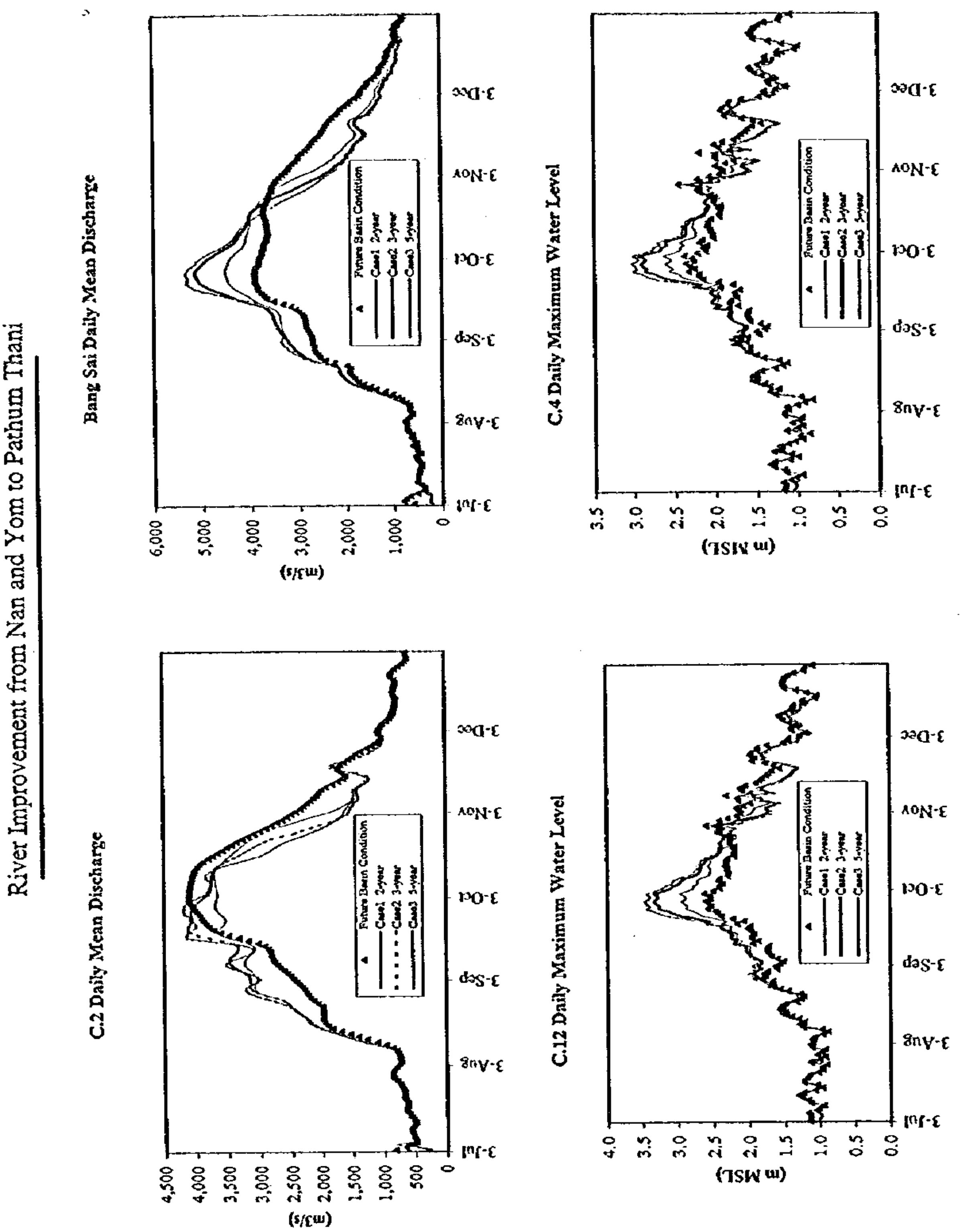

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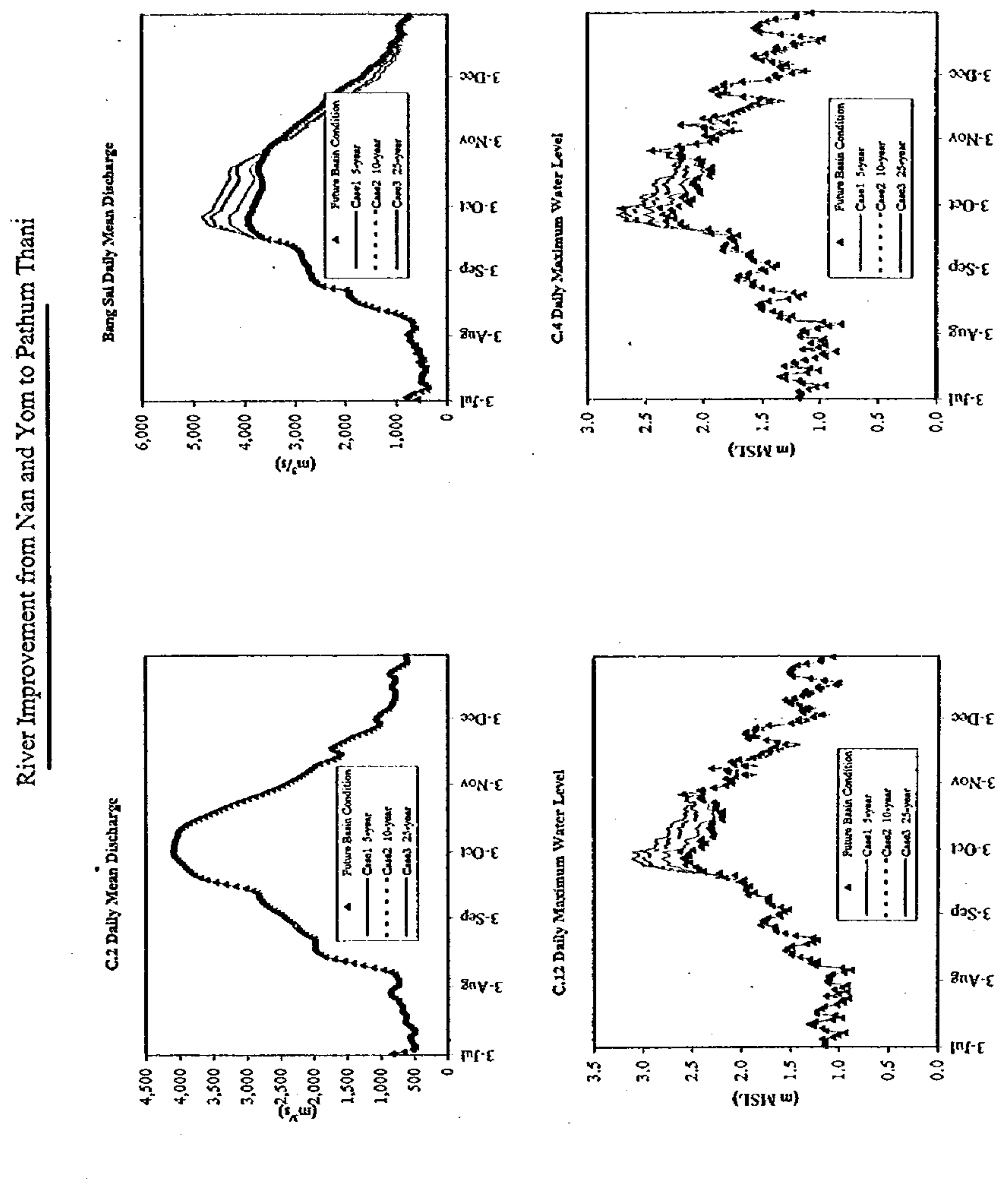

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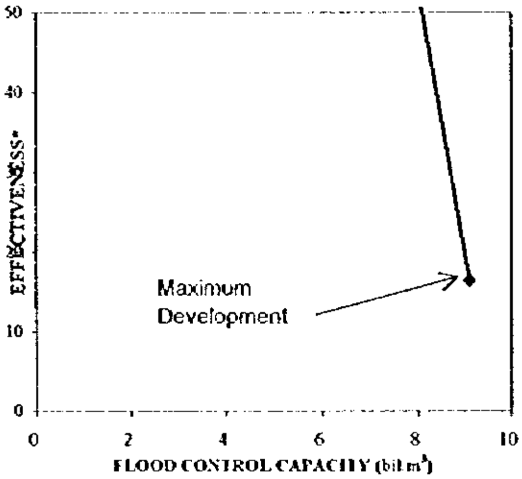
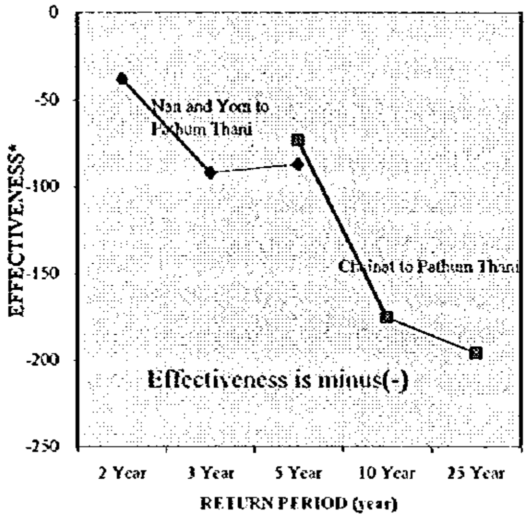
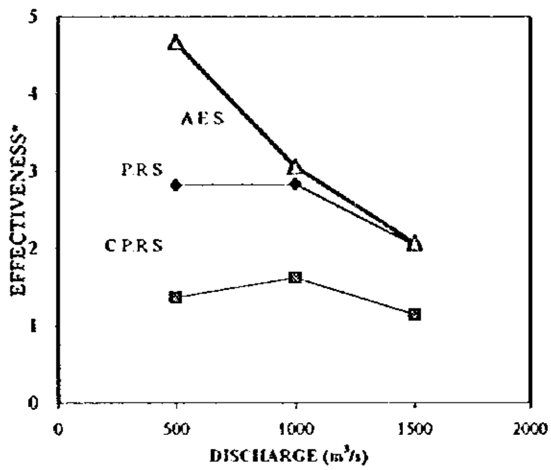


RIVER IMPROVEMENT



DIVERSION



*:Effectivness is expressed in a manner of decrease of flood damage in 1995 by cost.

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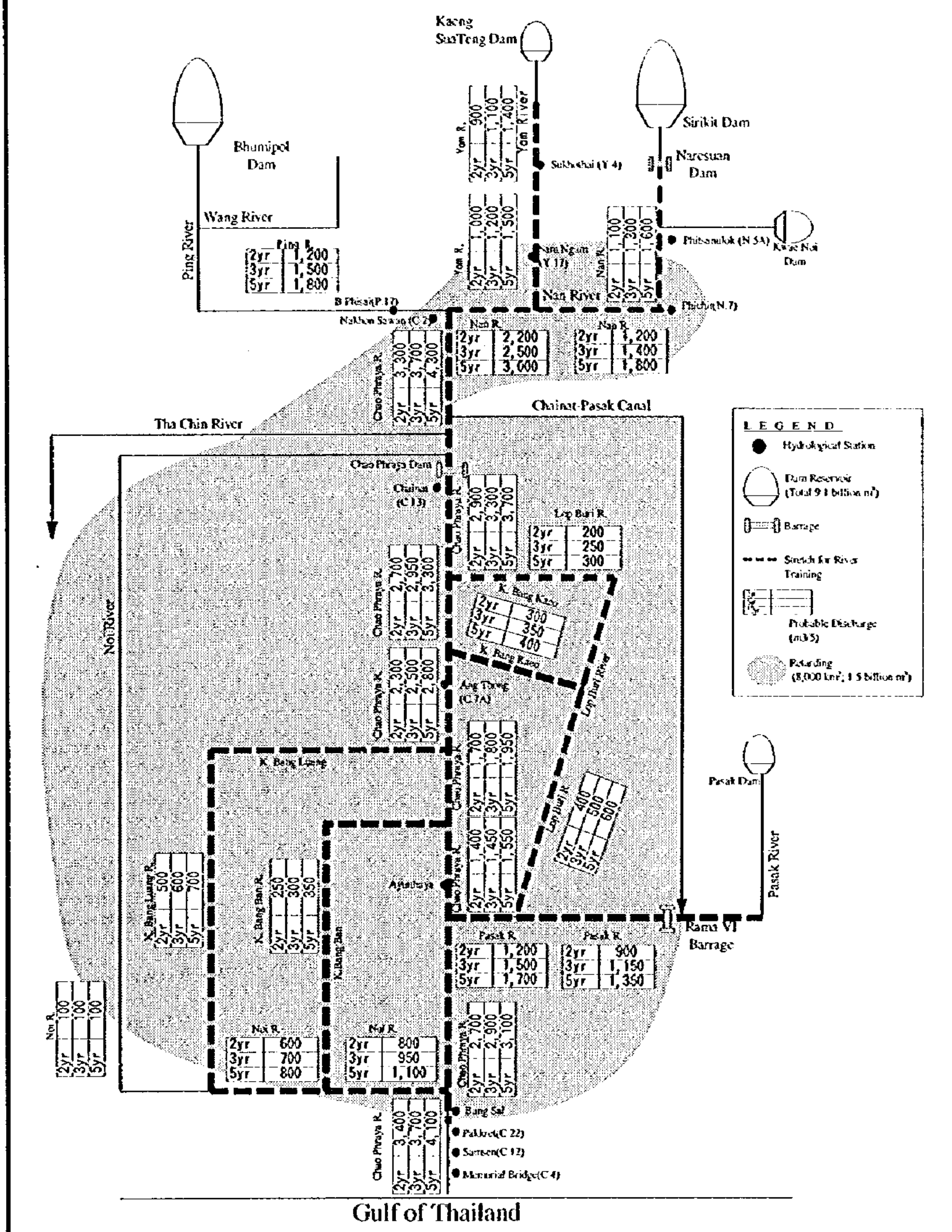
From Nan and Yom to Pathum Thani



