(3) Study on Alternative Cases

(a) Alignment

Alignment is set along the existing channel, or along the irrigation canal course, but smoothing is applied for the stretch with severe meandering. In addition, the route is set in a manner to minimize built-up areas.

(b) Longitudinal Profile

Longitudinal profile is tentatively set, connecting the bottom height of sections between the beginning and terminal end considering the variation of bottom height between two sections. (Refer to Fig. 3.1.3.)

(c) Cross Section

In both cases of newly constructed channel and existing channel, cross section to confine the flood discharge is set in principle by widening with embankment. (Refer to Fig. 3.1.4.)

(d) Estimation of Cost (Widening, Embankment, Land Acquisition)

The major factors to decide the cost are work volume of widening and embankment, amount of land acquisition and number of house relocation. These figures are roughly obtained by applying the said alignment, longitudinal profile and cross section to the survey results including the topographic map. For the estimation of cost, the exchange rate as of December 1998 is applied; US$1.00 = ¥115.7 = 36.5 Baht. The cost is summarized in the following table. (Refer to Table 3.1.2.)

Summary of Cost of Diversion Channel Routes

Case	Diversion Route	Cost (in million Baht)		
		Case-A	Case-B	Case-C
1	Tachin River Diversion (Mouth to 319 km)	87,165	52,689	22,325
2	Chainat-Pasak-Rahpipat-Sea Diversion (Mouth to 260 km)	87,505	60,016	33,115
3	Chainat-Pasak-Rahpipat-Ban Pakong Diversion (Mouth to 362 km)	130,546	87,326	46,996
4	Pasak-Rahpipat-Sea Diversion (Mouth to 127 km)	42,728	30,051	18,126
5	Pasak-Rahpipat-Ban Pakong Diversion (Mouth to 229 km)	86,573	58,684	33,725
6	Ayutaya-West Bank-Sea Diversion (Mouth to 105 km)	74,353	52,339	30,336
7	Ayuthaya-West Bank--Tha Chin Diversion (Mouth to 160 km)	81,417	53,441	34,646
8	Ayuthaya-East Bank-Sea Diversion (Mouth to 96 km)	59,060	35,000	23,476
9	Chao Phraya II Diversion (Mouth to 57 km)	77,460	53,961	30,639
10	Greenbelt Diversion (Mouth to 78 km)	95,247	66,954	38,559

(e) Number of House Relocation

The number of house relocation is summarized in the following table.

Number of House Relocation

Case	Diversion Route	No. of House Relocation		
		Case-A	Case-B	Case-C
1	Tachin River Diversion (Mouth to 319 km)	6,500	4,000	1,500
2	Chainat-Pasak-Rahpipat-Sea Diversion (Mouth to 260 km)	2,400	2,200	1,700
3	Chainat-Pasak-Rahpipat-Ban Pakong Diversion (Mouth to 362 km)	3,000	2,800	2,000
4	Pasak-Rahpipat-Sea Diversion (Mouth to 127 km)	1,400	1,200	1,000
5	Pasak-Rahpipat-Ban Pakong Diversion (Mouth to 229 km)	2,000	1,900	1,300
6	Ayutaya-West Bank-Sea Diversion (Mouth to 105 km)	3,200	2,900	2,200
7	Ayuthaya-West Bank--Tha Chin Diversion (Mouth to 160 km)	3,600	2,500	1,500
8	Ayuthaya-East Bank-Sea Diversion (Mouth to 96 km)	1,600	1,500	1,400
9	Chao Phraya II Diversion (Mouth to 57 km)	11,000	8,000	5,700
10	Greenbelt Diversion (Mouth to 78 km)	2,500	2,300	2,300

(4) Selection of Optimum Route

The features related to cost and benefit of the ten (10) alternative routes are summarized in Table 3.1.2 and in Figs. 3.1.5 and 3.1.6. From the Table, the following points are noted:

- The number of house relocation which is one of the significant factors from the social aspect, is less in Case 4, Case 8 and Case 5 in that order.
- The order of construction cost among the ten (10) routes is different depending on the case of diverted discharge. For Case B, at the diverted discharge of 1,000 m^3/s, construction cost is less in Case 4, Case 8 and Case 9 in that order.
- Although project benefit is not evaluated yet, project effectiveness can be roughly evaluated by the ratio between the cost and number of benefitted people corresponding to the residents in the beneficial area. Judging from the ratio, benefit comes in Case 4, Case 2 and Case 8 in that order.

From the above comparison results, it seems that one of the optimum routes of diversion channel is Case 4, Pasak-Paphipat-Sea Route. The applicability of the Chainat-Pasak-Raphipat-Sea Route and the Ayuthâya-East Bank-Sea Route is also worthy of examination. (Refer to Fig. 3.1.7.)

As for the two alternatives utilizing the Ban Pakong River, they require a huge construction cost and need a lot of house relocation. Thus, these two alternatives are not recommendable for further study. However, regarding the utilization of Ban Pakong River, it is considered that the diversion channel of Case 4 be connected to Ban Pakong River near the river mouth, so that maintenance of the mouth of the diversion channel can be facilitated. This is discussed further in the feasibility study after confirmation of the suitability of diversion channel.

(4) Necessity of Further Study for Optimization

As discussed above, the flood diversion channel is also one of the applicable structural measures. For the optimization of route and scale of diversion channel of the three routes (Pasak-Raphipat-Sea, Chai Nat-Pasak-Raphipat-Sea, and Ayuthaya-East Bank-Sea) it is necessary to conduct a further study on the combination with other measures after confirmation of the effectiveness by simulation.

For the Ayuthaya-East-Sea route, further discussion was made and an alternative route was proposed considering the present and future land use condition.

In Appendix, the study results of the rough comparison of the alternative routes, Ayuthaya-East-Sea (1) and (2) for the route were summarized. (See Appendix in this sector.)

3.1.3 Tidal Barrage with Pump

(1) General

The construction of a tidal barrage has been proposed and its effectiveness was examined in the previous study named "Chao Phraya Flood Management Review" in 1996. As the result of hydraulic simulation, the negative reverse flow, which emerges in the range of 1,000 m^3/s at maximum when the tide rises up, is cut off. The discharge capacity of the Chao Phraya River is thus increased from 3,000 m^3/s to 3,250 m^3/s by the operation of barrage, considering the water level reference point at Pakret.

In this present study, the effectiveness of a tidal barrage is further examined in combination with drainage pump, which can lower the water level through constant drainage of flood discharge.

(2) Location and Plan

The tidal barrage is proposed at the river mouth of the Chao Phraya River, as shown in Figs.3.1.8 and 3.1.9.

(3) Hydraulic Calculation Condition

The effectiveness was examined by hydraulic calculation in the following conditions:

(a) Non-uniform calculation method is applied assuming that the influence of tidal fluctuation is negligible with the construction of a tidal barrage.

(b) The calculation stretch is from the river mouth to Chainat Barrage, applying the cross section data surveyed in 1983.

(c) The following combinations of initial water level and discharge are adopted:

- *Initial water level:* Four (4) cases (1.70 m, 1.0 m, 0.8 m, and 0.5 m above MSL)
- *Discharge:* Five (5) cases (1,000, 2,000, 3,000, 4,000 and 6,000 m^3/s)

(4) Calculation Results

The calculation results are shown in Fig. 3.1.10. Based on the calculation results, the following effectiveness are assumed:

(a) In the case of initial water level of MSL+1.60 m and discharge of 3,000 m^3/s, the calculated water level roughly corresponds to the design water level for construction of polder dike as proposed by the BMA. Thus, the river channel will have the flow capacity of 3,000 m^3/s and the clearance of about 1 m for the design dike height.

