

The locations of these areas are as shown in Fig. 2.2.1. The drainage capacities from the urban areas to the river are as shown in Table 2.2.2 and Figs. 2.2.2 and 2.2.3. For the areas with no drainage system improvement plan, the capacity of the drainage facility is presumed on the basis of figures from the feasibility study and detailed design (refer to Fig. 2.2.4).

(2) Land Subsidence

Land subsidence in the BMA and neighboring areas is one of the factors which will seriously affect the flooding condition, mainly in the following manner (refer to Fig. 2.2.5):

- Decrease of flow capacity of the Chao Phraya River around the Bangkok metropolitan area, because the dike height may also decrease in accordance with the subsidence.
- Decrease of capacity of drainage channel and pump due to lowering of height of drainage channel and pumping station compared to the water level at the outlet.

Several studies have been conducted as to land subsidence. Among them, the following are specified:

- Study on Management of Groundwater and Land Subsidence; JICA, 1995.
- Master Plan for Basic Infrastructure Systems and Preliminary Design for the Flood Protection and Drainage System in Eastern Suburban Bangkok; BMA, 1996.

The former study presented nine (9) scenarios to predict future land subsidence based on the tendency of groundwater abstraction by pump. The latter study presumed the future land subsidence of 2 cm/year for the formulation of a drainage improvement project with 2006 as the target year. The land subsidence of 2 cm/year corresponds to the average land subsidence among the said nine scenarios in the former study. (Refer to Fig. 2.2.6)

Based on the latter study, BMA is implementing the project to raise the height of dikes as flood barrier. BMA assumes that this height of dike is maintained for adoption by projects proposed in the future, because piles are driven 20 m deep under the river dike to minimize the influence of land subsidence. However, the effect was hardly evaluated in a quantitative manner by the previous study results.

In this present study, the following two scenarios are prepared:

- The dike height is maintained and is adopted as the design dike height in the future.
- The present dike is lowered due to land subsidence at the rate of 2 cm/year in the future.

(3) Road Development Plan

The road development plans will also affect the flooding condition because the constructed roads may function as barrier in the flood prone area. At present, the major road development plans are the Outer Ring Road and the Truck Route. Their outline and cross-sections are as shown in Figs. 2.2.7(1/2) and 2.2.7(2/2).

These road development plans are proposed to have an embankment of 90 cm in height above the recorded maximum inundation water level and this will change the behavior of inundation water. It is thus necessary to consider such condition for the formulation of the Master plan, so that the future flooding condition is examined in this study, assuming that these road development projects are completed.

(4) Channel Loop-cut at Bangkok Port

In principle, the optimum river improvement plan is to be proposed in this study. However, there are some ongoing plans for river improvement to protect urban and agricultural areas. Among them, the cutting of the channel loop at Bangkok Port is specified as follows:

To shorten the drainage path and to increase the flow capacity by making a steeper gradient, the project of cutting off the loop at Bangkok Port is ongoing and it is expected to be completed in a few years (refer to Fig. 1.4.3). By cutting off the loop, the flow capacity of the Chao Phraya River channel through Bangkok will increase from 130 to 440 m^3/s depending on the tide water level during a flood peak of 3,000 m^3/s.

In this study, therefore, the Master Plan is formulated assuming that the channel loop-cut is completed.

(5) Future Change of Land Use

Information on present land use condition was obtained from the GIS data of the Ministry of Agriculture and Cooperative in 1997. Based on the data, the present land use was examined by dividing the flood prone area into four (4) sub-basins: Upper Central Plain, Nakhon Sawan Area, Higher Delta in the Lower Central Plain, and Lower Delta in the Lower Central Plain. Considering the present land use, the future land use was mapped out in the following manner.

(a) Increase of Urban Area

In the flood prone area, urban development is being promoted mainly on adjacent urban areas. Although there is no statistical data showing the increase of urban area, DTCP has urban development plans for major cities in the basin. In this study, it is assumed that the urban areas will increase in accordance with the urban development plans prepared by the DTCP.

(b) Change of Agricultural Land

The above increase of urban area comes as a result of the change of land use of agricultural lands. In addition to this, land use in agricultural lands has also changed as to crops cultivated such as paddy to field crops or paddy to fruits trees.