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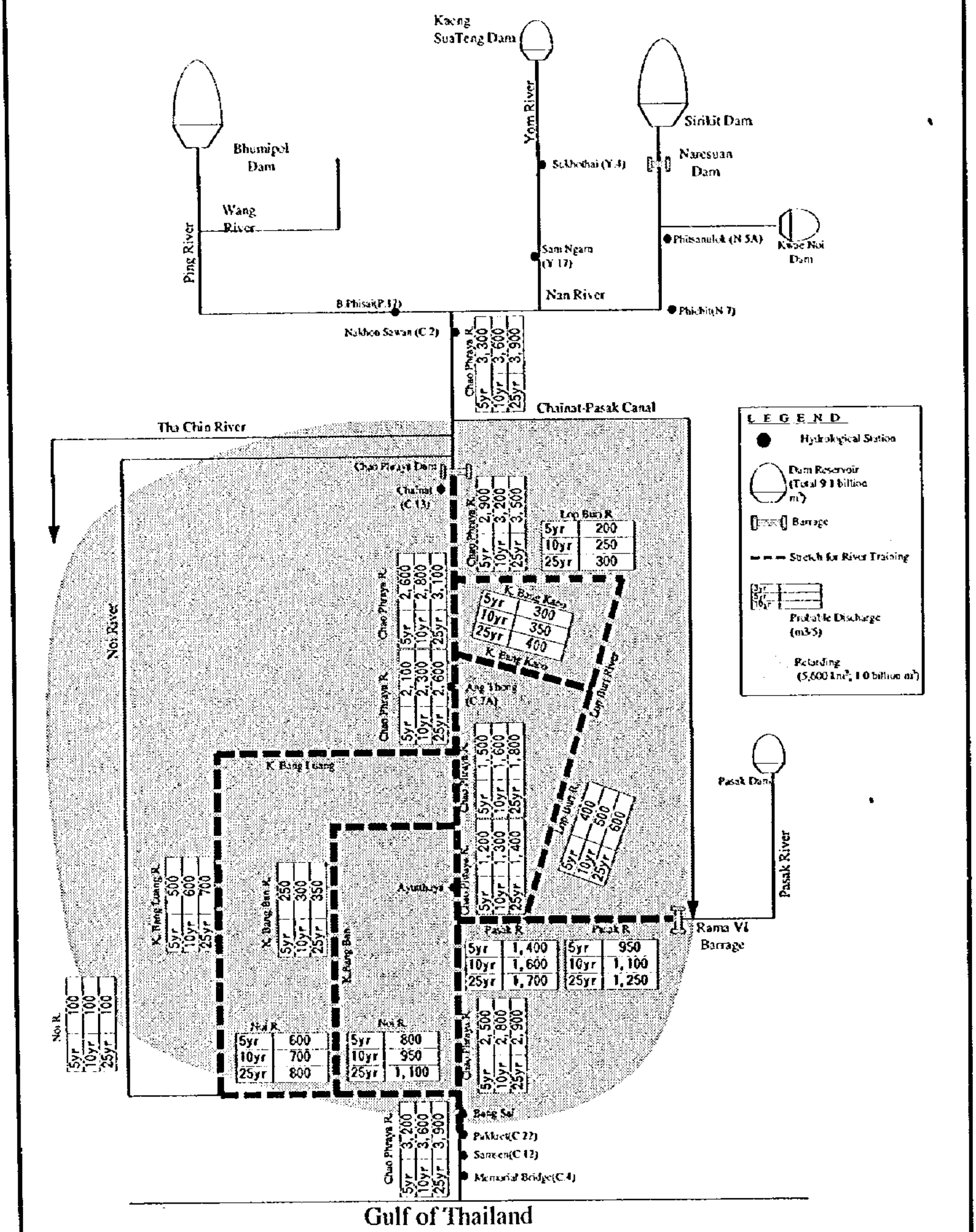

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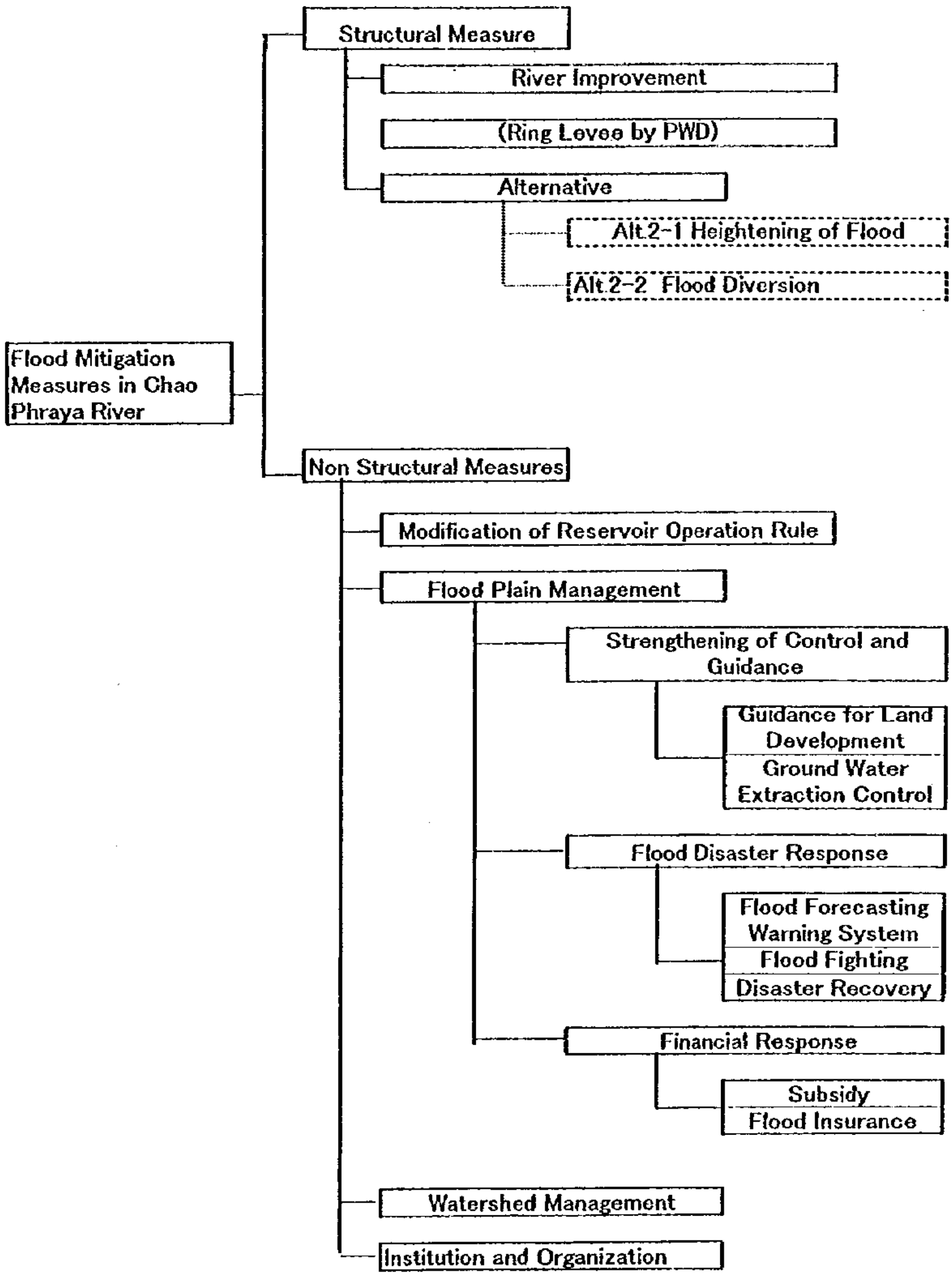

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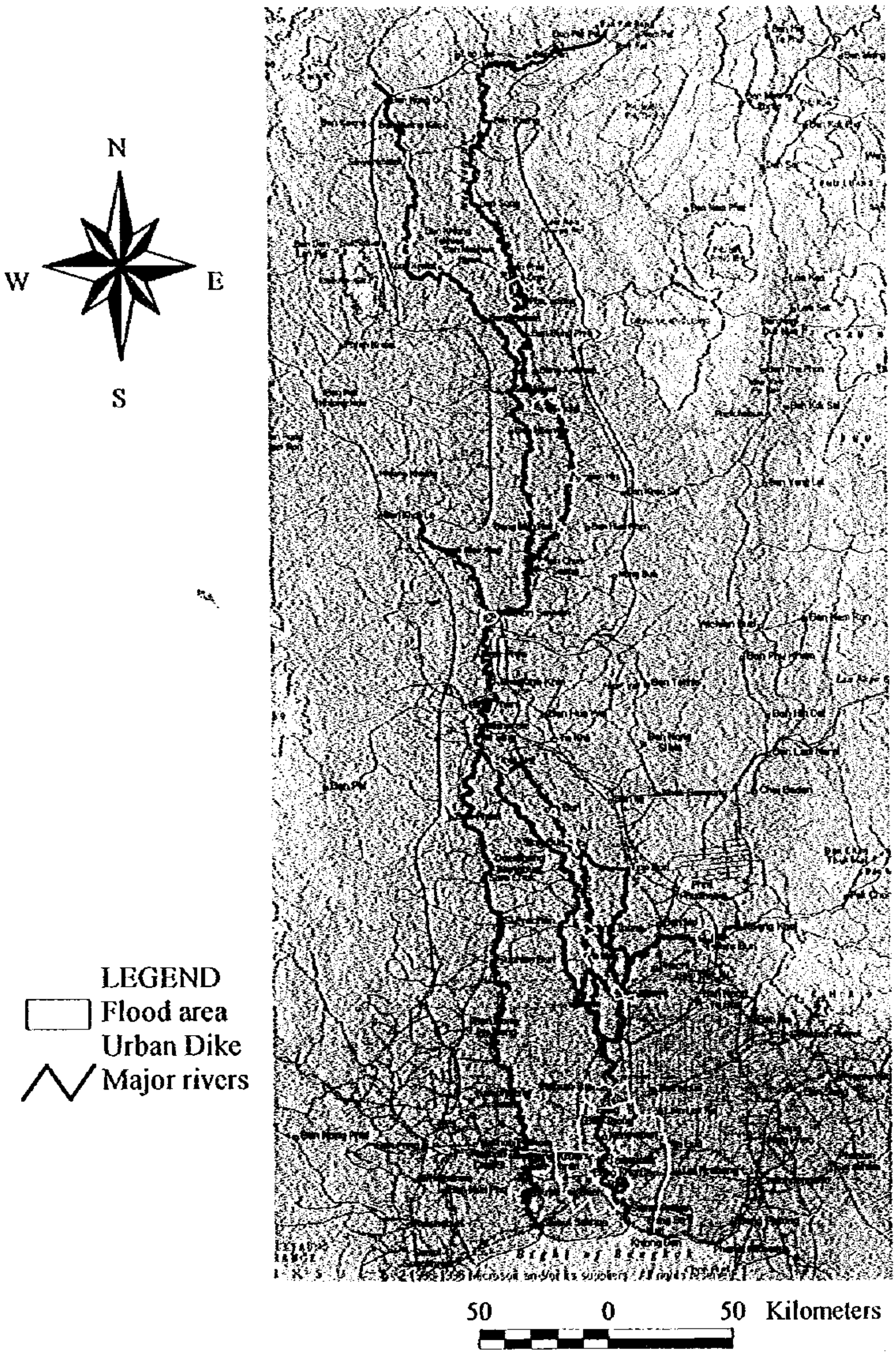

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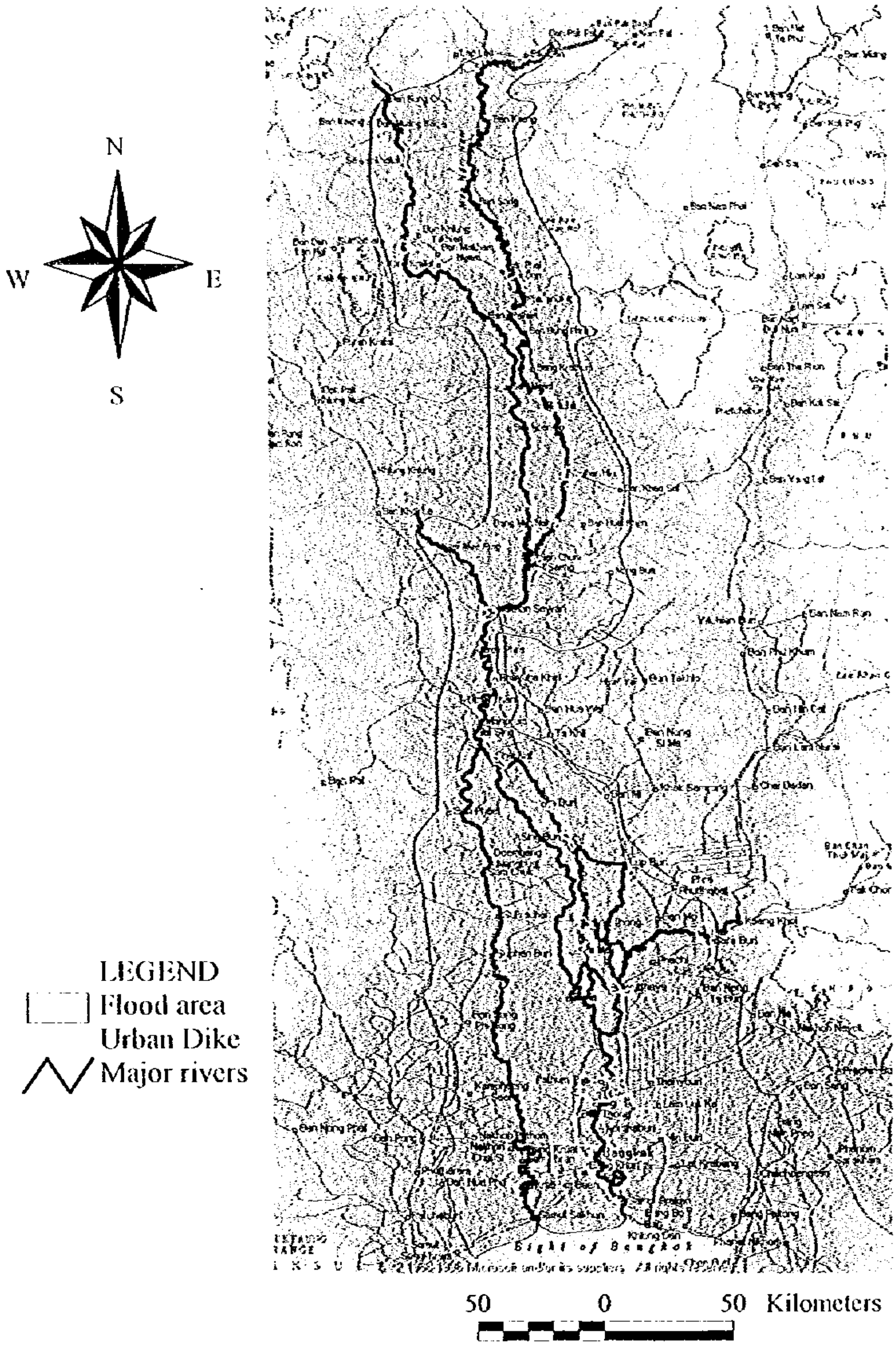

STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAOPHYARA RIVER BASIN	Fig 3.1.1 URBAN PROTECTION DIKE IN 2005
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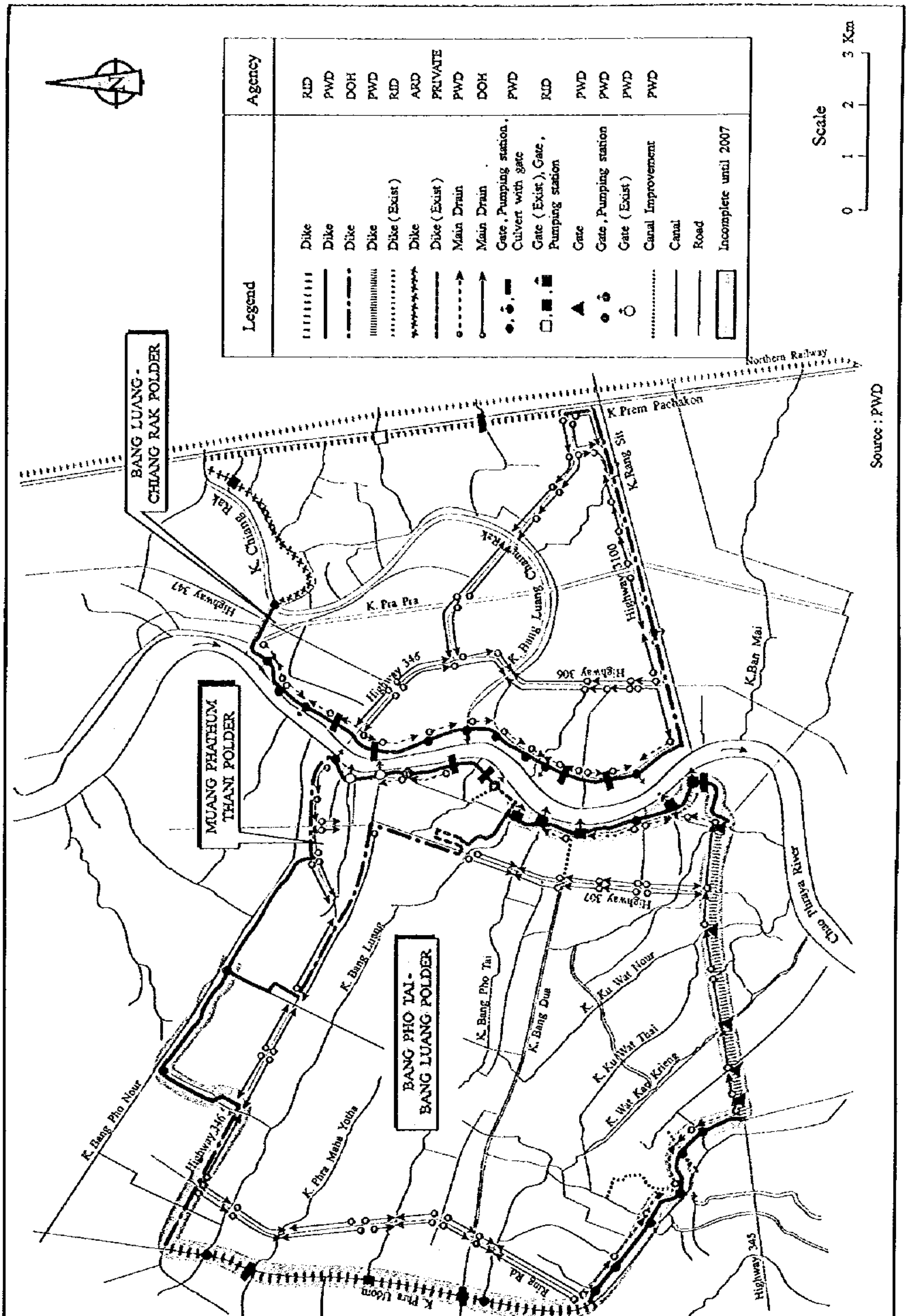

STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN

CTI ENGINEERING CO., LTD AND INA CORPORATION

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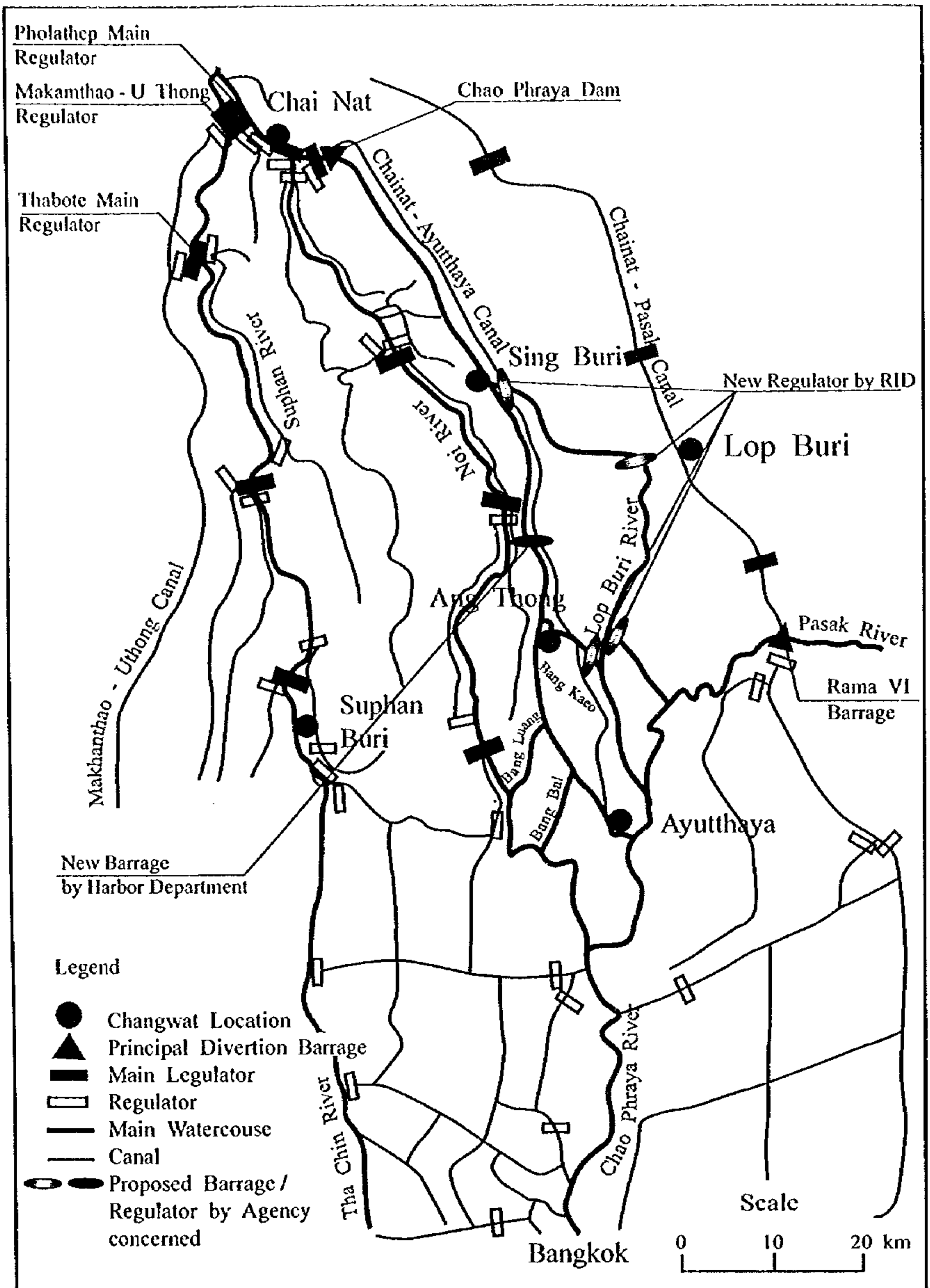

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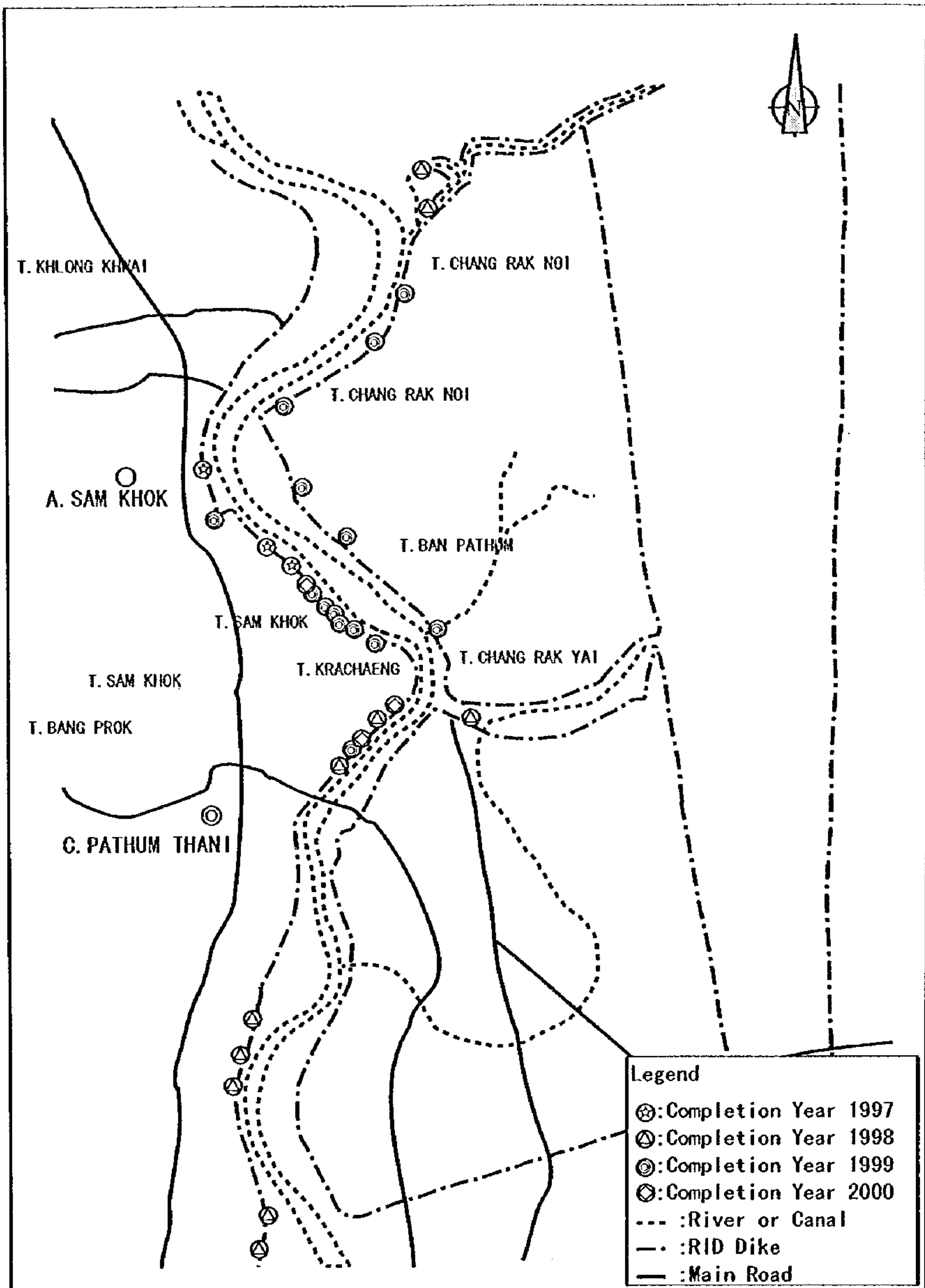

STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN

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Fig. 3.1.4
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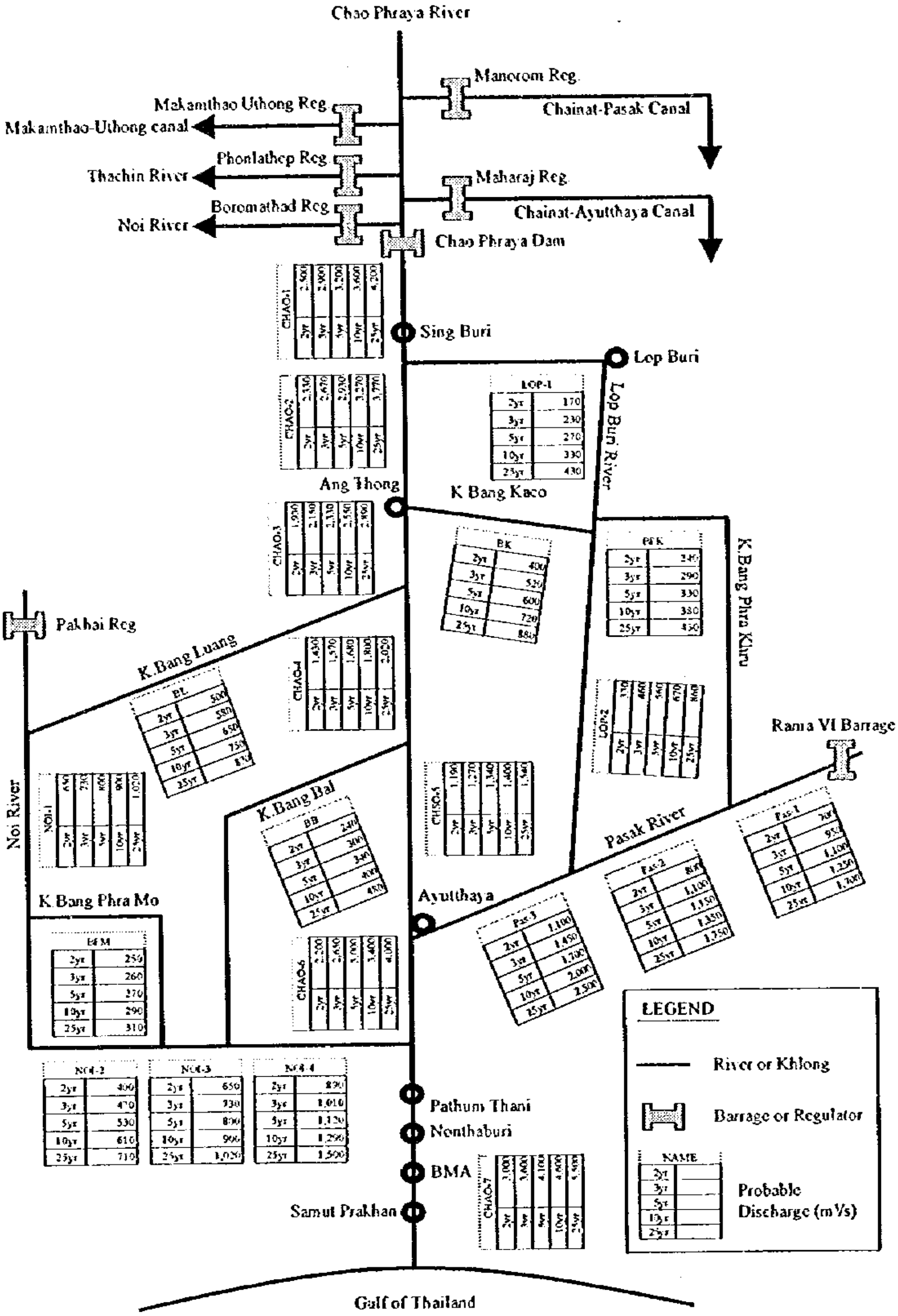