(b) In the case of a combination of initial water level of MSL+1.0 m, 0.8 m and 0.5 m and discharge of 4,000 m^3/s, the calculated water level shows the influence of initial water level until the 45 Km upstream point from the river mouth. Thus, for the flood discharge of 4,000 m^3/s, the effect of pumping station is expected until the 45 Km upstream point. It is noted in this connection that the Bangkok metropolitan area is located in the stretch between the 20 Km and 85 Km upstream points.

(c) In the case of a combination of the above initial water level and the flood discharge of 3,000 m^3/s, the influence can be expected until the 130 Km point upstream. Especially, assuming that the pump is fully operated to keep the water level at MSL+0.5 m, the water level at Bangkok can be lowered to about 1.0 meter below the proposed design water level. Thus, it is possible to lower the design dike height at Bangkok to 1.0 meter below the proposed design dike height.

(d) In the case of combination at the initial water level of 0.5 m, the pump has to be operated for 45% of the day according to the tidal level at the river mouth (refer to Fig. 3.1.11). This will affect navigation conditions.

(5) Cost Estimate

The construction cost of the barrage and pumps is roughly estimated, as shown in the following table.

Work Item	Cost (in million Baht)
Pump Equipment and Pipe	90,000
Pumping Station	4,500
Diversion Works	4,320
Weir	15,000
Navigation Channel and Lock	5,000
Miscellaneous Works	8,000
Land Acquisition	4,000
House Relocation	200
Total	131,020
(O&M Cost)	6,500/year

(6) Evaluation of Measures by Barrage and Pump

As identified by the hydraulic calculation, the measure consisting of barrage and pumps is effective in lowering the flood water level at Bangkok up to the flood discharge of 3,000 m^3/s. Considering the difficulty to implement the embankment of polder around the Bangkok metropolitan area and the influence of land subsidence inside the area, it is crucial to lower the water level in the Chao Phraya River channel.

Apart from this downstream condition, the flood discharge at Chainat upstream of Bangkok sometimes reaches the level of 5,000 m^3/s to 6,000 m^3/s, and this measure is not effective to control these flood discharges. Furthermore, this measure requires a huge cost and involves social problems influencing navigation, although it does not need any house relocation.

Accordingly, it is determined that this alternative measure should not be implemented immediately, and thus, this measure is not taken into consideration for further study on alternatives. However, it should also be noted that there is a possibility for this measure to be considered in combination with other measures in the future.

3.1.4 Retarding Basin

As discussed in the Strategy of the Master Plan, the basic concept for the flood mitigation is the preservation of the present natural retarding effect, which most of the agricultural areas are currently functioning in flood time. For the preservation of the present natural retarding effect, it is essential to apply the nonstructural measures, especially control of land use and guidance.

On the other hand, retarding basin, in general, involves the introduction of some structures to let a certain area or areas have a retarding function through structures such as embankment, water intake facilities and drainage facilities. To apply such an area as a retarding basin, it is necessary to purchase or compensate the area for its utilization.

In this connection, the following points are emphasized for the study on retarding basin:

- Possible enhancement of the present natural retarding function through the introduction of additional facilities.

- Possible employment of areas such as swampy areas and ponds as retarding basin.

(1) Possible Enhancement of the Present Natural Retarding Function

Paddy fields widely spread in the flood prone area and they are used as the target area to examine the possibility. However, due to topographic disadvantages, the paddy fields are not effective as retarding basin to enhance the retarding function. Furthermore, a huge compensation cost as well as construction cost is required for the necessary facilities, which were confirmed through the cost comparison for the hydrological effectiveness. Thus, it is not recommendable to employ the paddy field as a retarding basin.(Refer to Fig.3.3.10.)

(2) Possible Employment of Areas such as Swampy Area as Retarding Basin.

(a) Site Conceivable as Retarding Basin

In the Chao Phraya River Basin, the following areas are conceived as sites for retarding basin judging from the topographic and runoff conditions:

- Existing lake and large swamp
- Ponds along the old river course

(b) Evaluation of Applicability of Retarding Basin

As the result of rough evaluation of effectiveness, the possible retarding basins are as summarized in the following table:

Evaluation for Possible Retarding Basins

Item	Sub-item	Possible Area for Retarding Basin (km^2)
Existing Lake and Large Swamp	Bung Boraphet Lake	219.8
Pond along Old River Course	-	Not Applicable

In this connection, the applicability of Bung Boraphet Lake is considered as follows:

- Bung Boraphet Lake is presently used as a large scale fishing farm under the administration of the Fishery Department. Therefore, a social problem will arise for people engaged in the fishing farm when the lake is used as a retarding basin.
- The area surrounding the lake is a precious habitat for wildlife as designated in the United Nations Convention for Wetlands (Ramsar Convention). Therefore, to take any artificial action for utilization of the lake as a retarding basin will also cause a significant environmental problem.

Thus, it is not advisable to apply the lake as an artificial retarding basin, because it is envisioned to function as a natural retarding basin.

(4) Necessity of Further Study for Optimization

In view of the above considerations, a further study on retarding basin was not undertaken in the Master Plan stage. However, a study for preservation of the natural retarding effect by nonstructural measures was made.

3.2 Preliminary Selection of Nonstructural Measures

Nonstructural measures are essential to mitigate flood damage or risk through various means such as modification of reservoir operation rule, land use control, flood disaster response, financial response and institutional setup. They are also necessary to maximize the effect of structural measures. The applicability of the following six (6) nonstructural measures was examined in this study.

(1) Modification of Reservoir Operation Rule

(2) Strengthening of Control and Guidelines

- Land Use Control and Guidelines for Development
- Groundwater Extraction Control

(3) Flood Disaster Response

- Flood Forecasting and Warning System
- Flood Fighting Activity
- Disaster Recovery

(4) Financial Response

- Subsidy and Taxation
- Flood Insurance

(5) Watershed Management

(6) Institution and Organization

3.2.1 Modification of Dam Reservoir Operation Rule

The potential use of both existing and planned dams for flood control is herein examined through a review of their operation rules for five (5) dams selected among 45 dams. These are the Bhumibol, Sirikit, Kwae Noi, Kaeng Sua Ten and Pasak dams, and their locations are as shown in Fig. 1.5.1.

Modification of operation rule is examined in the following procedure:

(1) Setting up Operation Period for Flood Mitigation

The period of reservoir operation is decided as below, expecting the effectiveness for flood mitigation at the reference points:

- Sirikit Dam: July 1st to November 30th
- Kwae Noi Dam: August 1st to October 15th

- Kaeng Sua Ten Dam: August 1st to September 15th
- Pasak Dam: September 1st to October 15th

(2) Setup of Reservoir Capacity for Flood Mitigation

Three (3) cases of the reservoir capacities are proposed as follows:

- Case-1: In this case an ideal capacity for flood mitigation without any loss to irrigation and power generation is proposed.
- Case-2: This case accepts a loss to irrigation and power generation to some extent. The reservoir capacity is set as the medium case between Case-1 and Case-3.
- Case-3: This case is a case for the maximum development. The active storage volume is fully used for flood mitigation.

The proposed reservoir capacities for flood mitigation are summarized as follows:

Reservoir Capacity for Flood Mitigation (million m^3)

Dam	Case-1	Case-2	Case-3
Bhumibol	2,960	4,000	5,500
Sirikit	2,810	4,600	6,500
Kwae Noi	597	665	733
Kaeng Sua Ten	575	850	1,125
Pasak	473	605	772
Total	7,415	10,720	14,630

(3) Setup of Rule Curve for Reservoir Operation

After determining the operation period and the flood mitigation capacities, operation curves are drawn as shown in Figs. 3.2.1 and 3.2.2.

(4) Costs for Modification of Reservoir Operation Rule

The modification of reservoir operation rule will affect the original functions of the reservoir, through the reduction of water supply for irrigation and hydropower generation. Therefore, it is necessary to compensate such loss, and the compensation cost is regarded as the cost for modification of reservoir operation rule.