In the study entitled "Chao Phraya Basin Water Management Strategy (October 1997)," the future change of cultivated crops has been prospected in three (3) scenarios, i.e., high, medium and low, considering several factors such as past trend, relation between supply and demand and so on. Among these scenarios, the medium case, which seems to have a higher possibility, is adopted in this present study.

(c) Change from Forest to Agricultural Land

The development of agricultural area converted from forest areas through logging has been observed in the upper stream reaches. Although the data to show the future change of these lands are not available, the Master Plan is formulated assuming that the present agricultural and forest areas will be maintained in the following viewpoint:

The tendency of change of agricultural and forest areas seems to have subsided; i.e., agricultural land will not increase for increment of rice production, but diversification from traditional variety to high yield variety will be performed, and the existing forest area will be conserved in future through reforestation.

(6) Drainage System Improvement Plan in Agricultural Land

There is one ongoing drainage system improvement plan called "Monkey Cheek Improvement" (refer to Fig. 1.4.8). Since the improvement plan could be implemented within a few years, this present study is conducted assuming that the drainage project is completed before the target year 2018.

(7) Dam Projects

In the context of water resources development, there are several dam projects. Among them, the following dam projects have been planned and/or being implemented independently from this Study. In this Study, the Master Plan is formulated assuming that the dam construction projects are completed before the target year 2018 (refer to Chapter 5 of the main report). These dams are:

- Pasak Dam (under construction)
- Keaen Sua Teng Dam (under planning)
- Kuae Noi Dam (under planning)

(8) Other Related Projects

As for the other related projects, there are several ongoing projects at present. Among them, the following projects are assumed as completed before the target year 2018 (refer to Fig. 1.4.18 and the General Map):

- Damming Chao Phraya Project (under planning)
- Kok-Ing-Nam Project (under planning)

2.2.4 Future Flooding Condition

In combination with the future development and flood mitigation works, the flooding condition will change. Such change of flooding condition is evaluated using a simulation model. The following points are specified by the simulation results (refer to Table 2.2.3 and Fig. 2.2.8):

(1) Upper Central Plain (Upstream of Nakhon Sawan)

In the upper river basin, the major land uses are composed of agricultural area and several urban areas and flood damage due to poor river channel capacity are reported in these areas. As the future condition, drastic change in land use is not expected, although protection works for urban areas such as Sukhothai and Phitsanulok will be promoted.

According to the simulation results, it is revealed that the flooding condition will not change from the present situation and protection works for urban areas will not bring about severe adverse influence so much.

(2) Nakhon Sawan Area (between Nakhon Sawan and Chainat)

In the Nakhon Sawan area, the situation is similar to that in upper central plain. The flooding condition will not change from the present condition and protection works for urban areas will not bring about severe adverse influence so much.

(3) Higher Delta in Lower Central Plain (between Chainat and Ayuthaya)

In the higher delta in lower central plain, the change of agricultural land use in a manner of diversification as well as change of cropping pattern in paddy fields has been progressing. The urban area is also expanding and protection works for urban areas such as Chainat and Ayuthaya will be promoted. Since the diversification is mainly made from paddy to cash crops that are vulnerable to flood damage, flood damage tends to increase. However, as far as the simulation results are concerned, any change of flood discharge is not observed and severe adverse influence to the downstream is not expected.

(4) Lower Delta in Lower Central Plain (Downstream of Ayuthaya)

In the area, the change of land use is severe. Urbanization has been rapidly progressing and protection works for urban areas such as Pathum Thani and Nonthaburi will be provided.

The adverse influence mainly caused by protection works for Pathum Thani and Nonthaburi is quite large to downstream Bangkok. Hence, the safety level of Bangkok is expected to lower from 100-year return period to 10-year return period (refer to Figs. 2.2.9 and 2.2.10).

2.3 Major Issues Considered for the Master Plan

Under the above circumstances, the issues emphasized for the Master Plan are as follows (refer to Table 2.3.1):

(1) Upper Central Plain and Nakhon Sawan Area

In these areas, the following points are considered:

- For the urban areas, they will be protected at the scale 100-year return period and the protection works will not bring severe adverse influence to the downstream.
- For the agricultural areas, flood damage will still occur in the future. Therefore, it is considered to provide protection works for the agricultural areas to mitigate flood damage. However, such protection works will result in the reduction of natural retarding effect and bring about an adverse influence to the downstream.