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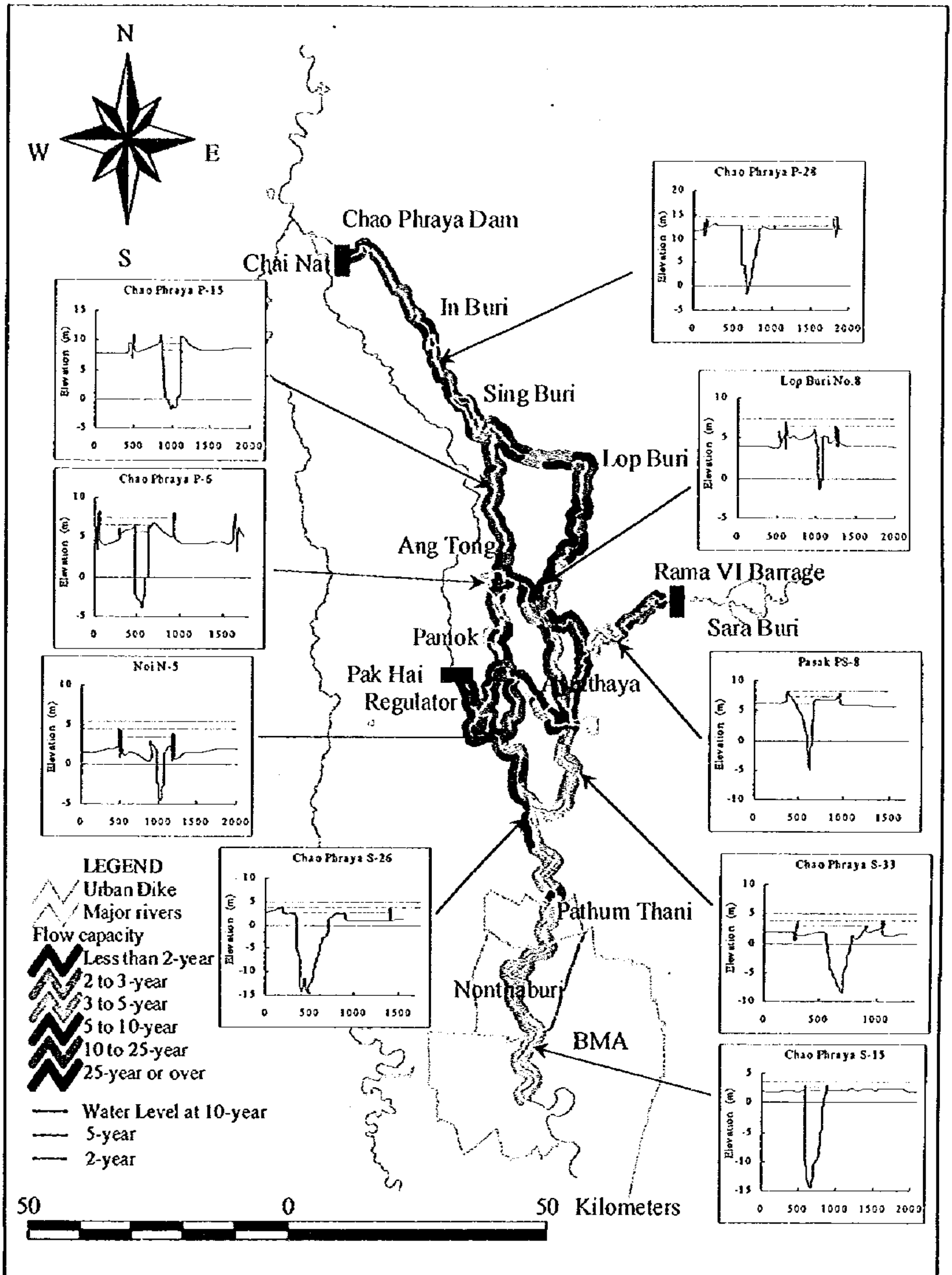

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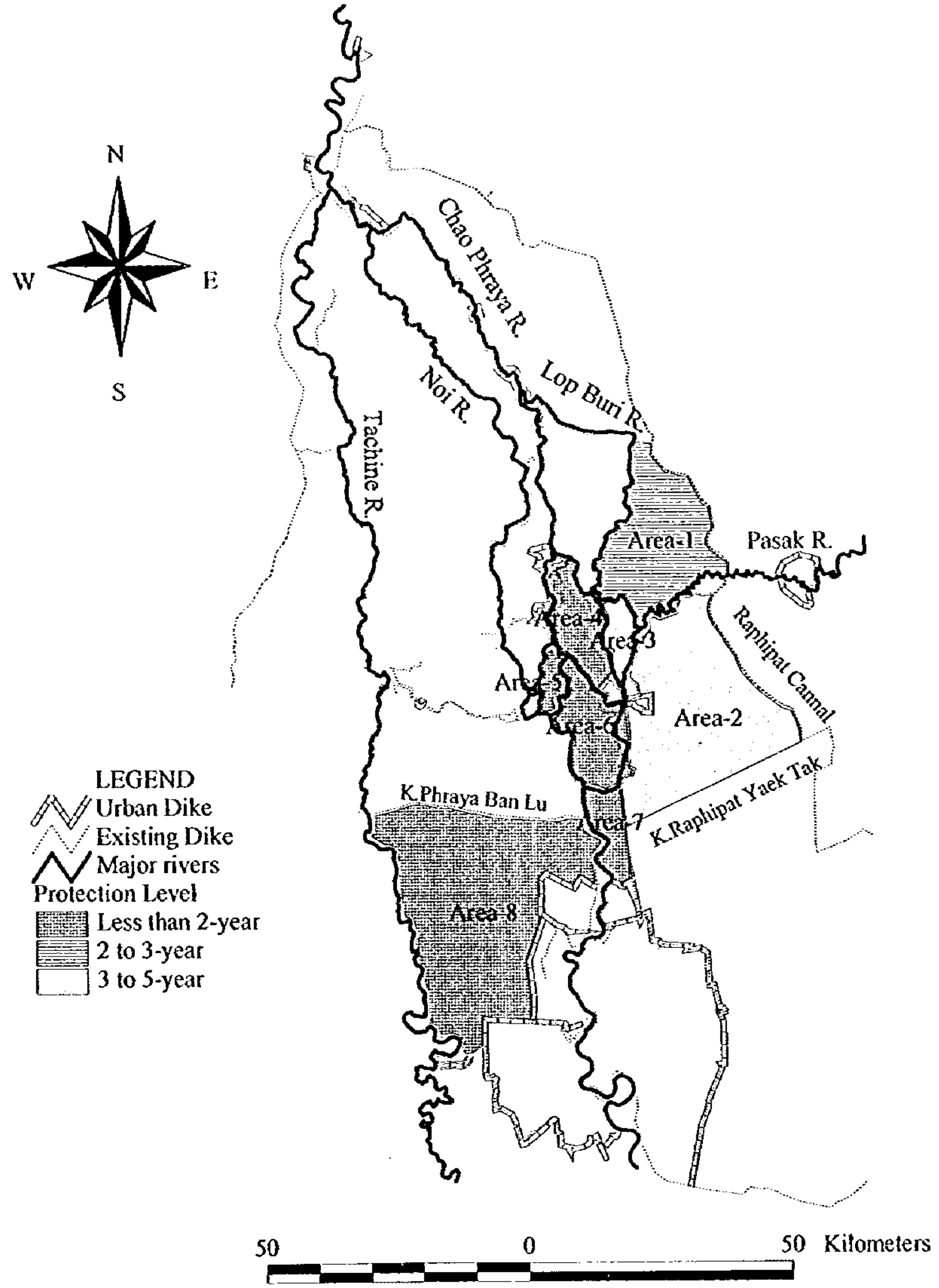

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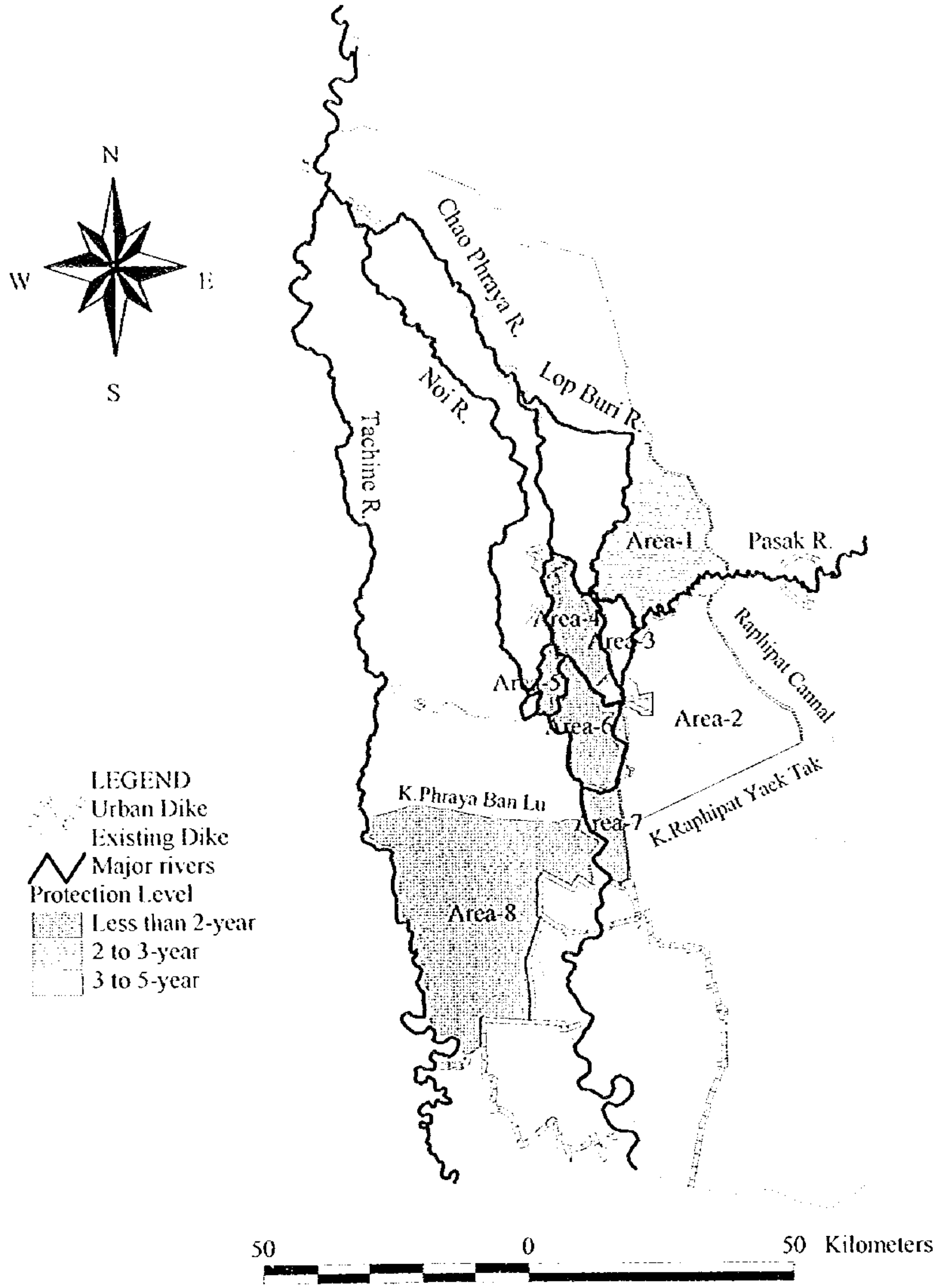

STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig 3.2.3 PROBLEM AREA DIVISION
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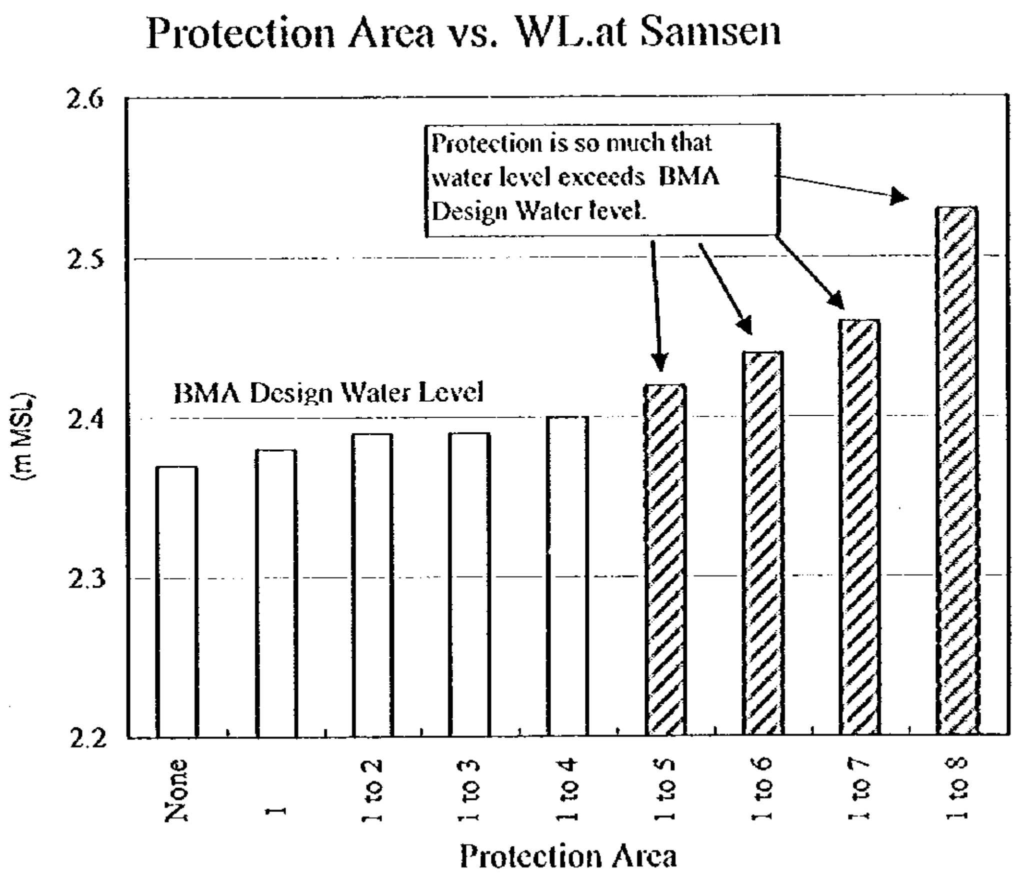

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SECTOR VIII

INTEGRATED DAM OPERATION PLAN

SECTOR VIII : INTEGRATED DAM OPERATION PLAN

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1. INTRODUCTION

Mitigation of flood damage by modification of existing/proposed dam operations in the Chao Phraya River Basin is studied in this Chapter. There are 17 completed dams and still some others are planned in the basin. Among these dams, most of medium and/or small scale dams are constructed for only a simple purpose of irrigation water supply. On the other hand, large dams such as the Bhumibol and Sirikit dams are multipurpose dam which were designed to supply water for irrigation and domestic utilities, hydro-power generation, and to function flood mitigation. However, both of these dams do not possess exclusive flood control capacity in the operation rules and there are some problems observed during the past floods. Considerable quantity of discharge from these reservoirs during heavy floods had been released. Therefore, it is necessary to modify reservoir operation rules for enlarging flood retention capacity and promoting effectiveness of the function.

2. CURRENT STATUS OF DAM RESERVOIR IN CHAO PHRAYA BASIN

2.1 General Features of Existing/Proposed Dam Reservoir

As was mentioned above, 17 dams have been completed and 28 plans are being implemented in the Chao Phraya River basin. Among the completed ones, 8 dams are categorized as large dam whose effective capacity exceeds 100 million cubic meters (MCM) and the other 9 dams are smaller ones with effective capacity less than 100MCM. Out of the 28 planned dams, 6 dams are large scale and the other 22 dams are classified as small one. General features of these dams are shown in Tables 2.1.1, while the principal features and locations of the large dams are shown in Table 2.1.2 and Fig.2.1.1, respectively.

The Bhumibol dam and the Sirikit dam have extremely large storage capacity and important roles in the Chao Phraya River System. The outline of these dams is as follows:

- Bhumibol Dam

  The Bhumibol Dam is the first multi-purpose and the highest dam in Thailand. Since its commencement in May 1964, it has been provided great benefits to Thailand including hydro-power generation, irrigation and flood mitigation. The Dam is large impounding dam constructed address the Ping River, a main tributary of the Chao Phraya River, in Tak Province which is located at approximately 480km north of Bangkok. It is the only concrete arch-gravity dam in Thailand. With its height of 154 meters and the crest length of 486 meters, it is capable for storing as much as 13,462MCM. The spillway, located on the right side abutment, can discharge the flood at 6,000m^3/s. The hydro-power plant has been one of the main support for the national development and well-being of the people. After completion of the dam, EGAT (Electricity Generating Authority of Thailand) implemented the project to increase the efficiency and the capacity of hydro-power plants. Total capacity of the Bhumibol hydro-power plant is amounted to 720.6 MW. For the purpose of irrigation, water released from the dam has sufficiently supplied 7.5 million Rai of farmland in Tak and Kamphaeng Phet provinces as well as for the Chao Phraya River Basin. In addition to hydro-power generation and irrigation, the dam is also playing an important role in lessening the flood hazard and saline water intrusion in the downstream areas.

- Sirikit Dam

  The Sirikit Dam is the largest earth-fill dam in Thailand with its height of 113.6m and crest length of 800m. The total capacity of the reservoir is 9,510MCM. Since its commencement in 1974, the dam has been contributed a great deal of benefits to the country in terms of irrigation, hydro-power generation and flood control, etc. The Dam is located on the Nan River at Tha Pla District, Uttaradit Province, approximately 500 km north of Bangkok and 60km upstream from Uttaradit Town. The crest of the dam at elevation 169.0m is 12m wide and 800m long. The volume of dam body is 9.8MCM. With total installed capacity of 500MW, the dam has been produced about 1,000GWh/year to strengthen the power supply system. For irrigation, the dam has been supplied water to 1.8 million Rai of farmland on both banks of the Nan River in the wet seasons. In dry seasons, it also has been supported for another 0.3 million rai of these plains plus 2.5 million Rai on the Chao Phraya River Basin. In addition to these, the dam has played an important role in minimizing the flood hazards on the Nan River Basin and, being combined with the Bhumibol Dam, in mitigating the flood damage and saline water intrusion in the central plains of the Chao Phraya River Basin.

2.2 Current Status for Flood Mitigation

None of the dam reservoirs in the basin has an exclusive capacity for flood control. However, the two giant dam reservoirs of Bhumibol and Sirikit can regulate flood runoff by using the vacant capacity above the controlled water level, namely Upper Rule Curve(URC). The other dam reservoirs do not have such curves, but they may also be able to regulate flood runoff to some extent as a result of impounding water.

The total reservoir capacity of dams in the Chao Phraya River Basin is summarized as follows:

Dam Reservoir Capacity in the Chao Phraya River Basin

River Basin	①Drainage Area of River Basin (km²)	②Number of Reservoirs in River Basin		③Total Reservoir Capacity (MCM)		Storage in Depth (=③/①) (mm)	
		Existing	Total (With proposed ones)	Existing	Total (With proposed ones)	Existing	Total (With proposed ones)
Ping	39,880	5	13	10,268	10,853	257.5	272.1
Yom	23,550	2	12	13	248	0.6	10.5
Wang	11,240	4	5	123	313	10.9	27.8
Nan	31,830	4	9	6,693	7,482	210.3	235.1
Pasak	18,200	0	1	772	772	42.4	42.4
Chao Phraya	160,200	16	45	18,070	19,976	112.8	123.3

The total existing reservoir capacity in the Chao Phraya River Basin is approximately 35% of runoff during the wet season, and it will exceed 40% of that in the future. Observing each tributary, storable volume is extremely different each other. In the Ping and Nan river basin, by virtue of the Bhumibol and Sirikit reservoirs, the storable capacities will exceed 70% of average runoff during the wet season. Hence, in the

Yom river basin, the existing storable volume is almost zero and future capacity will be only 4% of runoff. In the Pasak river, the Pasak Dam was completed in 1998 and a new reservoir of approximately 770MCM appeared. The Pasak Dam's catchment area of 12,929Km^2 occupies 71% of that of the Pasak river basin, however, the storable volume is only 15% of runoff during the wet season.

Accordingly, from the viewpoint of flood mitigation, it is important to secure the additional storable volume in the Yom and Wang river basin as well as expanding the storable volume in the Pasak river basin.

2.3 Current Status of Reservoir Operation

Normally, giant multi-purpose reservoirs such as the Bhumibol and the Sirikit, which include hydro-power generation, are operated by EGAT. Since RID (Royal Irrigation Department) is responsible for the operation of diversion dams, the optimization of water utilization to meet all demands are carried out by a joint committee of EGAT RID and agencies concerned. The concept of water utilization is to avoid spillage during the flood period and not to empty the reservoir during the dry season.

Based on the concept, to fulfill various purposes, the reservoir zoning, so called the Rule Curves is set up in accordance with the hydrological characteristics of the basin. The operation rule curves and the water release according to the curves are as follows:

- Flood Regulation Rule Curve

  Whenever the reservoir water level is higher than this curve, excess water will be released.

- Conservation Rule Curve (Upper Rule Curve ; URC)

  Whenever the water level is higher than this curve, the water will be released at the maximum generation capability in order to preserve reservoir capacity for flood retention and to reduce spillage in the following periods.

- Buffer Rule Curve (Lower Rule Curve ; LRC)

  Whenever the water level is higher than this curve and lower than the Conservation Rule Curve, the water will be released to meet the downstream requirement and also the need of power generation. Whenever the water level is below this curve, the water release will be reduced. The minimum water release, however, will be confined by the Rationing Policy.

For the flood regulation purpose, it is recommended to secure a certain vacant capacity in the reservoir in advance of the occurrence of flood. In actual operation, however, water storage for irrigation and power generation purposes is given higher priority and a specified capacity for flood regulation is not appropriately considered. The remaining vacant capacity at the beginning of the flood season, which changes year by year depending on the climatic condition, may function to retain some amount of flood discharge.

Figs. 2.3.1(1) and (2) show the present Upper Rule Curves of the Bhumibol and Sirikit Reservoirs with the result of actual reservoir operations in each year.

3. STUDY ON MODIFICATION OF RESERVOIR OPERATION RULE IN MASTER PLAN STUDY

3.1 Purpose of the Study

The purpose of the study on modification of reservoir operation rule is to expand the flood mitigation effect of each dam by setting up new reservoir operation rule in flood season. It means to add the viewpoint of flood control function to each dam.

3.2 Strategy for Study on Modification of Reservoir Operation Rule

3.2.1 Principle of the Study

Considering the aforementioned problems in current reservoir operation in heavy flood period, the following principle for the study is set up.

- To establish the Upper Rule Curve(URC) which can reduce discharge from the reservoir during heavy flood period without spill.

3.2.2 Procedure for the Study

(1) Selection of Objective Dams

In the Chao Phraya River basin, there are many existing/planed dams. In the target year of 2018, more than 10 new dams and relevant projects such as Kok-Ing-Nan Water Diversion Project (hereinafter referred as KIN project) will be completed. However, most of the reservoirs have small storage capacities and are oriented to single purpose of irrigation water supply. Then, it may not be practical to examine all of them. From these circumstances, objective dams for the study are selected considering the flood mitigation effect for major reference points in the downstream.

(2) Evaluation of Present/Proposed Reservoir Operation

The present/proposed reservoir operations of selected dams are examined and issues in the present operation rules are pointed out from the flood mitigation viewpoint.

(3) Modification of Reservoir Operation

Based on the raised issues in the present operation rules during the heavy flood period and on the characteristics of reservoirs, modification of reservoir operation rules is carried out. The new operation rule curves are set up considering the following characteristics:

(a) Traveling time of flood flow from the concerned dam to the downstream reference points;

(b) Maximum vacant capacity that gives no adverse influence against water utilization;

(c) Maximum storable volume for flood retention.

(4) Evaluation of Proposed Operation Rule:

Economic viability of the new operation rules are evaluated, comparing the cost for the reduction of water utilization and benefit of flood mitigation. The cost comprises the compensation cost for reduction of irrigation water supply and that of hydro-power generation. The benefit is the reduction of the potential flood damage attributed to the new operation.

Based on the flood mitigation effect and the economic viability, the optimum operation rule is selected.

3.3 Selection of Objective Dams

3.3.1 Criteria

As shown in Table 2.1.1 and Fig. 2.1.1, there are totally 45 dams including existing 17 dams and 28 dams under planning. The active storage capacity of these dam reservoirs ranges from 3MCM to 9,660MCM and the distance from the reference points, such as Nakhon Sawan and Bangkok, to the respective dam location is different. Hence, it is not realistic to examine the potential of all these dams judging from such a wide variety of reservoir capacity and distance to the reference points. Therefore, the number of objective dams are narrowed down considering the effectiveness of each dam for flood mitigation in the following criteria:

- Catchment area

Dams with a catchment area of less than 1,600km^2, which corresponds to 1 % of the entire catchment area of the Chao Phraya River, are not expected flood mitigation effect so much. For instance, a rough estimation shows that a dam with a catchment area of 1,600km^2 would reduce only 25m^3/s out of 5,000m^3/s of flood discharge at Bangkok even if the dam would consume all the storage capacity for flood control. Therefore, dams in this group are excluded.

- Dams located upstream of the Bhumibol dam

A dam close to the areas to be protected is more effective in terms of flood mitigation than those located upstream. Three dams located upstream of the Bhumibol dam, namely Mae Ngat, Mae Kuang and Mae Khan dams are screened out considering that the cooperative flood mitigation operation by 4 dams including the Bhumibol can be represented simply by the most downstream Bhumibol reservoir.

- Irrigated area by dam

During the dry season, the water demand for irrigation (active storage capacity divided by irrigation area), to be supplied from the reservoirs, is estimated approximately 1,000 to 3,000mm. This means that the dams with less water demand for irrigation share larger command area in terms of irrigation water supply. In order to lessen the extent of affected irrigation areas cause by the modification of operation rule, a dam whose water demand for irrigation is less than 10,000m³/ha (=1,000mm) is excluded.

3.3.2 Selected Dam

On the basis of the criteria described above, selection of objective dams is carried out.

- Catchment area and location of dams

  The selection is carried out by focussing on the catchment area and location of dams and the result is shown in Table 3.3.1. As shown in the table, 38 existing/proposed dams are excluded because of their small catchment areas and small capacities compared with inflow discharge except the Kiu Kho Ma dam. The Kiu Kho Ma dam will be operated together with the Kiu Lom dam, then the Kiu Kho Ma dam is included here.

- Irrigated area by dams

  Seven dams are examined focusing on the irrigated area and the active capacity. The total active capacity of the Kiu Kho Ma and the Kiu Lom Dam is 286MCM and the total irrigated area by these dams is 30,018ha. The irrigation water demand on dams is less than 1,000mm, then the Kiu Kho Ma and Kiu Lom Dam are excluded considering adverse impact for irrigation water supply. As the result, the following 5 dams are finally selected as the objective dams to examine the potentiality of flood mitigation.