The total annual compensation costs are summarized in the following table.

Average Annual Compensation Cost (in million Baht)

Item / Case	Total			Bhumibol			Sirikit			Kwae Noi			Pasak			Kaeng Sua Ten		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Average annual compensating cost	-	10	234	-	-	41	-	-	148	-	5	12	-	1	6	-	4	27

(5) Necessity of Further Study for Optimization

Modification of the reservoir operation rule is one of the essential nonstructural measures to expect the effectiveness of flood mitigation in a quantitative manner. Therefore, it is necessary to confirm the effectiveness of each case by flood simulation.

3.2.2 Strengthening of Control and Guidance

For the Chao Phraya River Basin, the following considerations are taken in terms of management strengthening: control of land use and guidance to land development and control of groundwater extraction.

(1) Land Use Control and Guidance to Land Development

In the Chao Phraya River Basin, land development is being promoted in accordance with the economic growth. Such land development is sometimes conducted in a disorderly manner such as the urbanization of flood prone area and the conversion of paddy from low yield variety to high yield variety in low-lying land resulting in the increase of flood damage potential.

Land development in a flood prone area will result in the decrease of retarding function during floods. Thus, it is necessary to control land use and provide guidance to land development to minimize the increase of flood damage potential and decrease of flood retarding function.

(a) Control of Major Land Use Changes in the Basin

In Sector III, Land Use, the major land use changes in the basin are described as urban development of agricultural land, change of cultivated crop from paddy to tree or upland crop, and conversion of forest land into agricultural land.

(b) Land Use Control and Guidance to Land Development through Flood Risk Map

As mentioned above, the disorderly land use of flood prone areas in the basin will result in the increase of flood damage potential and loss of retarding function. To control such a disorderly land use, it is essential to prepare a flood risk map that will show not only the flood risk area but also the retarding area. Land development shall thus be guided according to the flood risk map.

In this study, the flood risk map (or flood hazard boundary map) is prepared for the Chao Phraya Delta. This map indicates the inundation area together with the average inundation depth and recurrent probability. Based on the map, the assumed flood prone area is broadly classified according to the following considerations:

- Bangkok and other major cities will be inundated in the case of over a 100-year return period flood event.
- Rural towns and villages will be inundated in the case of over a 25-year return period flood event.
- Riverine belts having the width of 0.5 to 1.0 km and confined by flood dike or road at both sides of riverbanks will be habitually inundated in every few years.
- Farmlands that are designated as retarding basin will be habitually inundated in every few years.
- Farmlands that are designated as floodwater conservation area will be inundated in the case of over 5 to 25-year return period flood event.

Land use shall be controlled considering the risk of inundation. In case land development is planned in a habitually inundated area, protection works shall be obligatory to minimize the flood damage potential.

Moreover, land development with the provision of public facilities shall be planned, by referring to the flood risk map to minimize the decrease of retarding function. Among the public facilities, roads in a flood prone area are vulnerable to flood damage and they sometimes hamper the free movement of floodwater resulting in the loss of retarding function of the flood prone area. Thus, the construction of roads shall be planned in consideration of flood risk by minimizing the damage potential and not decreasing the retarding function of the flood prone area.

(2) Control of Excessive Groundwater Extraction

In Bangkok and vicinity in the Chao Phraya River Basin, land subsidence due to excessive groundwater extraction is one of the major issues related to flood control. The land subsidence is directly connected to the decrease of dike height resulting in the decline of safety level against floods of the Chao Phraya River.

In the previous study result, it is mentioned that the rate of land subsidence along the Chao Phraya River in Bangkok and vicinity will gradually come to a constant level of 2 cm/year. Assuming that the rate of 2 cm/year will continue up to the target year 2018, the flood barrier being constructed by BMA with a crest elevation of EL. 3.00 m above MSL, for example, has the possibility to settle down to the level of EL. 2.60 m, and this implies a corresponding reduction in the river discharge capacity. Thus, the control of excessive groundwater extraction is strongly recommended so as not to lower the safety level of dikes against flood of the Chao Phraya River.

To realize the control of excessive groundwater extraction, nine (9) scenarios were prepared by the JICA Study in 1995, i.e., the first (most severe scenario) up to the ninth (optimistic scenario) and the rate of 2 cm subsidence seems to be achieved, at least, under the fifth scenario. Thus, in this Study, it is recommended that the fifth scenario (5B) shall at least be executed as stated below, although it is desirable to control groundwater extraction under the most severe scenario.

Scenario-5B. Control of Groundwater Extraction

2000-2010	Regulate all types of pump, except that pumping by MWA is reduced from 100% to 50% of 2000's amount.
2011-2017	Reduce all types of pump, except that pumping by MWA is kept constant at 50% of 2000's amount.
2011-2017	Maintain 75% of 2000's amount.

The previously presented Fig. 2.2.6 in Section 2 demonstrates the estimated subsidence in Bangkok and vicinity under the strict control given above. Fig. 2.2.7 demonstrates the estimated subsidence along the Chao Phraya River course.

(3) Necessity of Further Study

Control of land use and guidance on land development and control of groundwater extraction are also essential measures to mitigate flood damage. However, the effectiveness of these measures is sometimes uncertain, because the realization of these measures will rely on public participation and efforts by agencies concerned. Considering such conditions, the necessity of further study is examined after the confirmation of effectiveness by the simulation model.

3.2.3 Flood Disaster Response

(1) Flood Forecasting and Warning System

(a) Flood Forecasting System in the Chao Phraya River Basin

Up to the present, no comprehensive flood control project covering the whole Chao Phraya River Basin has been prepared, i.e., flood control works have been executed locally or as a secondary purpose only. It is, therefore, imperative that effective measures be figured out on the basis of a long-term and wide-view strategic plan, considering that it will take a long time to realize a comprehensive flood control plan due to the large area of the basin. The flooding problem has to be resolved urgently.

A flood forecasting system is one of the solutions to urgently mitigate the flooding problem; besides, it also contributes to flood risk management even after the long-term strategic plan is provided. Thus, several flood forecasting systems have been implemented by several agencies in the Chao Phraya River Basin for their own purposes, as summarized below.

(i) Flood Forecasting System of MED

MED operates weather radar stations in Bangkok and Chiang Mai, making qualitative predictions regarding rainfall for weather forecasts. The data of a total of 72 rainfall stations throughout the basin are transmitted every hour in time of flood and delivered to RID.

(ii) Flood Forecasting System of EGAT

EGAT has a flood forecasting system based on a combination of models and empirical techniques. The stream flow component is used to predict the catchment runoff to the Bhumibol and Sirikit reservoirs for dam operation. Hydrologic data from the dams are delivered to RID.

(iii) Flood Forecasting System of RID

RID operates more than 100 rainfall and many water level gauges, with radio and telephone communication to the central operations office in Bangkok, for flood protection works mainly in agricultural areas and for the operation of flow control facilities. All but a few of the gauges are in the lower basin below Nakhon Sawan, where they serve in the operation of the irrigation distribution system.

(iv) Flood Forecasting System of BMA

BMA established a Flood Control Center with telemetric links to 25 monitoring stations for rainfall, water level, pump operation, gate opening and water quality for inland drainage and flood protection works in the Bangkok metropolitan area.

(v) Flood Forecasting System of PAT

PAT operates 8 tidal water level gauges in the lower 20 km of the Chao Phraya River. There are no special facilities to report the data in real time.

(b) Outline of Flood Forecasting System of EGAT and RID

Among the above forecasting systems, those of EGAT and RID are, in principle, able to cover the whole Chao Phraya River Basin. The outline of these systems is as follows:

EGAT had started flood forecasting for dam operation since 1979, and the flood information is transmitted to RID and other agencies concerned. The flood forecasting is based on the flood forecasting model developed by AIT. The model consists of sub-models, namely, stream flow synthesis and reservoir regulation, empirical runoff calculation, grid model and harmonic model. By using these sub-models, the future water stage is predicted seven days in advance at the Memorial Bridge in

Bangkok, together with the inflow volume to the Bhumibol and Sirikit dams and the discharge at Nakon Sawan Station.