Hence, the following issues are emphasized for flood mitigation in these areas:

- To seek measures to mitigate flood damage in agriculture areas and not to cause adverse influence to the downstream, or
- To seek the allowable extent to which flood damage is mitigated, providing countermeasures to absorb adverse influences.

(2) Higher Delta in Lower Central Plain

In addition to the condition in the upper central plain and Nakon Sawan area, the following points are considered:

- In the area, change of land use condition is progressing, so that flood damage tends to increase.
- Since the agricultural area plays an important role as natural retarding basin, it is necessary to consider the preservation of this effect.
- Since the paddy field is widely inundated and suffering from flood damage, it is necessary to consider mitigation of flood damage in the paddy fields.

Hence, the following issues are emphasized for flood mitigation in these areas:

- To control and guide the change of land use so that flood damage will not increase and the effect of the natural retarding basin will be maintained.
- To seek measures to mitigate the flood damage in agricultural areas.
- To seek measures to mitigate the flood damage in paddy fields, maintaing the natural retarding effect.

(3) Lower Delta in Lower Central Plain

In the area, the following points are considered:

- In the area, change of land use condition is severe, especially urbanization, so that flood damage tends to increase and the natural retarding effect will decrease.
- Since the protection works for Pathum Thani and Nonthaburi bring about severe adverse influence to Bangkok, it is necessary to consider measures to cope with the adverse influence.
- Since paddy fields are widely inundated and suffering from flood damage, it is necessary to consider the mitigation of flood damage in the paddy fields.

Hence, the following issues are emphasized for flood mitigation in these areas:

- To control and guide the change of land use so that flood damage will not increase and the effect of the natural retarding basin will be maintained.
- To seek measures to cope with the adverse influence.
- To seek measures to mitigate the flood damage in paddy fields, maintaining the natural retarding effect.

2.4 Strategy of Formulation of the Master Plan

2.4.1 Procedure of Formulation of the Master Plan

The Master Plan is composed of several conceivable measures, which are classified into structural and nonstructural ones, as shown in Fig. 2.4.1.

In principle, alternative cases to select the optimum measure are set by the combination of these conceivable measures. However, the number of alternative cases by the combination of applicable measures is so large that it may not be practicable to examine all of them. To facilitate the selection of the optimum measure in this study, the following steps were taken:

(1) First Step: Preliminary Selection of Applicable Measures

The applicability and necessity of measures among the conceivable ones are preliminary examined considering their features. Through the preliminary examination, the measures to be included in the master plan were identified. Also, the measures, which need a further study to evaluate effectiveness in a quantitative manner, are identified.

(2) Second Step: Evaluation of Measures based on the Simulation Model

The effectiveness is evaluated based on the simulation model for measures identified with the necessity of further study in the first step. The necessity of further study for optimization of measures in combination with other measures is also identified, considering the effectiveness of the measures.

(3) Third Step: Selection of Measures in Combination with Other Measures

The optimization of measures in combination with other measures is made for those identified having the necessity of further study. For the optimization, the cost and effectiveness of each combination are roughly calculated to identify the economic advantage.

Through the economic comparison among the measures mentioned above, the optimum combination is selected. The Master Plan is composed of the optimum combination together with the measures identified to be applicable in the first step.

2.4.2 Selection of Optimum Case, Preliminary Design and Cost Estimate

(1) Formulation of the Master Plan

The Master Plan is formulated to consist of the optimum combination of measures including measures whose applicability has been identified.

(2) Preliminary Design of Proposed Structural Measures

For the preliminary design of structural measures proposed to mitigate the flood damage, the specific items such as location and dimensions are determined.

(3) Cost Estimate

Project cost is estimated on a preliminary level by calculating construction cost, operation/maintenance cost and land acquisition cost for each structure, applying the exchange rate as of December 1998; namely, $1.00 = ¥115.7 = 36.5 Baht.

(4) Implementation Plan

Among the measures selected, the priority for implementation is examined considering cost-effectiveness, easy implementation, social and environmental impacts, and others. A phased implementation plan is prepared for the structural measures based on their priority, organizing the most preferable work schedule for all the structures proposed in the study area

2.4.3 Evaluation of the Master Plan

The proposed Master Plan is evaluated in terms of technical soundness, economic viability, social acceptability and environmental sustainability. Among them, technical soundness and social acceptability are evaluated through the confirmation of previous practices on the application of structural measures. The economic viability and environmental sustainability are examined in the following manner.