These are the Bhumibol, Sirikit, Kwae Noi, Kaeng Sua Ten and the Pasak dams. The location of these 5 dams are shown in Fig. 3.3.1.

3.4 General Features of Selected Dam Reservoir Operation

3.4.1 Outline of Selected Dam Reservoir Operation Rule

Among the selected five dams, the Bhumibol and Sirikit dams have been operated in long period. But the operation period of the Pasak dam is less than one year so far and the Kwae Noi and the Kaen Sua Ten dams are in the planning stage. Although there are some uncertainties in their operation rules, this study is conducted based on the existing operation plan for each dam.

(1) Bhumibol Reservoir

The Bhumibol dam reservoir is operated to maintain the reservoir capacity between two rule curves, namely the Upper Rule Curve(URC) and the Lower Rule Curve(LRC). The reservoir is operated in following manners.

- At the beginning of the dry season, RID establishes rules and guidelines to allocate water for irrigation, domestic and industrial, and navigation, etc (Command and Control System). The rules and guidelines are established by considering the available active storage in the reservoir at the end of the wet season (end of November) and carry-over volume of about 1,000MCM at the end of the dry season. (Refer to Fig.3.4.1)

- While the reservoir water level is blow the LRC; the water for irrigation, domestic/industrial purposes is released under the requirement by RID. At the same time, the released water is utilized for hydro-power generation.
- While the reservoir water level is between the URC and the LRC, the water is released by both requirement for irrigation and hydro-power.
- During flood period, the rerelease from the reservoir is controled considering flooding condition in the downstream as long as the reservoir capacity stays between the two operation rule curves. But it is also noted that, during big floods such as in 1975 and 1996, the released discharge was not controlled completely depending on the requirement of power generation.
- During the 1975 flood, the reservoir water level raised higher than the URC through September till December. After experienced this flood, the installed reservoir capacity for hydro-power generation was increased and, accordingly, the capacity under consideration in 1975 was approximately 60% of the present. By taking revised installed capacity into account, it is possible to keep the reservoir water level below the URC against floods of the same scale.

(2) Sirikit Reservoir

The Sirikit dam reservoir is operated in the same manners as the Bhumibol dam reservoir. However, the Sirikit dam reservoir has less storage capacity than that of the Bhumibol, the operation was conducted as follows:

- The Dam has experienced spill-over twice in 1975 and 1995 since its completion. In 1995 flood, the maximum water level has reached to EL.162.12m and the maximum discharge had spilled from the spillway, the amount of which had reached to 1,963m^3/s. The total spillage of 856MCM occurred through August 29 to September 26 and it was about 30 % of inflow flood discharge volume during the same period. In 1995 flood, the inflow flood discharge volume into the Sirikit reservoir from August to November was approximately 6,700MCM. The cause of overflow is attributed to that the flood runoff volume was too large in comparison with the storable volume and the available release discharge of 575m^3/s. The available capacity against flood discharge during the flood period from August to November is as less as about 2,800MCM when applying the vacant capacity below the Maximum Water Level and above its URC.
- In 1996 flood, even the reservoir water level lowered the URC, the discharge of 150 m3/s approximately was released from the reservoir to fulfill the requirement for power generation.
- After 1995 flood, a fourth generator was installed in November 1995. Due to this installation, the available release discharge through generators had increased by 125m^3/s up to 700m^3/s. Taking account of strengthened release volume, it is possible to prevent the spill for the same scale of floods.

- In due consideration of the actual reservoir operation above mentioned and the additional inflow of 2,000 MCM after the completion of KIN project, two operation rule curves are proposed by the Study on KIN project from the viewpoint of water utilization improvement. (JICA, March 1999, The Feasibility Study on Kok-Ing-Nan Water Diversion Project, Progress Report No.2).

  These are the following operation rule curve before the completion of KIN project and the rule curve after the KIN project.

Proposed Rule Curve by Kok-Ing-Nan project *   (Unit : million m3)

Rule Curve		Jan.	Feb.	Mar	Apr.	May	Jun.	Jul.	Aug	Sep.	Oct.	Nov	Dec.
Upper	Present	8700	8200	7750	7350	6950	6700	7000	8000	9300	9510	9510	9380
	B-KIN**	-	-	-	-	-	5000	5750	7050	8500	9150	9510	-
	A-KIN***	-	-	-	-	-	4150	5750	7850	8850	9350	9510	-
Lower	Present	6950	6700	6200	5800	5400	5000	4850	5800	6900	7150	7100	7000
	B-KIN**	5800	5650	5300	4850	4200	3850	-	-	-	-	-	5750
	A-KIN***	5450	4850	4250	3750	2950	2850	-	-	-	-	-	5950

* : Total storage at the end of month

** B-KIN : Before completion the KIN project

*** A-KIN : After completion the KIN project

The former curve is to lower the present URC and LRC at the beginning of wet season down to 5,000 MCM and 3,850 MCM respectively until the completion of KIN project in order to make more efficient reservoir operation.

The latter curve is to lower the URC at the beginning of wet season down to 4,150 MCM because the diverted water of about 2,000MCM will be conveyed from the Kok and Ing river during wet season after KIN project. Consequently, the vacant capacity at the biginning of wet season will become 5,360 MCM which is equivalent to 80 % of the active capacity.

(3) Pasak Reservoir

The Pasak dam was completed in 1998 at the middle-stream of Pasak River to fulfill the purpose of irrigation and domestic water supply. Although the hydro-power generation was originally considered, power plant is not installed yet because of its small energy production capacity and the change of economic condition. In the original plan, hydro-power generation is dependent on the release water for irrigation water supply, therefore, the reservoir does not possess exclusive capacity for power generation.

From the flood mitigation point of view, the features of the planned reservoir operation can be summarized as:

- The primary operation purpose is water supply for irrigation and domestic utilization. Although a function of flood control to some extent is additionally expected through the normal operation, the exclusive capacity for flood control is not allocated for the present reservoir.

- Because of its single purpose for water supply, any rule curve like that of the Bhumibol and/or the Sirikit reservoir is not provided. The principle of its operation in the wet season is to assure the full capacity in the early period for the irrigation water supply during the following dry season.

(4) Kwae Noi and Kaen Sua Ten Reservoir

The purposes of the Kwae Noi and Kaen Sua Ten dams are mainly for irrigation, domestic water and river maintenance flow supply. In the study, the feasibility of hydro-power generation are chosen. But hydro-power generation is dependent on the irrigation water release for both reservoirs.

3.4.2 Issues of the Operation Rule from the Flood Mitigation Aspect

Multipurpose dams have two major purposes, water supply and flood control. To satisfy the two functions, a thorough study is necessary because they are contradicting each other in their natures. In the viewpoint of improving flood control function, major issues in selected five dams can be summarised as noted below:

(1) Bhumibol Dam

The Bhumibol dam has shown its potential of flood control function during large floods occurred in 1975 and 1995. The high potential can be attributed to the huge capacity compared to its inflow volume. However, it was fortunate that the Bhumibol dam luckily have a large vacant capacity during the flood in 1995. The stored water level was lower than the Upper Rule Curve(URC). If the stored water level were closed to the URC, the dam would have forced to release the stored water during the flood. In addition, a large quantity of release for power generation occurred in the past even when the downstream is inundated. In order to secure sufficient storage volume at the beginning of the flood season, modification of the URC is necessary.

(2) Sirikit Dam

Although the catchment area of the Sirikit dam is only half of the Bhumibol's, inflow volume into the Sirikit reservoir is almost the same as that of the Bhumibol due to characteristics of precipitation and geography. On the contrary, active storage capacity of the Sirikit is only about 60% of the Bhumibol. These circumstances of the Sirikit leave it difficult to operate the reservoir during flood period. In the past floods in 1975 and 1995, the reservoir water level enormously exceeded the URC and stored water was spilled to inundate downstream areas. In 1995 flood, total discharge from the reservoir reached to approximately 1,900MCM during the heavy flooding period. Therefore, modification of the URC and the reservoir operation during flood are considered to be necessary.

(3) Pasak Dam

Storage in depth of the Pasak reservoir is so small that the reservoir can store only 60 mm of effective rainfall in the catchment area. The reservoir will be easily filled in short period of time during heavy flood. There is no URC for Pasak Dam. The inflow discharge will be stored from the beginning of the wet season and the reservoir will already be full before September in normal year. It means that the Pasak reservoir would have no vacant capacity to control floods during late September to October when the Chao Phraya river and the Pasak river receive high rate of flow. In order to maximise flood control capacity of the Pasak, the storage volume should be maintained to be able to receive discharge as much as possible during the heaviest flood. Consideration of such an URC is recommended in this study.

(4) Kwae Noi and Kaen Sua Ten Dam

The Kwae Noi and Kaen Sua Ten dams are still in planning stage. Specifications such as installation of power plant are not yet determined. However, it is certain that the hydro-power generation is dependent on the release water for irrigation supply and the URCs are not prepared for these dams. The storage depths of these dams are relatively large compared to that of the Pasak reservoir. Therefore, it takes long time to restore the full capacity than the Pasak reservoir. This means that gently-slope rule curve is appropriate for these dams. It also means that these dams are suitable for controlling small to medium scale floods. Setting up the rule curves are recommended to utilise these dams for effective flood control.

3.5 Modification of Reservoir Operation

3.5.1 Procedure for Study on Modification of Operation Rule

In Master Plan Stage, provisional rule curves are set, and each of them is evaluated in terms of its flood control effectiveness and the adverse impacts on storage for water supply in the following dry season. The study is curried out in accordance with the following procedure.

(1) First Step: Setting up the Flood Control Operation Period;

The operation period for flood mitigation is decided considering the frequency of floods and the travelling time from the dam to the down-stream reference points.

(2) Second Step: Setting up the Ideal Capacity for flood mitigation without any loss to Water Utilisation;

The ideal vacant capacity for flood mitigation without any loss to irrigation water supply and hydro-power generation is calculated by water balance simulation.

(3) Third Step: Setting up the Upper Rule Curves(URCs);

(a) Setting up the Maximum Vacant Capacities for Flood Mitigation

To strengthen the flood mitigation function, the following three cases of maximum vacant capacities for flood control are tentatively set at the beginning of flood period:

- Case-1 Ideal vacant capacity that gives no adverse impacts on water supply;

  (In case of the Bhumibol and Srikit dams, the capacity is set as same as the present URC.)

- Case-2 Intermediate capacity between Case-1 and Case-2;

- Case-3 Maximum vacant capacity using the full effective storage capacity:

  (In case of Bhumibol reservoir, the maximum vacant capacity is set to 5,500 MCM considering the total inflow discharge volume of large floods.)

(b) Setting up the Upper Rule Curve(URC)

After determining the operation period and the flood control capacity at the beginning of the flood period, URCs are set up with straight lines.

3.5.2 Modification of Operation Rule for Flood Mitigation

(1) Operation Period for Flood Control

- Traveling Time of Flood

The traveling time of flood from the Bhumibol and the Sirikit dams to the reference points, namely Nakhon Sawan and Bangkok, are estimated approximately about 4 days and 6 days, respectively. That of the Kwae Noi is about 3 and 5 days, and of the Kaeng-Sua-Ten Dam is 5 and 7 days, respectively. The traveling time from the Pasak Dam to Bangkok is only 2 days.

- Flood Period at the Reference Points

Frequencies of floods on these reservoirs and the reference points are shown in Fig. 3.5.1. Floods at Nakhon Sawan are concentrated from the mid-August to the end of October. The period of high water level in Bangkok is from October to November because of the tidal influence.

- Flood Period at the Reservoirs

  - Bhumibol, Sirikit, Kwae Noi reservoir -

On the other hand, floods occur from the July to the end of October in three dams, namely, the Bhumibol, the Sirikit and the Kwae Noi. Considering flood control function by the Bhumibol and the Sirikit reservoir, it can be noted that this fact indicates the flood characteristics between Nakhon Sawan and these dams to be almost reasonable with traveling time between these points. Therefore, it is recommended that the reservoir operations for flood control at these dams should focus on the effect of flood mitigation at Nakhon Sawan.

- Pasak reservoir -

In the Pasak dam, floods are concentrated from September to the first half of October. The traveling time down to Bangkok is very short. The recommended operation for flood control by the Pasak reservoir is to focus on the inflow discharge of the reservoir.

- Kaeng Sua Ten reservoir -

Flood occur, at the Kaeng SuaTen reservoir, from August to November. Henceforth, if only the basin run-offs in ordinary years are enough to restore the vacant capacity, it is advisable to set a long rule curve during the flood season. But the average annual inflow is approximately the same as the active capacity, therefore, it is not easy to restore the full capacity within the wet season under the condition that the vacant capacity for flood control should be kept during a long period. Accordingly, it is better to unfasten the limit of storing in early period. Considering the above mentioned two contradictory requirements, the end of the flood control operation period for the Kaeng-Sua-Ten Dam is set at September 15.

Based on the above mentioned evaluation, the period of reservoir operation for flood control is determined as shown in the following table:

Reservoir Operation Period for Flood Control

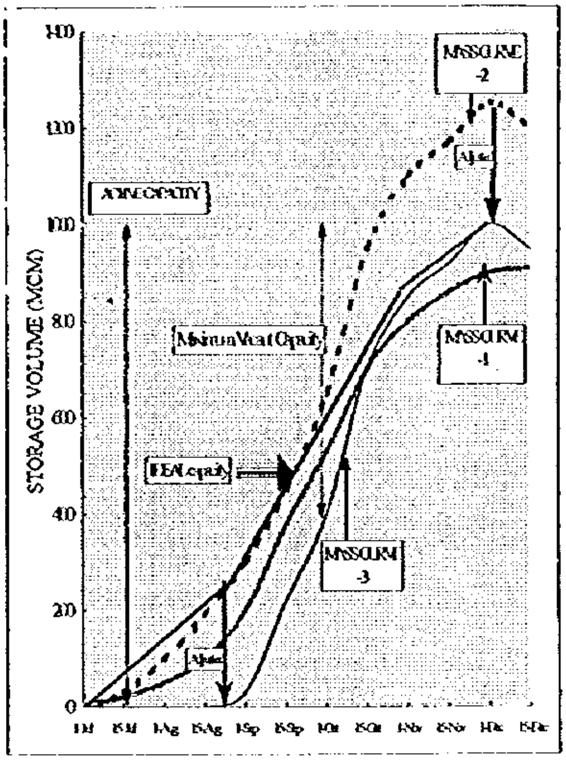
RESERVOIR	START TIME OF OPERATION	END TIME OF OPERATION
BHUMIBOL	July- 1	November – 30
SIRIKIT	July- 1	November – 30
KWAE NOI	August – 1	October – 15
PASAK	September – 1	October – 15
KAENG-SUA-TEN	August – 1	September – 15

(2) Setting up the Ideal Capacity for Flood Control without Any Loss to Water Utilisation

The ideal vacant capacity of the Kwae Noi, Pasak and Kaeng Sua Ten reservoir is conducted in the following procedure (Refer to figure shown blow) :

When the total storable inflow in the wet season is less than the active storage capacity, the maximum vacant capacity, which gives no adverse impacts on water supply, is equal to the vacant capacity at the concerned date ------ Mass curve-1 ;

On the other hand, when the total storable inflow in the wet season is greater than the active storage capacity (Mass curve-2), Mass curve is lowered in parallel until its maximum capacity meets to the active storage capacity. ---
-Mass curve-3 ;



In this case, the maximum vacant capacity is equal to the vacant capacity of Mass curve-3.