In 1988 RID conducted the study on flood forecasting system under the JICA technical cooperation program to introduce a new system aimed at improving the AIT model through the utilization of a new hydrological observation system and a data transmission system. As for the former system, the introduction of radar rain gauge as well as increase of number of hydrological gauge stations was emphasized, while radio transmission link for exclusive use and online system with data transmission were emphasized in the latter system.

(c) Issue on Current Flood Forecasting System

In general, the major requirements for a flood forecasting system are the assurance of accuracy of forecasting results and enough duration of forecasting time, based on which flood fighting and urgent flood protection works are undertaken by the agencies concerned.

In the currently practiced flood forecasting system, enough forecasting time is assured because of the longer traveling time of flood from upstream to downstream where provision of urgent flood protection works are emphasized and more effective than in the upper basin. However, as for the accuracy of forecasting results, there may be some room for improvement, because the flood forecasting system has not been remarkably changed; i.e., RID practices flood forecasting based on the information transmitted by EGAT, although the number of hydrological stations has been slightly increased. Besides, EGAT disseminates the flood prediction results only by hand to RID and BMA in the form of weekly reports. A more frequent dissemination is considered necessary.

(d) Improvement of Flood Forecasting System

To enhance the accuracy of forecasting results and to disseminate the flood prediction results more often, the following improvements to the system are conceived:

- Improvement of hydrological observation network
- Improvement of data transmission system
- Improvement of data management system
- Improvement of data dissemination system
- Improvement of flood forecasting model

In principle, these improvements were proposed in the "Flood Forecasting System Based on Updated Facilities" (JICA Study in 1988), although some systems may need further improvement in accordance with the development of technology and the change of basin conditions after then. The improvements of system proposed on the basis of the previous JICA Study are summarized as follows:

(i) Improvement of Hydrological Observation Network

The following new hydrological stations are proposed (refer to Fig. 3.2.3 and 3.2.4):

Rainfall Gauging Station	65 places
Water Level Gauging Station	26 places
Rainfall/Water Level Gauging Station	19 places
Radar Rain Gauge	2 places

(ii) Improvement of Data Transmission System

The data transmission system proposed is featured as follows (refer to Figs. 3.2.5 and 3.2.6):

- To assure the reliability and speed of data transmission, the radio transmission link for exclusive use is employed.
- To prevent occurrence of error due to manual intervention, the online system with data transmission is employed.
- Mutual exchange of information and instruction is made by means of voice communication.

(iii) Improvement of Data Management System

For the improvement of data management system, both hardware and software are required. The hardware shall consist of the engineering workstation (EWS), the data storage equipment, the printer and color hard copy unit and the video projector. The configuration of a data management system is shown in Fig. 3.2.7.

Likewise, major software shall include the operating system, as well as utility and application programs.

(iv) Improvement of Data Dissemination System

For the effective use of flood prediction results, it is necessary to disseminate information to agencies involved in the flood protection and flood fighting works. The agencies involved are LAD, BMA, EGAT, and RID Regional Office No. 7 and No. 8. The facilities to be provided at the agencies concerned are the remote terminal computer for monitoring, facsimile/telephone and hotline telephone.

(v) Improvement of Flood Forecasting Model

In the previous JICA Study, the flood forecasting models were composed of the following sub-models:

- Basin runoff prediction model based on the tank model calculation method.

- River channel routing model based on the storage function method.
- Flood plain routing model based on the empirical calculation method.
- Tidal influence model based on the unsteady flow calculation method.

As to simulation results, the proposed flood forecasting model can provide enough results for flood protection work. However, it is necessary to modify the model based on the recent river and basin conditions because of change of basin conditions during the recent nine (9) years.

In this connection, consideration is made on an alternative to develop a new flood forecasting model based on the simulation model applied in this Study.

(e) Flood Warning System

(i) Present Status of Flood Warning

At present, flood warning is issued by agencies concerned as follows:

- *Warning issued by MD Nationwide:* The Meteorology Department issues flood warning nationwide based on the weather forecasting results. The warning is issued through the mass media such as the TV, radio and newspapers.
- *Warning issued by MD Basin-wide:* The Meteorology Department also issues warning on floods for the Pasak River Basin based on the flood forecasting results, applying the water level correlation method.
- *Warning issued by RID in relation to Dam Operation:* In connection with dam operation, RID issues warning to people in the downstream, when dams such as Bumibol and Sirikit need to release excess water urgently.
- *Warning issued by RID in case of a large scale flood:* RID issues a warning when a large scale flood is expected on the Chao Phraya River Basin. As the indicator to issue the warning, the flood discharge at Nakhon Sawan is adopted when it is over 3,000 m^3/s. The warning is disseminated to the RID Regional Office, which further disseminates it to the Governor. Finally, the warning is disseminated to the public through the mass media.

(ii) Deficiencies of the Present Warning System

Among the warnings issued on different occasions as mentioned above, only the warning issued by RID in case of a large scale flood is addressed in this Study. The warning has the following deficiencies:

- The warning is issued on the basis of experimental judgment. There is no guideline to specify the objective, responsibility and so on, so that the authorization of warning is not clear.
- Since the reference point of warning is only Nakhon Sawan, the flood caused by the other basins may sometimes be neglected.
- Since the warning is issued once at a certain level of flood discharge, the agencies concerned hardly take consecutive action.

(iii) Improvement of the Flood Warning System

In view of the issues of the present flood warning system, it is necessary to make it more systematic through the preparation of a guideline for warning systems. The guideline shall specify mainly the following items:

- Objective, role, responsibility and restriction of the warning system.
- Agency issuing the warning.
- Setup of reference points to issue the warning together with the timing of action. For that purpose, several water stages at reference points shall be designated for different levels of action.

(2) Flood Fighting

As well as the establishment of flood forecasting system, flood fighting is also regarded as one of the essential measures as flood disaster response to mitigate flood damage. In this Study, flood fighting is defined as urgent and temporal activities to cope with a flood right before, during, and right after a flood.

(a) Agencies Concerned in Flood Fighting

In the Chao Phraya River Basin, flood fighting is undertaken by the following agencies to protect their respective management areas of responsibility:

- *Civil Defense Committee:* Policy decision and planning of flood fighting for entire Thailand including the Chao Phraya River Basin. The Local Administration Department (LAD) plays the role of Secretariat to the Committee.
- *BMA (Department of Drainage and Sewage, DDS):* Execution of flood fighting for the protection of the Bangkok metropolitan area.
- *RID:* Execution of flood fighting for the protection of agricultural areas.

- *Provincial Governments:* Execution of flood fighting for the protection of provincial urban areas in cooperation with LAD, RID and the Department of Public Works (PWD).

(b) Practice of Flood Fighting

Flood fighting is, in principle, practiced every flood time by the agencies concerned. As to the recent flood fighting activities, those in the 1995 and 1996 floods are specified.

In the 1995 flood, 2,000 RID staff and farmers, together with about 400 from each major province and the Bangkok Metropolitan Administration (BMA), were engaged in the flood fighting activities assisted by the military and volunteers. The flood fighting activities were mainly conducted in a manner of piling up of sandbags on the embankment to mitigate the spill of floodwater from the river channel and the operation of movable pumps to facilitate drainage from the inundation area.

Based on these activities, it is in general evaluated that the present system of flood fighting is relatively well developed and organized. The system is funded by the agencies concerned such as RID, BMA and the Local Government.