(1) Economic Viability

The economic viability of the Master Plan is examined in terms of internal rate of return (IRR), benefit-cost ratio (B/C) and net present value (NPV), comparing the economic project cost and annual average benefit which may accrue in accordance with the expected cost-benefit flow in the project life. The benefit and cost are obtained based on the following procedure.

(a) Annual Benefit

Major flood control benefit is defined as the reduction of potential flood damage attributed to the provision of structural measures. The reduction is obtained as the difference between the estimated flood damage under the with- and the without-the-project situations.

The annual average benefit or potential flood damage is calculated by mesh units (5km x 5km), applying the inundation depth obtained from the flood inundation analysis. Such benefit or flood damage is estimated at the development stage in the target completion year 2018.

(b) Economic Cost

For the economic evaluation, the aforementioned project cost is converted to economic cost, which is a nominal figure reflecting the true economic value of goods and services involved. For the purpose, transfer items such as taxes and duties imposed on construction materials and equipment, including government subsidy and contractor's profit, are excluded from the elements of financial cost.

(2) Environmental Sustainability

The optimum measure among all conceivable measures is selected. During the master plan study stage, IEE (Initial Environmental Examination) is conducted to assess the selected alternatives from the environmental point of view.

(a) Parameters included in the IEE

In April 1979, the National Environmental Board issued a manual, Guidelines for Preparation of Environmental Impact Evaluations, which also mentions IEE. According to the Guidelines, parameters for the IEE should be the same as in a full-scale environmental study (EIA). However, the Guidelines provide parameters only for the following project types that require EIA:

"Agro industries, Coastal zone development, Dams and reservoirs, Dredging and filling, Highways, Housing projects, Human settlements, Industrial estates, Industries, Institutions, Mining, Nuclear power, Offshore mining, Oil pipelines, Ports and harbors, Rapid transit projects, Thermal power, and Land drainage."

The alternative measures proposed in this study may not be included in these project types and, therefore, may not be obligated by law to undergo the official EIA process. However, the environmental impact of measures adopted in this study may not be negligibly small; therefore, it is necessary to abide by the Guidelines.

Since the Guidelines do not stipulate any suitable set of parameters for proposed flood control measures, a customized set of parameters as shown in Table 2.4.1 is used for the IEE of each alternative measure.

(b) Extent of the Study for IEE

The Guidelines state that the objective of IEE is "to reach a decision on whether such evaluations (detailed evaluation of each environmental parameter) are needed." However, it is also stipulated that "if the conclusion of the study is that an EIS (detailed evaluation) is not needed, IEE will serve as EIS." Therefore, it is important that IEE is arranged in a manner to satisfy this purpose.

(c) Evaluation in the IEE Stage

In principle, the IEE will cover similar contents as the EIA except that the evaluation is done based on readily obtained information. It has four major components, as follows:

- Description of proposed measures.
- Discussion of probable environmental effects caused by proposed measures according to the parameters shown in the above table together with the references used for the evaluation.
- Tabulation of impacts found in initial evaluations as the summary.
- Conclusions including comments on the necessity of further study.

3. STUDY ON APPLICABLE MEASURES

In accordance with the strategy discussed in Section 2, the applicability of conceivable structural and nonstructural measures are preliminary examined, as the first step, assuming that these measures are individually applied. Then, the effectiveness of some of these measures is evaluated in a quantitative manner, as the second step, based on the simulation model. Herein, the discussion is made on these steps, and the applicability of measures is preliminarily identified.

3.1 Preliminary Selection of Structural Measures

3.1.1 River Improvement

(1) Consideration of River Condition Based on the Flow Capacity

The Chao Phraya river channel has been improved so far in accordance with the RID design criteria as shown in Fig.3.1.1. According to the figure, some parts of the stretch have the safety level of 25-year return period based on the frequency analysis for observed water level. However, the probable water level may have a deficiency for evaluation of change of basin conditions such as river improvement and flow control in the upstream. In this section, the flow capacity of the river channel is reevaluated based on the probable discharge.