(ii) The storable inflow mass curve is calculated for 45 years, and the above mentioned maximum vacant capacities in each year are obtained:

(iii) The maximum vacant capacity, which gives no adverse effects on water utilization, is the minimum one in 45 years:

The ideal capacities for flood control without any loss to water utilization are summarized in Table 3.5.1:

(3) Setting up the Rule Curve for Reservoir Operation

Based on the above-examined operation period and ideal capacity, the operation rule curves for the selected 5 dams are set up.

The proposed URCs for the selected dams are shown in Table 3.5.2 and Fig. 3.5.2.

3.6 Evaluation of Proposed Reservoir Operation

3.6.1 Effect of Proposed Reservoir Operation

The effect of proposed reservoir operation is evaluated by reduced release volume from the reservoir during the flood period. In case of the Sirikit reservoir operation, the effect is compared with the aforementioned proposed operation rule of the KIN project. The flood mitigation effects for major 4 big floods are shown in Table 3.6.1.

3.6.2 Cost for Proposed Reservoir Operation

The modified reservoir operation rule will affect the original functions of the concerned reservoir by reducing water supply for irrigation and hydro-power generation. Therefore, it is necessary to compensate such affect and the compensation cost is regarded as the additional cost for modification of reservoir operation rule.

The calculation of the compensation cost, on the reduction of irrigation water supply and energy generation, is carried out by observing the following procedure:

(1) Reduction of Irrigation water supply

(a) Reduction of Storage Volume

The average storage volume at the end of the wet season (November 30) is calculated for each operation rule. The reduced storage volume of each case is obtained by subtracting the average storage volume under the current/planned rule from that under the modified rule. The average storage volume and the reduced storage volume of each case are shown in Table 3.6.2.

(b) Reduction of Irrigation Area

Based on the reduced storage volume mentioned above, the reduced irrigation area is roughly calculated by dividing the reduced volume by the unit water supply volume required over each reservoir. The required unit water supply volumes are as shown in the following table:

Required unit water supply volume (Unit: m^3/ha)

Name of Dam	Bhumibol	Sirikit	Kwae Noi	Pasak	Kaeng-Sua-Ten
Unit Supply	25,000	25,000	29,000	21,000	20,000

The reduced irrigation area of each case is shown in Table 3.6.2.

(2) Reduction of Hydro-Power Generation

The hydro-power generated before and after the modification of reservoir operation rule is calculated by applying the following rating curves, respectively(Refer to Fig.3.6.1, 3.6.2). In case of the Kwae Noi and the Kaeng Sua Ten dam, the tentative combined efficiency of equipment is set as 0.85.

$Rate = 14.782 \times 10^{-3} \times Storage^{0.3018}$ -------------- Bhumibol Dam.

$Rate = 2.8435 \times 10^{-3} \times Storage^{0.4708}$ -------------- Sirikit Dam.

where

Rate: rate of generation (in Gwh/MCM);

Storage: storage volume (in MCM)

The values of reduced average annual hydro-power generation in Cases 1, 2 and 3 are shown in Table 3.6.2.

(3) Calculation of Compensation Cost

(a) Compensation Cost for the Reduction of Irrigation Water Supply

The average annual compensation costs are calculated by multiplying the reduced irrigable area by the unit production value from irrigation area. The unit production value is as following:

Gross Value :	16,400 Baht/ha
Input Cost :	9,400 Baht/ha
Unit Production Value :	7,000 Baht/ha

The annual compensation costs for the three dams, namely, the Kwae Noi, the Pasak and the Kaeng-Sua-Ten are calculated for 45 years from 1952 to 1996. In case of the Bhumibol dam, the calculation is carried out for 32 years from 1965 to 1996 when the operation result is available, and, in case of the Sirikit dam, the calculation is carried out for 23 years from 1974 to 1996 when the calculation result of conveying water from the Kok and the Ing rivers are available. The calculated compensation costs for irrigation water supply are shown in Table 3.6.2.

(b) Compensation Cost for Reduction of Hydro-Power Generation

The compensation cost for reduction of hydro-power generation is calculated by multiplying the reduced generated energy with the following generating cost:

Unit Cost:	1.60 Baht/kwh
Transmission Loss:	15 %
Generating Cost:	1.36 Baht/kwh (= 1.60 x 0.85)

(c) Total Compensation Cost

The total annual compensation casts are summarized in the following table:

Average annual compensating cost (million Baht/year)

Item	Total			Bhumibol			Sirikit			Kwae Noi			Pasak			Kaeng Sua Ten		
Case	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Compensation Cost	0	10	234	0	0	41	0	0	148	0	5	12	0	1	6	0	4	27

(4) Establishment of Proposed Reservoir Operation

From the calculation result of flood mitigation benefit and compensation cost, the operation rule curve of Case-3 is selected in accordance with the following judgement:

- Flood mitigation benefit of Case-3 is conspicuous. For 1995 flood, flood mitigation benefit of Case-3 is approximately 3 times of that of Case-1 and 1.7 times of Case-2.
- Though economic viability of Case-3 is less than that of Case-1 and Case-2, it exceeds that of other countermeasures facilities such as river improvement and flood diversion channel, greatly.
- Accordingly, from the viewpoint of securing similar effect for flood mitigation of the Chao Phraya river system with comprehensive countermeasures, it is recommendable to select the operation rule of Case-3 .

The proposed URCs are shown in Table 3.6.3.

3.7 Other Related Study

The additional study for 'without case' of two dams - the Kwae Noi and Kaeng Sua Ten dams, and the case of 'before Kok-Ing-Nan water diversion project' is also carried out. The flood mitigation effects of the 'without' case of two dams are shown in Table 3.7.1. The result of study is summarized as follows:

(1) Without Case of the Kwae Noi and the Kaeng-Sua-Ten Dam

In the Chao Praya Delta, the increased inundation volume resulted from the 'without' case is negligible small as less as 2.0MCM in 1995 flood.

The increased inundation volume in the Upper Central Plain is approximately 880MCM, the amount which comprises 770MCM without the Kaeng-Sua-Ten and 110MCM without the Kwae Noi.

(2) Case of 'before Kok-Ing-Nan Water Diversion'

The vacant capacity for flood mitigation of the Sirikit dam, which can achieve almost the same effect as that of the case after KIN project, is 5,500MCM. The optimum URC is shown in the following table:

Optimum upper rule curve in case of 'before Kok-Ing-Nan water diversion'
- Sirikit Reservoir - (Unit : million m^3)

Date	Jul.1	Jul.15	Aug.1	Aug.15	Sep.1	Sep.15	Oct.1	Oct.15	Nov.1	Nov.15	Dec.1
Storage	4,000	4,200	4,500	5,600	7,000	8,200	9,000	9,200	9,400	9,480	9,510

4. STUDY ON MODIFICATION OF RESERVOIR OPERATION RULE OF FEASIBILITY STUDY

4.1 General

In the Master Plan study, it is assumed that the Bhumibol and the Sirikit dams are operated for hydro-power generation during flood season according to the requirement for electricity. As the result, it is clarified that the proposed reservoir operation in the Master Plan Study has more effectiveness for flood mitigation compared with the operation under the present and the proposed 'before KIN project' rule curve; upper rule curve. However, from the flood mitigation point of view, it is desirable to reduce the discharge for hydro-power generation during the flood period.

With reference to the energy (electricity) demand and supply balance in Thailand until 1996, the reserve capacity varied from 1,000 Mw to 1,700 Mw, which was only 8 to 12 % of the total energy demand. Therefore, the release for power discharge from the Bhimibol and Sirikit reservoir had been inevitable even in the heavy flood period. Since 1997, the energy balance has improved to a great extent because of the change of economic situation and the installation of new power plants, and therefore the reserve capacity has been increased up to 5,000 Mw or more. In accordance with the energy forecast compiled by EGAT, the reserve capacity is to be secured and increased. Thus, it will be possible to reduce and stop the release for power discharge from the reservoir during the heavy flood period.

Considering these situation, in Feasibility Study stage, a further study is carried out putting more emphasis on released discharge for hydro-power generation during heavy flood period to minimize the flood damage due to released discharge from reservoir.

4.2 Strategy for Feasibility Study

4.2.1 Principle of the Proposed Reservoir Operation

The most idealistic flood control operation is to cut-off the whole flood discharge from the reservoir during the flood season. However, the total discharged water into the reservoir during major flood exceeds its effective capacity, and therefore the flood cut-off operation is not practical. Thus, the objective of 'Modification of Operation Rule' in this feasibility study is to reduce the flood release from reservoirs as much as possible in observing the flood situation in the downstream area.

The principle of the study on modification of the reservoir operation rule is set up according to the following conditions;

(1) Assurance of enough Reservoir Capacity at the Beginning of the Flood Season

To assure the reservoir operation considering the flood mitigation, each reservoir should provide enough vacant volume to store the flood discharge at the beginning of flood season.

(2) Minimisation of Released Discharge from Reservoir.

While the flood damage is observed in the downstream areas, the released discharge from reservoir should be fully controlled to minimize the flood damage due to released discharge from reservoir.

(3) Prompt Release of Discharge to assure Reservoir Capacity for Flood Mitigation

While the river channel in the downstream has enough capacity to receive the flood discharge, the dam should promptly release the stored water in accordance with the hydro-power requirement and/or irrigation water supply, so that the vacant capacity for flood mitigation can be assured against the expected flood discharge after that.

4.2.2 Objective Dams

The Kwae Noi and the Kaen-Sua-Ten dams, and the KIN project will still be under implementation by the year 2005, the target year of this F/S. Therefore, the objective dams for the F/S are selected only the Bhumibol, Sirikit and the Pasak dams, and the inflow of the Sirikit reservoir will be only the discharge from Nan river basin.

4.2.3 Procedure

In order to set up the above mentioned operation rule for flood mitigation, the following procedure is applied:

(1) Selection of Reference Point

As earlier mentioned, the reservoir operation for flood mitigation is carried out considering the flood condition in the downstream.

To identify the flood condition, it is necessary to select reference points which represent critical flood conditions in downstream and which are selected focusing on the hydrological bottleneck of the river course. The allowable release discharge from the reservoir is to be confined with the flow capacity at the reference points.

(2) Setting-up Rule Curves

Due to the change of the operation principle for flood mitigation, the rule curve is modified. The modification of rule curve is undertaken through some water balance simulation on major recorded floods as discussed below:

(a) Upper Rule Curve; URC

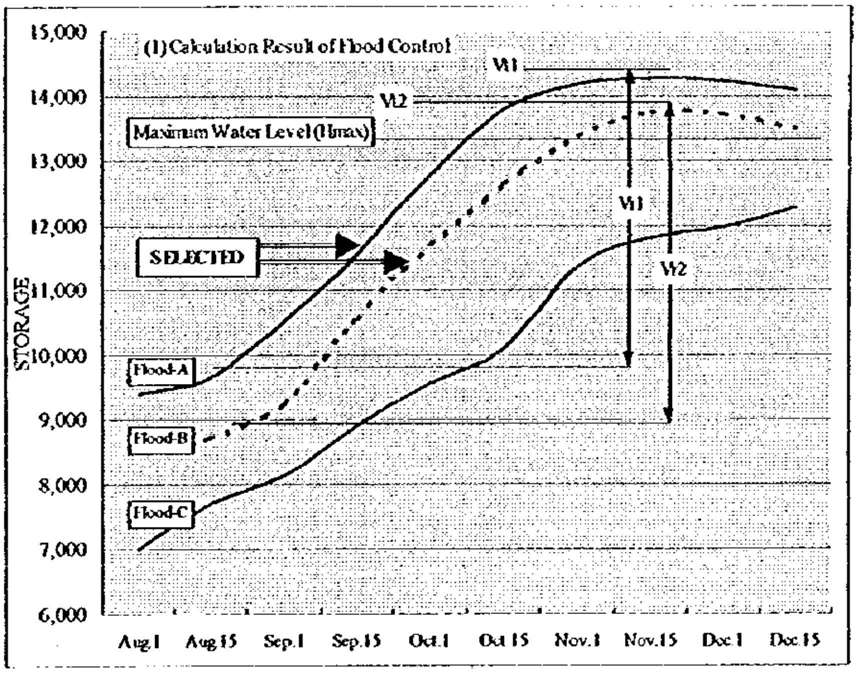
The Upper Rule Curves for the Bhumibol and the Sirikit reservoirs are tentatively set up with following manner.

i) Principle of reservoir operation

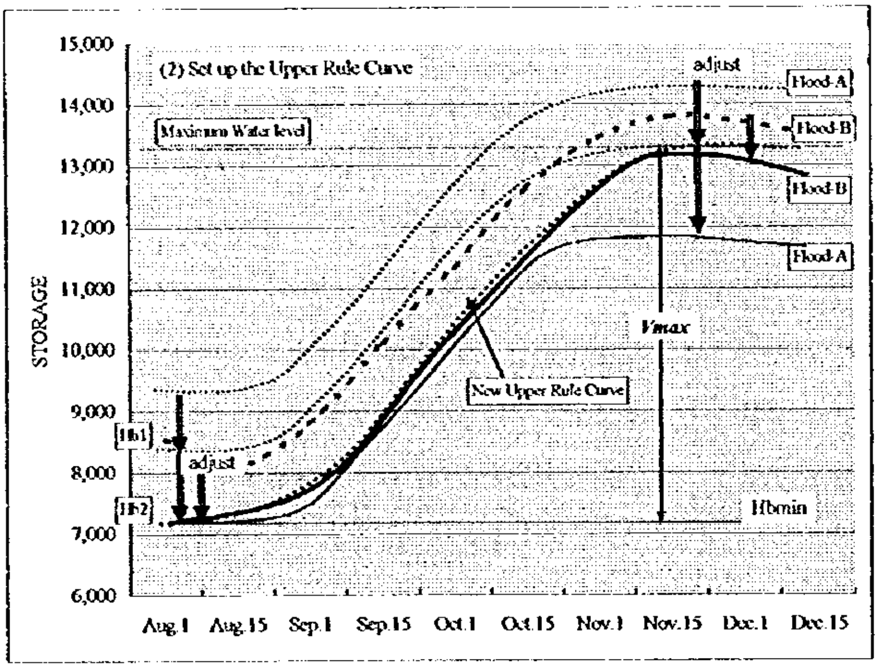
- While river channel in the downstream has still enough capacity to receive the released water from reservoir at the reference points, required amount of water for hydro-power and irrigation is released from the reservoirs.
- On the other hand, the river channel has no more capacity to receive the released water from reservoir, the release will be stopped.

ii) Setting-up the upper rule curve

- Though the simulation applying the above principles to past floods, the reservoir water level transition curves (water level regime) are obtained.
- The past floods among which the water level regime excees the Maximum water level of the reservoir (Hmax) are selected.
- Also the total stored volume (Vt) and required volume for flood mitigation (Vr) of selected floods can be obtained.