(c) Deficiencies of the Present Flood Fighting System

Although the responsible agencies make every effort on flood fighting, it is also pointed out that there are several deficiencies of the present system. The following deficiencies are among them:

- Budgetary constraint to prepare enough materials and equipment, as well as manpower
- Lack of enough engineering skill to apply and develop the suitable flood fighting methods, including materials and equipment.
- Shortage of enough flood information to execute the flood fighting works.
- Shortage of educational program for inhabitants who join the flood fighting operations.
- Conflict among inhabitants to be protected, due to adverse influence resulting from the flood fighting.
- No specific law or regulation to deal with floods.

(d) Establishment of Suitable Flood Fighting System

To cope with the current issues mentioned above, the following proposals are made for the establishment of a suitable flood fighting system:

- Assurance of funds for the operation of a suitable flood fighting system with enough equipment, materials and manpower through the decision of protection level.

- Analysis of a suitable flood fighting method, considering the required equipment, materials and manpower, based on the previous flood damage condition.
- Establishment of a suitable dissemination system to inform the flooding condition to people concerned.
- Periodical training of inhabitants expected to join the flood fighting works.
- Educational campaign and advertisement on the necessity of flood fighting system to avoid conflicts among people concerned, and the introduction of remedial measures to compensate for the adverse influence.
- Promulgation of a law on flood fighting to clarify the administration structure and job responsibilities of all concerned agencies, resulting in a well organized and more effective flood fighting.

(3) Flood Disaster Recovery

When suitable actions for flood recovery are not properly undertaken, flood disasters are sometimes severe even after the direct flood damage has almost settled down. In the case of Chao Phraya River Basin, it is essential to provide recovery works in a proper way, because the flood damage sometimes lasts for a long time resulting in a secondary disaster due to waterborne diseases.

Although the statistics of the Ministry of Health do not suggest any causal relationship between the recent flood and communicable waterborne diseases, the Ministry pointed out that diseases such as mosquito carried diseases, skin diseases and gastrointestinal diseases are remarkable when flood inundation lasts long.

To prevent such waterborne diseases, the Ministry of Health makes effort to provide drinking water and first aid kits, including deployment of ambulance and district and sub-district health officers assisted by about 600,000 volunteers nationwide.

To support and strengthen such an effort, prompt action for recovery works should be taken by agencies concerned. Such recovery works are emphasized with the prompt drainage of inundation water. They are grouped into the following items of work:

- Prevention of inflow water into inundation area through rehabilitation of damaged portions of flood protection dike.
- Promotion of drainage of inundation water through rehabilitation of damaged drainage channel and temporary provision of drainage facilities.

Although the data showing such activities are not well arranged, the former item of work is promptly taken as a whole, according to the interview survey, but sometimes delayed due to financial constraint. The latter item, on the other hand, is scarcely undertaken, because the significance of introducing the works is not well understood.

In this connection, the following actions are proposed for the implementation of prompt recovery works:

- Promotion of advertisement and educational campaign on the necessity of prompt action for recovery.
- Assurance of enough funds for the recovery based on expenses for implementation of such required works in previous floods, including contingency in case of a severe flood.

(4) Necessity of Further Study

The above three nonstructural measures are essential to mitigate flood damage and they are applicable to the formulation of the Master Plan. However, the effectiveness of these measures cannot be evaluated in a quantitative manner and the features of these measures are thus discussed simply on the master plan study level in this section. In this study, no further study is undertaken for these three measures.

3.2.4 Financial Response

(1) Subsidy

(a) Necessity of Subsidy

Agricultural production is, in general, vulnerable to abnormal weather condition such as drought and flood, so that people engaged in the production can hardly stabilize their living conditions. For a sustainable development of the nation, it is essential to stabilize living conditions of people engaged in agricultural production. For this purpose, the introduction of a support system is considered in the form of subsidy in case of damage due to abnormal weather conditions.

(b) Current Support System by the Government

As one of the major current support systems provided by the government, the subsidy for agricultural damage is taken up. A subsidy for agricultural damage has been established in MOAC, as outlined below.

(i) Objective

The objective of this system is to compensate for agricultural damage due to natural disasters such as drought and flood and abnormal breaking out of insects.

(ii) Compensation Method

The compensation is made by providing materials such as seedlings and fertilizers to damaged objectives for the subsequent cropping and not in the form of money.

(iii) Organization Concerned

DOAE (Department of Agricultural Extension), and the Fishery Department, MOAC are the agencies executing compensation works.

Another support system is the reduction of interest on loans provided by the government. For planting, farmers get loans to purchase seeds and fertilizers and to hire machinery for cultivation. In case flood occurs and agricultural products are damaged, the interest on loans is reduced when the farmers repay the money. This is managed by RID.

(c) Consideration on the Current Support System

As discussed above, people engaged in agricultural production are benefited in the current support system in the form of compensation and reduction of interest for flood damage on a certain range. However, it is pointed out that the level of compensation is less than enough to cover damages, especially flood damage. Thus, strengthening of the current support system to compensate for flood damage and to reduce the interest on loans is considered.

(2) Flood Insurance

It seems that the subsidy provided by the government is not sufficient to support people frequently suffering from flood damage, because of financial constraint. To cope with this shortage, the application of another system in the form of flood insurance by the public sector is considered.

So far several trials on agricultural insurance have been examined in the form of insurance for damage to agricultural products such as paddy, maize, cotton, soybeans, and livestock, including cattle and pig. However, not all trials have been successful mainly due to shortage of funds, insufficient information to decide the insurance premium and so on. As the result, there is no law on agricultural insurance, but only laws for general insurance, and there is no insurance company selling insurance for agricultural damage. Moreover, people engaged in agricultural production have no interest in buying such insurance due to lack of information and knowledge, and lack of finance.

Under the circumstances, in the 8th Agriculture Development Plan from 1997 to 2001 approved by the Cabinet Meeting in November 1996, it was proposed that the Government should take the following actions on such agricultural insurance:

- To promote agricultural insurance for products such as staple food and exported products with high benefit based on the existing system;
- To promote necessary institutional arrangements including subsidy to strengthen the agricultural insuranse system; and
- To develop the agricultural insurance through systems improvement for the agricultural industry.

Although the above discussion is not only for flood insurance but includes damages caused by other natural disasters, strengthening and improving of the existing agricultural insurance system in the form of flood insurance is proposed in this study. The flood insurance for agriculture or buildings in other countries is outlined below for reference.

(a) Agricultural Insurance in Japan

The Government of Japan established the agricultural insurance in 1947 to insure the estimated loss from standard agricultural production, as summarized below.

(i) Objective

The objective of this system is to insure agricultural damage on rice, fruit, livestock, sericulture and some designated upland crops such as potato and cereal, due to drought, flood, strong wind, fire, pest and insect, etc.

(ii) Insurance Method

Based on the standard yield determined by accurate agricultural statistics on individual fields, the damage of more than 30% of the standard yield is insured by the official price. About 50% of the insurance premium is paid by the individual farmer and the Government subsidy, respectively.

(b) Insurance Program for Buildings in the USA

In the USA, the National Flood Insurance Program (NFIP) was established by the Government in 1968 to insure the estimated loss of buildings and houses as summarized below.

(i) Objective

The system is a basic tool to successfully carry out flood plain management and to alleviate flood damage potential through insurance of buildings, houses and facilities.

(ii) Insurance Method

The inhabitant can buy the insurance through an insurance agent. However, government subsidy is only for extreme floods determined according to a special fund of the American Flood Insurance Fund.

For the application of this insurance, the following conditions must be satisfied:

- To join NFIP.
- To observe flood plain management regulations on the basis of flood hazard boundary map.

- To control all new constructions under the building construction regulation.

(3) Difficulty of Realization of Financial Response

As discussed above, two nonstructural measures are considered to strengthen or improve the current system; namely, subsidy and flood insurance for agricultural products. Although these measures are helpful to support and stabilize the life of people engaged in agriculture, there are several difficulties for realization of financial response. They are specified as follows.