(a) River Condition of Upstream of Nakhon Sawan

The flow capacity of Yom River is quite small along almost all the stretches from Sukhothai to Nan River. The flow capacity at Sam Ngam, Y.17 is about 900 m^3/s, which is less than the 2-year discharge. There is a bottleneck at the downstream of Sukhothai, which has a flow capacity of only 50 m3/s.

The flow capacity of Nan River is also small. The flow capacity is between 1,000 m^3/s and 1,500 m^3/s, while the 2-year discharge is 1,100 to 1,300 m^3/s according to the simulation result. The lower stretches near Nakhon Sawan is influenced by backwater from the Chao Phraya River. Water levels in these stretches are possibly raised high over the dike levels by the backwater even when the river discharge is small.

(b) River Condition of Downstream from Nakhon Sawan to River Mouth

The Chao Phraya River System from Nakhon Sawan to the Lower Delta (from Nakhon Sawan to the river mouth) has a very complicated channel network. The Chao Phraya River has distributaries, the Tha Chin, Noi, Lop Buri Rivers and a tributary, the Pasak River. In addition, many khlongs connects these rivers.

The flow capacity decreases toward the downstream, from 4,000 m3/s at Chao Phraya Dam (corresponding to the 3-year discharge) to 3,000 m3/s in Bangkok (much less than the 2-year discharge). This implies that spillage from the river channel gradually occurs in the upstream when a large scale flood occurs; hence, spillage do not concentrate in the downstream. This situation contribute to alleviation of flood damage to Bangkok, while the spilled water is widely retained in the agricultural area in a manner of inundation.

The flow capacity in Bangkok is as small as 3,600 m^3/s even after the completion of the on-going flood barrier dikes.

(2) Strategy of River Improvement

(a) River Training of Upstream from Chainat

(i) Yom River

For the Yom River, it is drastically necessary to improve the river channel to raise the safety level even up to a 5-year return period. The river channel improvement is examined in the following manner:

- In the Yom River, there is a restriction for river improvement, i.e., at Sukho Thai City, the urban area has developed along the river course so that it may be difficult to improve the river in this section. To cope with this restriction, the construction of a bypass channel is considered in this stretch.
- To increase the flow capacity of the bottleneck situated downstream of Sukho Thai, improvement of the river channel in a manner of widening and embankment is proposed.
- Likewise, for the river training of other sections, the flow capacity is increased in a manner of widening of river channel and embankment.

(ii) Nan River

For the river improvement of Nan River, the following principles are applied:

- Since the Nan River has a relatively large flow capacity, only minor improvement is proposed in a manner of embankment.
- Also, in the stretch near the confluence with Ping River, the flow capacity is increased in a manner of embankment in the stretch or widening of downstream stretch to lower the influence of backwater.

Needless to say, the river training results in the increase of flood discharge in the downstream, an adverse influence. As discussed later, the river improvement in the downstream has some restrictions at the Bangkok metropolitan area, so that it is necessary to minimize such an adverse influence to the downstream. In this connection, the river improvement in the upstream is proposed, considering the above situation.

(b) River Improvement of Downstream from Nakhon Sawan to the River Mouth

In case of river training for the stretch from Nakhon Sawan to the river mouth, the following consideration is made:

Most of the sections in the river channel are full of discharge during major flood events. Therefore, partial river improvement to increase the flow capacity at any section will possibly result in increase of spilled discharge somewhere in the downstream which may finally affect the Bangkok metropolitan area as an adverse influence.

Consequently, for the river training of the Chao Phraya River, it is essential to improve the whole stretch including Bangkok so as not to cause adverse influence by partial river improvement. It is, however, understood that river improvement further than the ongoing project in the Bangkok section has less possibility, and thus, the training of the Chao Phraya River has the following restrictions:

- River improvement for the whole stretch may not be preferable due to the restriction on river improvement at the Bangkok metropolitan area. Even on a small scale with a flow capacity of over 3,000 m^3/s corresponding to the 5-year return period probable discharge at Chainat, the Bangkok metropolitan area may have flood damage.
- Only partial improvement on a minor scale may be possible in the stretch, where an adverse influence to the downstream is not severe, or where a combination of other measures to minimize the adverse influence is applicable.
- Among the other measures to minimize the adverse influence, retarding basin and diversion channel may be considered.