- Since the Maximum water level (Hmax) is fixed for each reservoir, the upper rule curve which avoid the spill over the Hmax is naturally set adjusting the storage water level at the beginning of the flood period (Hb).
- The maximum required volume (Vmax) among the selected floods is obtained in this process and the storage water level at the beginning of the flood period (Hbmin) is fixed for the flood with the maximum required volume.
- The water level regime of selected floods which exceed the Hbmin – the water level at the beginning of the flood period of above mentioned flood, are adjusted in parallel to the Hbmin and overplayed starting.
- The upper rule curve is set enveloping the water level transition curves for selected floods.



- The upper rule curve is finally examined their propriety with the 45-year-consecutive simulation because the storage water levels at the beginning of flood season of each flood are changed through the modification of the present upper rule curve.

As for the Pasak reservoir, three cases of upper rule curves are temporary set up with the same manner as in the Master Plan study.

(b) Lower Rule Curve; LRC

The current rule curve of the Bhumibol reservoir is adopted as the proposed LRC. The LRC for the Sirikit reservoir is set-up the same as the one proposed in the Kok-Ing-Nan project.

(3) Evaluation of Proposed Operation Rule

The new operation rules would promote the effectiveness for flood mitigation. On the other hand, they may cause some adverse influence on water utilization such as irrigation water supply and hydro-power generation. Therefore, optimization of the scale of modification of reservoir operation rule is examined based on the economic evaluation. The economic benefit of new operation rules is calculated by reduction of the flood damage, while the cost is counted for the reduction of the rice production due to reduction of irrigation water supply in dry season and reduction of hydro-power generation.

4.3 Modification of Operation Rule

In accordance with the aforementioned strategy, the modification of reservoir operation rule is examined as follows:

4.3.1 Selection of Reference Point

Based on the flow capacities along the Chao Phraya River shown in Fig. 4.3.1, the reference points for operation of the reservoir are selected considering the main objective of flood mitigation by reservoir operation. That is, the main objective of flood control is to reduce flood inundation volume in agricultural areas because the major urban areas will be protected from flood by ring dikes, whose scale will be 1/100 years.

The reference points for each dam are selected as follows:

(1) Bhumibol Dam

The reference point for operation of Bhumibol dam is designated at the Nakhon Sawan, since the immediate downstream at the point forms a bottleneck of the downstream of the Chao Phraya River, before the river flows down to the Chao Phraya dalta and the flooding condition in the downstream can be broadly identified at the point. The flow capacity of the bottleneck is about 2,500 m3/s.

(2) Sirikit Dam

Nakhon Sawan and Phichit are selected as the reference points for operation of Sirikit reservoir. Since the Nan river has a bottleneck at the immediate downstream of Phichit and confluence to the Chao Phraya river at Nakhon Sawan. The flow capacity at Phichit reference point is 1,200 m^3/sec.

(3) Pasak Dam

As for the Pasak dam, because of its small reservoir capacity compared with inflow volume during flood period, it is difficult to stop the release of water from the reservoir completely, and the discharge from the reservoir is controlled by upper rule curve. Therefore, the purpose of selecting of the reference points is not to determine the reservoir operation but to evaluate the flood mitigation effect. That is, the flood mitigation effect is evaluated with reduction of inundation volume at reference points.

The reference points of the Pasak dam are selected at the Rama VI Barrage and the Chao Phraya Barrage focusing the bottlenecks of the Pasak river and Chao Phraya river. Flow capacity at the Rama VI Barrage and that of the Chao Phraya Barrage is 1,000 m^3/sec and 2,900 m^3/s, respectively.

4.3.2 Modification of Upper Rule Curve(URC)

According to the principle and procedure for modification of the rule curve mentioned in § 4.2.3, the URC of each dam is set up as follows:

(1) Bhumibol Reservoir

The result of water balance simulation for major past floods is shown in Table 4.3.1.

As shown in the table, the maximum stored volume is approximately 14,000 MCM for 1975 flood, and the required capacity to store the flood discharge is approximately 3,500 MCM. The maximum capacity of Bhumibol reservoir is 13,462 MCM, therefore, the reservoir has the difficulty on flood control for the scale of 1975 flood.

To cope with the situation, it is necessary to reduce the storage at the beginning of flood period to 9,950 MCM (13,462-3,500).

Starting with the storage of 9,950 MCM at beginning of flood period, the transition curve from the beginning to the end of the flood period for 1975 flood is drawn.

As for the other past floods, stored volumes do not exceed the maximum capacity of the reservoir and the aforementioned transition curve, therefore, the situation of these floods has no influence on modification of URC.

The proposed URC is set by enveloping the transition curve of storage for 1975 flood.

The URC during the dry season is set up in accordance with the current release plan during the dry season.(Refer to Table 4.3.2). That is, the release plan shows the monthly release rate for stored water at the end of wet season. For example, 12 % of stored water is released from the reservoir in December. According to this plan, the upper rule curve at the end of December is lowered by 12 % of the difference in volume between the storage of URC at the end of the wet season and that of the beginning of the wet season.

The lower rule curve is based on the present rule curve.

The rule curves are shown in Table 4.3.3 as well as in Fig. 4.3.2.

(2) Sirikit Reservoir

The result from water balance simulation for major past floods is shown in Table 4.3.1.

In Sirikit reservoir, the stored volume of 1995 and 1975 floods exceeds the maximum capacity of the reservoir. The maximum stored volume of 11,800 MCM is occurred in 1995 and the maximum required capacity to store the flood discharge is approximately 4,500 MCM for 1995 flood.

The maximum capacity of Sirikit reservoir is 9,510 MCM, therefore, it is necessary to reduce the storage to 5,000 MCM(9,510-4,500) at the beginning of flood period of 1995 flood, Aug.1.

Starting with the storage of 5,000 MCM at beginning of flood period, the transition curve of storage from the beginning to the end of the flood period for 1975 and 1995 flood is drawn through the water balance simulation.

The proposed URC in flood period is set by enveloping the transition curves of storage for 1975 and 1995 floods, and the URC for whole the year is set up in the same manner as for the Bhumibol Dam.

The new URC is shown in Table 4.3.2 and Fig.4.3.3, respectively.

(3) Pasak Reservoir

The Pasak reservoir can not operate with the same manner as the Bhumibol and Sirikit reservoir because of it's small capacity. The URC of the Pasak reservoir is set up in order to secure the flood mitigation functions by maintaining vacant capacity, when flood peak comes out.

From the viewpoint of flood mitigation, the most effective resolution is to secure the whole active capacity of 772 MCM for flood control operation. However, such reservoir operation may result in reduction of the storage at the end of the wet season and, consequently, the adverse influence for water supply occurs in the dry season. In this reason, the following three cases of URCs are examined considering the characteristics of reservoir and the flood period of the reference points:

- Case-1: URC without loss in water usage;
  The maximum vacant volume at Sep.15 is 559 MCM
- Case-2: URC with intermediate loss in water usage;
  The maximum vacant volume at Sep.15 is 662 MCM
- Case-3: URC for maximising flood control effect:
  The maximum vacant volume at Sep.15 is 772 MCM

The proposed upper rule curves are shown in Table 4.3.3 and Fig. 4.3.4, respectively.

4.4 Evaluation of Proposed Operation Rule

The benefit for flood mitigation and the compensation cost for adverse influence of water use are compared to the 'without' case. The without case of each reservoir operation is as follows:

- Bhumibol reservoir--- Present operation
- Sirikit reserboir --- Operation with proposed rule curve by KIN Study
- Pasak reservoir --- Operation with non- rule curve

Due to the current water shortage for irrigation, allocation on water release from the Bhumibol and the Sirikit reservoirs has been taken the initiative by RID throughout the year. In this study, considering this actual situation, water balance calculation for irrigation water supply and hydro-power generation is tentatively setup so as to meet the irrigation water supply.

4.4.1 Flood Mitigation Effect

The flood mitigation effect by the proposed reservoir operation is evaluated with reduced inundation volume of the reference points.

The flood mitigation effects for 5 major floods are shown in Table 4.4.1 and summarised as in the following table.

Reduction Volume of Inundation in Major Flood (unit : million m^3)

Name of Dam	Operation Case	1975 flood	1995 flood	Average (5 major floods)
Bhumibol	Without	3,436	3,681	1,998
	Proposed Operation	4,477	3,773	2,232
Sirikit	Without	2,323	2,725	1,180
	Proposed Operation	2,813	3,510	1,458
Pasak	Without	0	0	0
	Proposed Operation (case-1)	175	288	103
	Proposed Operation (case-2)	370	587	213
	Proposed Operation (case-3)	438	695	252

On focusing the result of 'the 1995 flood', historical maximum flood, the inundation volume of about 1,600MCM is expected to be reduced through the operation by proposed rule curve for three reservoirs. This volume corresponds to about 10% of the total inundation volume of 1995 flood.

4.4.2 Influence on Water Use

The compensation costs for adverse influences are based on the reduced amount from the case of proposed operation minus 'without' case aforementioned.

According to the stored volume at the end of the wet season(November 30), the principle for irrigation water supply is defined in aforementioned Fig. 3.4.1. Monthly water release ratio during the dry season and minimum required irrigation water supply in wet season are set as in the Table 4.2.2.

Based on the above-mentioned release plan for irrigation water supply, the reduction of water supply for irrigation and hydro-power generation is calculated through water balance simulation for 45 years(1952-1996).

(1) Reduction of Irrigated Area

Reduction of irrigated area, caused by reduced water supply during the dry season, is estimated in the same manner as in the Master Plan study. Reduction of water supply is converted, dividing by the required amount of water for unit area, to reduction of irrigated area.

Table 4.4.2 , 4.4.3 and Fig. 4.4.1 indicates the simulation result of the released volume for irrigation water supply in dry season.

The reduction of water supply and irrigated area is summarised as in the following table.

Reduction of Water Supply Volume and Irrigation Area

Item	Unit	Bumibol	Sirikit	Pasak		
				Case-1	Case-2	Case-3
Water supply volume in dry season	Million m^3	4,710	3,162	1,446	1,427	1,403
Reduced supply volume from case of 'without'	Million m^3	-	56	0	19	43
Reduced irrigation area from case of 'without'	1000 ha	-	2.3	0	0.9	2.1

(2) Reduction of Power Generation

Table 4.4.2 and Fig. 4.4.1 also indicate the generated electricity and the reduction for each year. The applied rating curve is the same as that in the Mater Plan study.

The reduction of the annual average power generation of the Bhumipol Dam and the Sirikit Dam is summarised as in the table below.

Reduction of Annual Average Power Generation (unit : Gwh)

Item	Bumibol	Sirikit
Annual average power generation	1,195	899
Reduction from case of 'without'	13	14

(3) Compensation Cost

The annual average compensation costs for irrigation water supply and hydro-power generation are calculated. The unit value of rice product and the unit net price of power generation are the same as in the Master Plan study. The total compensation costs are summarized as in the following table.

Annual Compensation Cost* (unit ; million Baht)

Item		Bhumibol Dam	Sirikit Dam	Pasak Dam			Total		
							With Pasak Dam		
				Case-1	Case-2	Case-3	Case-1	Case-2	Case-3
Compen-sation cost	Irrigation	-	16	-	6	15	16	22	31
	Power	18	19	-	-	-	37	37	37
	Total	18	35	-	6	15	53	59	68

* 1998 price

(4) Optimum Rule Curve

From the result of the calculation for compensation costs, the optimum rule curves of three reservoirs, namely the Bhumibol, the Sirikit and the Pasak, are recommended in accordance with the following reason:

- In both the Bhumibol and the Sirikit reservoirs, as is evaluated in 'Sector XIII –Economic Evaluation', the annual average benefit of 445 million Baht for flood mitigation is more than eight(8) times larger than the annual compensation cost. Therefore, proposed rule curves are justified as the suitable rule curves.
- As for the Pasak reservoir, the annual average benefits are quite large compared with the annual compensation costs of all cases, and every case is economically viable. As identified in Master Plan study, modification of reservoir operation rule shows higher economic viability compared with the other structural measures, and the flood mitigation effect by Case-3 is the biggest among others. From this reason, it is recommendable to apply Case-3 as the suitable operation rule curve for Pasak reservoir.

The proposed curves are shown in the following table and the operation results of three reservoirs with proposed operation are shown in Fig. 4.4.2

Optimum Operation Rule Curves (unit: million m^3)

Name of Reservoir	Curve	Jan. 1st	Feb. 1st	Mar. 1st	Apr. 1st	May 1st	Jun 1st	Jul. 1st	Aug .1st	Sep. 1st	Oct. 1st	Nov .1st	Dec. 1st
Bhumibol	Upper	13050	12250	11300	10500	10100	10050	10000	9950	10400	11750	13462	13460
Sirikit	Upper	8800	7800	6650	5700	5250	5100	5050	5000	7000	8900	9510	9300
Pasak	Upper	-	-	-	-	-	-	13	13	13	400**	785	-

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