(a) Equity Problem

Both measures involve income transfer from the government to the flood victims, thus the equity problem emerges. This is a sensitive and delicate domestic issue to deal with.

(b) Difficulty of Implementation

The following are constraints for implementation of the measures:

- Pre-determination of extent flood victim compensation.
- Identification of flood victims among people who may pretend to be flood victims.
- Minimization of dependency of victims to the Government.
- Operation and management of the flood insurance by a private company.

To cover up for these difficulties, many agencies with specialists and authorities to make decisions may be involved, so that it will take a long time to establish measures for financial response. In this regard, further discussion on measures for financial response is not undertaken in this study.

(4) Necessity of Further Study

As well as the three measures in flood disaster response, these two nonstructural measures are also essential to mitigate flood damage and they are applicable to the formulation of the Master Plan. However, the effectiveness of these measures cannot be evaluated in a quantitative manner, so that the features of these measures are discussed simply in the master plan study level in this section. No further study is therefore made for these two measures.

3.2.5 Watershed Management

As discussed in Chapter 3, the forest area was reduced from 166,000 km^2 in 1942 to 106,000 km^2 in 1983, and 92,000 km^2 in 1995. Such deforestation influences the flood phenomenon through the reduction of water conservation, resulting in the increase of peak flood discharge as well as decrease of low water discharge. The influences to the flood phenomenon due to reduction of forest area are hardly evaluated in a quantitative manner as shown in the following statements in the AIT Report named "Chao Phraya Flood Management Review":

- Quantification of the effect of deforestation on runoff is difficult, and statistical analyses of runoff over the decades are frequently inconclusive.
- Studies based on modeling techniques indicate that the peak flow from a clear-cut area increases by 25%.
- Also, such studies show that the total runoff volume from a flood only slightly increases and, for the upstream catchments, would advance for a few days. The effect on flooding in the lower Chao Phraya and Bangkok is minimal.

However, for watershed management, as generally understood, it is essential not to increase flood peak discharge and to maintain the current low water discharge. Fortunately, deforestation in the recent 10 years shows a decrease of about 4% (26% of the territory is covered by forest in 1993) due to strict government control after the Cabinet Resolution of December 3, 1985 which aims to keep 40% as the forest area through reforestation.

In this connection, further vital efforts for watershed management through restrictions on logging in forest area and reforestation are required of agencies concerned in order not to increase flood peak discharge but to increase recharging capacity of the watershed for flood mitigation and water resource conservation, respectively.

Needless to say, the measure is applicable to the Master Plan. However, further study on watershed management is not made in this study, because of difficulty of evaluation of effectiveness in a quantitative manner.

3.2.6 Institution and Organization

Institution and organization are discussed in detail in Sector XI. The outline of the institution and organization is as follows:

In Thailand, most of the necessary institutional arrangements were established together with the setting up of the necessary organization. In principle, there is no conflict in the designation of the agencies responsible for operating and managing flood mitigation measures, as long as these measures can be solely managed in accordance with their purpose. However, to enhance the flood mitigation function of these measures, coordination of their operation and management among the agencies concerned is necessary.

In Thailand, there is neither a single agency nor a coordination agency administering river and/or flood basin-widely, and thus such coordination is in general not undertaken. A coordinating committee among the agencies concerned has thus become necessary so that the Government set up the National Water Resource Committee in 1989. Further recognizing current problems on water related situations such as shortage of water during dry season and flooding during rainy season, preparation works on the Water Resources Act, in which the establishment of a River Basin Committee as the organization to handle the problems is stipulated, is ongoing.

Sometimes it takes a long time to set up a new organization together with the provision of necessary law to designate the role of the organization. However, resolution of most of the present deficiencies on the realization of comprehensive flood control is expected through the Water Resources Act.

Thus, this Study recommends that the Water Resources Act should be pursued and promulgated as early as possible.

Considering the above situation, it is not necessary to undertake a further study on institution and organization in the Master Plan study.

3.3 Evaluation of Effectiveness of Measures based on the Simulation Model

In the preceding sections, the applicability of both structural and nonstructural measures was preliminary examined. The effectiveness of measures is herein evaluated in a quantitative manner based on the simulation model.

3.3.1 Evaluation of Influence of Future Development

As mentioned in Subsection 6.2.3, Expected Future Basin Condition, the Chao Phraya River Basin will have several development projects which will influence the flood water behavior. As the first step to evaluate the effectiveness of flood mitigation measures, the influence of future development is evaluated by simulation of the following cases as discussed below:

- Influence of urban development through the provision of ring levee together with drainage pumps.
- Influence of change of agricultural cultivation in combination with urban development.
- Influence of dam construction in combination with urban development and change of agricultural cultivation.
- Influence of loop-cut construction in combination with urban development, change of agricultural cultivation and dam construction.

The 1995 flood is applied to the simulation, and Table 3.3.1 shows the basin conditions for the examination.

(1) Influence of Urban Development with Ring Levee and Pump

The urban area is to be developed in accordance with the development plan of DTCP, and the protection works for the future urban areas will be provided by PWD in a manner of ring levee together with drainage pumps. The influence of this urban development and the protection works is evaluated as follows:

Monitoring Item	Present Condition (1995 Flood)	Future Urban Development (1995 Flood)
Nakon Sawan Discharge (m^3/s)	4,600	4,430
Bang Sai Discharge (m^3/s)	4,150	4,070
Samsen Water Level (MSL+m)	2.32	2.80

As identified in this table, the influence of future development will be very severe, because it will result in the increase of water level at Samsen Point at Bangkok from 2.32 m at present to 2.80 m after urban development applying the case of the 1995 flood. Thus, it is desirable to minimize the increase of water level through the preservation of retarding function when the flood prone area is developed or urbanized.

(2) Influence of Urban Development and Change of Agricultural Cultivation

In parallel with urban development, the change of agricultural cultivation has also been promoted mainly from paddy to fruit trees in the flood prone area of about 2,000 km^2. Although the area where the change is predicted is hardly identified, it is assumed that the change is expected in areas adjacent to the current fruit cultivation areas.

The influence of change of agricultural cultivation in combination with urban development is calculated as follows:

Monitoring Item	Present Condition (1995 Flood)	Change of Cultivation + Urban Development (1995 Flood)
Nakhon Sawan Discharge (m^3/s)	4,600	4,430
Bang Sai Discharge (m^3/s)	4,150	4,070
Samsen Water Level (MSL+m)	2.32	2.81

As noted from the above table, the influence of change of agricultural cultivation is not large compared with that of urbanization. The change of agricultural cultivation will lead to the increase of water level of only 1 cm at Bangkok in case of the 1995 flood, while urbanization will have 48 cm.

(3) Influence by Typical Agricultural Development in Combination with Urban Development

In the above Case (2), it is assumed that the change of agricultural cultivation from paddy to fruit tree will be gradually promoted in the area adjacent to the existing fruit tree area. A typical agricultural development case is also examined by the simulation model assuming that the present floating and deep water rice areas of about 800 km^2 in total existing near Ayuthaya are converted to fruit tree areas through land reclamation. The result of examination of this Case (3) is as shown in the table below.

Monitoring Item	Present Condition (1995 Flood)	Change of Cultivation + Urban Development (1995 Flood)
Nakhon Sawan Discharge (m^3/s)	4,600	4,430
Bang Sai Discharge (m^3/s)	4,150	4,570
Samsen Water Level (MSL+m)	2.32	3.13

As shown in this table, the influence of a typical case of agricultural development is relatively large and will result in additional increase of water level of 81 cm at Bangkok from the water level under the urban development condition.