(3) Further Study Cases for Optimization

Although river improvement has such restriction, it is still one of the essential measures to mitigate flood damage. In this connection, further study for optimization is necessary for the scale of river improvement in combination with the other measures. The several cases of flood discharge corresponding to between a 2-year and 25-year return period are thus further examined to optimize the scale of river training in both upstream and downstream:

The distribution of flood discharge to each distributary is based on the ratio of the present discharge distribution.

3.1.2 Flood Diversion Channel

A flood diversion channel is considered as a measure to mitigate flood damage in the downstream from Nakhon Sawan to the river mouth. There are several alternative routes conceived for the flood diversion channel and the optimum flood diversion channel route is selected in the following manner:

(1) Hydraulic Calculation Condition

(a) Objective Discharge

To select the optimum diversion channel route, the following discharge cases are examined:

- Case-A: 1,500 m^3/s
- Case-B: 1,000 m^3/s
- Case-C: 500 m^3/s

(b) Water Level at River Mouth

MSL +1.6 m is adopted as the water level at the river mouth, which is the high tide in flood season.

(c) Roughness Coefficient

Roughness coefficient of 0.025, which is generally adopted for artificial channels in Japan, is applied.

(2) Alternative Routes

There are ten (10) alternative routes of flood diversion channel consisting of those previously and newly proposed, as shown in Fig. 3.1.2. Among them, the alternatives previously proposed in the 1980's, which are to divert flood discharge from the upstream point near Bangkok, have not been implemented due mainly to huge cost and social impacts. However, those proposals are worthy of examination considering the magnitude of recent flood damage.

On the other hand, to lighten such social impacts as well as the cost using the existing river or irrigation channel and sparsely populated area, new routes diverting further from the upstream such as points near Chainat and Ayuthaya are considered.

The following ten (10) alternative routes of diversion are proposed. The outline of alternative routes is shown in Table 3.1.1.

(a) *Case 1:* Tha Chin River Diversion (newly proposed)

This route aims at full utilization of the existing Tha Chin River and the diversion point is proposed to be near the Chainat point.

(b) *Case 2:* Chainat-Pasak-Raphipat-Sea Diversion (newly proposed)

This route aims at utilization of the existing irrigation canal of Chainat-Pasak-Raphipat, and the diversion point is proposed to be near the Chainat point as in Case 1.

(c) *Case 3:* Chainat-Pasak-Raphipat-Ban Pakong Diversion (newly proposed)

This alternative is based on the route proposed in Case 2, but with the utilization of Ban Pakong River. The route aims at utilization of the existing irrigation canal of Chainat-Pasak-Raphipat and Ban Pakong River, and the diversion point is proposed to be near the Chainat point as in Case 1.

(d) *Case 4:* Pasak-Raphipat-Sea Diversion (newly proposed)

This route is the same as Case 2, but the stretch is only the downstream from the confluence point of the Chainat-Raphipat Irrigation Canal with the Pasak River. The purpose of this diversion channel is to reduce the discharge from the Pasak River, which has a great influence on the peak discharge of the Chao Phraya River.

(e) *Case 5:* Pasak-Raphipat-Ban Pakong Diversion (newly proposed)

This route is the same as Case 3, but the stretch is only the downstream from the confluence point of the Chainat-Raphitpat Irrigation Canal with the Pasak River when Case 4 is applied. The purpose of this diversion channel is also to reduce the discharge from the Pasak River, which has a great influence on the peak discharge of the Chao Phraya River.

(f) *Case 6:* Ayuthaya-West Bank-Sea Diversion (newly proposed)

This route aims at utilization of the existing West Bank Irrigation Canal. The diversion point is proposed to be near the Ayuthaya point and the route is directly connected to the Sea.

(g) *Case 7:* Ayuthaya-West Bank-Tha Chin Diversion (previously proposed)

Similar to Case 6, this diversion route is proposed to divert near the Ayuthaya point aiming at utilization of the existing West Bank Irrigation Canal, but connected to Tha Chin River on the way, not to the Sea.

(h) *Case 8:* Ayuthaya-East Bank-Sea Diversion (newly proposed)

This route aims at utilization of the existing East Bank Irrigation Canal, and the diversion point is proposed to be near the Ayuthaya point.

(i) *Case 9:* Chao Phraya II Diversion (previously proposed)

This alternative is based on the route previously proposed.

(j) *Case 10:* Greenbelt Diversion (previously proposed)

This alternative is also based on the route previously proposed.