(4) Influence of Land Subsidence in Combination with Urban Development and Change of Agricultural Cultivation

In Bangkok metropolitan and adjacent areas, land subsidence is still going on. The simulation model has calculated the influence of land subsidence to inundation condition, as shown below:

Monitoring Item	Present Condition (1995 Flood)	Change of Cultivation + Urban Development + Land Subsidence (1995 Flood)
Nakhon Sawan Discharge (m^3/s)	4,600	4,430
Bang Sai Discharge (m^3/s)	4,150	4,570
Samsen Water Level (MSL+m)	2.32	2.81
Total Inundation Volume (mil. m^3)	15,700	16,200

As noted from the table above, the water level at Bangkok became lower as the influence of land subsidence while total inundation volume increased in a wide range resulting in the increase of flood damage. This is because the inundation water spilling over the river channel will hardly return to the river channel due to increase of difference between water level in river channel and ground level.

(5) Influence of Construction of Dam in Combination with Urban Development, Change of Agricultural Cultivation and Land Subsidence

As discussed before, three (3) dams are to be constructed within the target year. Although the primary purpose of these dams is irrigation, they will, in general, bring about favorable influence to flood mitigation. Furthermore, the effect of modification of reservoir operation rule of the Sirikit Dam is included, which can be attained by installation of new discharge facilities. The influence is evaluated in combination with the other factors such as urban development and change of agricultural cultivation and the result is as shown in the table below.

Monitoring Item	Present Condition (1995 Flood)	Construction of Planned Dam + Other Factors* (1995 Flood)
Nakhon Sawan Discharge (m^3/s)	4,600	4,110
Bang Sai Discharge (m^3/s)	4,150	4,000
Samsen Water Level (MSL+m)	2.32	2.77

* Other Factors: Urban Development and Change of Agricultural Cultivation

As noted from the above table, the construction of planned dams has an effect on the decrease of water discharge of about 490 m^3/s at Nakhon Sawan, finally decreasing the water level at Bangkok by 4 cm, although the influence at Ayuthaya is as small as 10 m^3/s. This is because the influence is attenuated by the spill from the river channel between Nakhon Sawan and Ayuthaya. For Bangkok, the construction of Pasak Dam has a relatively large influence on flood mitigation, which is identified from the decrease of flood discharge of about 150 m^3/s at Bang Sai.

(6) Influence of Construction of Loop Cut in Combination with Construction of Dam, Urban Development, Change of Agricultural Cultivation and Land Subsidence

As discussed before, BMA has a river channel improvement project in a manner of loop-cut at Bangkok Port. The primary purpose of the project is to decrease the water level at Bangkok by increasing the flow capacity of the Chao Phraya River channel. Therefore, the project has a limited influence; i.e., only to the downstream of the Chao Phraya River. The influence is evaluated in combination with the other factors: construction of three dams, urban development and change of agricultural cultivation, and the result is as shown in the table below.

Monitoring Item	Present Condition (1995 Flood)	Construction of Loop Cut + Other Factors* (1995 Flood)
Nakhon Sawan Discharge (m^3/s)	4,600	4,110
Bang Sai Discharge (m^3/s)	4,150	3,980
Samsen Water Level (MSL+m)	2.32	2.62

* Other Factors: Construction of Dams, Urban Development, Change of Agricultural Cultivation and Land Subsidence

(7) Evaluation of the Influence of Future Development

(a) Evaluation based on the 1995 Flood

As gleaned from the discussion above, the influence of future development including all factors will finally result in the decrease of flood discharge by about 500 m^3/s at Nakhon Sawan and the water level rise of 30 cm at Bangkok based on the conditions of 1995 flood. However, this will not bring about increase of inundation at flood prone areas including the Bangkok metropolitan area. The decrease of inundation volume is estimated at about 1,600 million m^3 corresponding to the decrease of inundation area to 1,200 km^2 in total with 150 km^2 in the Bangkok metropolitan area.

(b) Evaluation based on 45 Previous Floods

By applying the future development condition to the simulation model, calculation for 45 previous floods was made to evaluate the flood condition, which was further used for probability analysis of the flood discharge and water level at several reference points.

The calculation results are shown in Table 3.3.2. Based on the calculation results, probable discharge and water level at the reference points were obtained as shown in Table 3.3.3 and in Figs. 3.3.1 and 7.3.2. According to the results, the probable discharge of a 100-year return period at Nakon Sawan decreases from 6,300 m^3/s to 4,200 m^3/s, while the water level at Samsen in Bangkok increases from 2.40 m to 2.80 m above the mean sea level.

3.3.2 Evaluation of the Effectiveness of Nonstructural Measures

(1) Effectiveness of Land Use Control

As discussed in the previous Subsection, the water level in the Chao Phraya River is increased by urban development and change of cultivation in agricultural area by 49 cm at the Memorial Bridge in Bangkok in case of the 1995 flood (refer to Table 3.3.1). In this connection, it may be theoretically possible to maintain the present water level by preservation of present land use through land use control. However, it is not realistic to control such urbanization, which is a given condition for this Study, although the influence of change of agricultural cultivation is minimal. Consequently, it is difficult to expect so much effectiveness of land use control on flood damage mitigation so that this measure is not further examined in combination with other measures.

(2) Effectiveness of Guidance to Land Development

To minimize flood damage, guidance on land development is considered by providing a flood risk map, as shown in Fig. 3.3.2. However, the effectiveness of such guidance cannot be evaluated in a quantitative manner.

Sometimes, the construction of public facilities brings about unfavorable influences for flood damage mitigation, as discussed in Subsection 4.2.2. This is especially true with the embankment of roads and canal dikes in flood prone areas, which does not only result in decrease of natural retarding area but also increase in damage to the area impounded with floodwater. To minimize such unfavorable influences in case of road or canal construction, big openings including box culverts and siphons should be considered.

However, it seems difficult to provide these openings to existing embankments because it may trigger other conflicts between the upstream and downstream sides, although they may be applicable to new embankments in the future. Considering the nature of this measure, it is not further examined in combination with other measures.

(3) Effectiveness of Strengthening of Control of Groundwater Extraction

Judging from the influence of land subsidence, it is considered to mitigate flood damage by strengthening the control of groundwater extraction, which measure is applicable to the Master Plan. However, the realization of control of groundwater extraction will involve uncertain factors, because the effectiveness will depend much on public participation. Therefore, this measure is not further examined in combination with the other measures.

(4) Effectiveness of Modification of Reservoir Operation Rule

As one of the major nonstructural measures whose effectiveness can be evaluated in a quantitative manner, the modification of reservoir operation rule for Sirikit, Kwae Noi, Kaeng Sua Ten and Pasak dams is considered in three cases as discussed in Subsection 7.2.1.

(a) Effectiveness of Each Case

The simulation model has evaluated the effectiveness of modification of reservoir operation rule, as shown in Table 3.3.1. Judging from the table, Case 3, with the flood mitigation capacity of 14,600 million m^3 in total, is effective to reduce the peak discharge by 290 m^3/s at Nakhon Sawan and to reduce 1,000 million m^3 of inundation volume in the whole inundation area under the 1995 flood condition. The effectiveness for Bangkok is expected mainly from Pasak Dam, which will reduce the water level from 2.45 m to 2.41 m under the same flood condition.

(b) Relation between Cost and Flood Control Capacity

To assure the flood control capacity, compensation cost for reduction of irrigation water supply and hydropower generation is required. The relation between compensation cost and flood control capacity is shown in Fig. 3.3.4. Based on this figure, the relation between total cost and effectiveness shown in a manner of reduction of flood discharge or water level at several reference points and inundation volume is as shown in Table 3.3.1. The ratio between cost and effectiveness is also included in Table 3.3.1.

(c) Applicability of Modification of Reservoir Operation Rule

Based on the above results, the applicability of modification of reservoir operation rule is considered as follows:

(i) Effective Area for Flood Mitigation

The modification of reservoir operation rule is, in principle, effective to mitigate flood damage to the downstream area of the dam site. In this connection, this measure is applicable for protection of any of the divided sub-basin areas; namely, upper central plain, Nakhon Sawan area, higher delta in lower central plain and lower delta in lower central plain. The effectiveness in the lower stream will depend on the distance from the dam site.

(ii) Applicable Extent of Modification of Reservoir Operation Rule

The ratio between cost and effectiveness shows a lower value in proportion to the flood control volume of 9,100 million m^3, and it seems that the applicable extent of modification of the reservoir operation rule is 9,100milion m^3. However, the modification of reservoir operation has a limit on effectiveness for reduction of water level at Bangkok to the level of MSL+2.4 m, when the measure is solely applied. Therefore, it is necessary to combine this measure with the other measures such as flood diversion channel and retarding basin.

3.3.3 Evaluation of the Effectiveness of Structural Measures

(1) River Improvement Works

As discussed in Subsection 3.1.1, river training in the upstream may have an adverse influence to the downstream. Considering such adverse influence, the effectiveness of river training is evaluated in the following procedure:

(a) Study Cases of River Improvement and Simulation Results

The following cases of river improvement are examined:

- *Design River Discharge:* Between 2-year return period and 25-year return period
- *River Improvement Stretch:* The river stretch as broadly divided into two sections: from Pathum Thani to Chainat and from Chainat to upstream including the Yom and Nan rivers. The following two cases are examined: (1) River improvement for only the stretch from Pathum Thani to Chainat, and (2) River improvement from Phatum Thani to the upstream.

The simulation results are shown in Table 3.3.1 and Fig. 3.3.5. As shown in this figure, the river improvement in the upstream causes an increase of discharge and water level in the downstream. In the case of river improvement from Phatum Thani to upstream with a project scale of 2-year return period, the flood discharge will be 3,600 m^3/s at Nakon Sawan, which almost corresponds to a 10-year return period probable discharge before river improvement in the upstream.

The flood discharge will be 4,000 m^3/s at Bangkok, which is beyond the flow capacity of 3,000 m^3/s. Thus, river improvement will bring about adverse influence in the downstream, especially Bangkok, although the river improvement from Pathum Thani to upstream will increase the safety level for the area along the river course.

(b) Relation between Cost and Effectiveness

The cost of river training under each case is summarized in Table 3.3.1. Based on the cost, the relations between cost and effectiveness expressed in a manner of reduction of flood discharge or water level at several reference points and the inundation volumes are as shown in Table 3.3.1. The ratio between cost and effectiveness is also included in Table 3.3.1.

(c) Applicability of River Training

Based on the above results, the applicability of river improvement is considered as follows:

(i) Effective Area for Flood Mitigation

River improvement is effective to mitigate flood damage to the area along the river course where it is provided. In this connection, this measure is applicable for the protection of any of the divided sub-basin areas; namely, upper central plain, Nakhon Sawan area, higher delta in lower central plain and lower delta in lower central plain.

Needless to say, the river improvement is not effective to the area where it is not provided. Moreover, river improvement sometimes causes adverse influence to the downstream as mentioned before.

(ii) Applicable Size of River Improvement

In general, based on the ratio between cost and effectiveness, the applicable size of river improvement may be obtained. Practically, however, river improvement shows a negative effectiveness to Bangkok, and thus, it is not applicable due to the adverse influence on the downstream when the measure is solely applied. Consequently, it is necessary to examine the applicability of river improvement in combination with the other measures such as retarding basin and flood diversion channel, to minimize the adverse influence. In this context, the applicable size of river improvement shall be examined further in combination with the other measures.

(d) Typical Case of River Improvement for Reference

To identify the adverse influence of river training to the downstream, the following three typical cases of river training are examined:

- The case where all flood discharges are confined in the river channel.
- The case where all stretches of river channel dike is heightened to 20 cm.
- The case of heightening of dike to protect Bangkok metropolitan area.

(i) The Case where All Flood Discharges are Confined in the River Channel

The simulation results are shown in Table 3.3.2. As noted from the table, in the 1995 flood, the flood discharge of 4,850 m^3/s at Nakhon Sawan ran down to Bangkok where the river water level rose to 3.87 cm.

(ii) The Case where all stretch of the River Channel Dike is heightened

In the case of heightening of dike to 20 cm, the flood discharge at Nakhon Sawan was 4,350 m^3/s, which corresponds to a 100-year return period, and the water level at Bangkok rose to 3.46 cm.

(iii) The Case of Heightening of Dike to Protect Bangkok Metropolitan Area

The heightening of dike to more than the current design dike height to protect Bangkok metropolitan area is almost impossible, considering the magnitude of social and environmental impacts. The other measures also involve similar impacts from the economic and social aspects. In this connection, the case of heightening of protection dike for Bangkok metropolitan area was examined by means of calculation of cost, for reference.

The relation of cost and heightening of dike is shown in Table 3.3.3. For the protection of Bangkok metropolitan area from a 100-year return period flood, it is necessary to raise the dike height to 40 cm on the average, unless other measures to lower the water level are undertaken. For the heightening of dike to 40 cm, the cost of 310 million Baht is required, which is not too much compared to the cost of other measures such as diversion channel and retarding basin.

However, it may be far more difficult to heighten the dike to 40 cm, considering the current issue on heightening of protection dike. In this connection, the case of heightening of dike seems to be a kind of final option, when the applicability of any other measure is not identified.

(2) Diversion Channel

In Subsection 7.1.1, three alternative routes of diversion channel were proposed: Pasak-Raphipat-Sea, Chainat-Pasak-Raphipat-Sea, and Ayuthaya-East Bank-Sea. For these alternative routes, the effectiveness of the diversion channel is evaluated in the following procedure:

(a) Study Cases of Diversion Channel and Simulation Results

Cases of design diversion channel discharge; namely, 500 m^3/s, 1,000 m^3/s and 1,500 m^3/s, were examined. The simulation results are shown in Table 3.3.1.

(b) Relation between Cost and Effectiveness

The cost of diversion under each case is summarized in Table 3.3.1. Based on the cost, the relations between cost and effectiveness expressed in a manner of reduction of flood discharge and water level at several reference points as well as inundation volume are as shown in Table 3.3.1. The ratio between cost and effectiveness is also included in Table 3.3.1.

As shown in this Table, the diversion channel of Ayuthaya-East Bank-Sea is the most effective to reduce the water level as well as the inundation volume at Bangkok, and the case with 800 m^3/s on the route shows a higher effectiveness.

(c) Applicability of Diversion Channel

Based on the above results, the applicability of diversion channel was considered as follows:

(i) Effective Area of Flood Mitigation

The diversion channel is effective only for the mitigation of flood damage to the downstream area where it is provided. In this connection, the Ayuthaya Diversion Channel is effective only for the mitigation of flood damage to Bangkok metropolitan area and adjacent areas, and not effective for the protection of agricultural areas in the upstream from Ayuthaya. For the mitigation of flood damage in the other areas, it is necessary to combine the diversion channel with the other measures such as dam and river training works.

(ii) Applicable Size of Diversion Channel

To decrease the water level at Bangkok up to MSL+2.3 m, which corresponds to a 100-year return period at Bangkok, it is necessary to provide the Ayuthaya Diversion Channel at the design discharge of 1,500 m^3/s when solely applied. The most economical design discharge for the diversion channel is 500 m^3/s, judging from the cost and benefit ratio.

In this connection, it is necessary to examine this case further in combination with the other measures such as dam, loop-cut and river training works.

(3) Distribution System Improvement

The effectiveness of structural measures has been evaluated by a simulation model, which was developed in this study to present the flooding condition basin-widely (see Fig. 3.3.6.) However, the simulation model may not be suitable to evaluate the change of flood damage by the distribution of inundation water in natural retarding area due to the following reasons:

- The basic idea of the distribution system improvement in this study is to mitigate flood damage in the paddy field with less cost through distribution of inundation water from the area with severe inundation to the other area with less inundation.
- To present such distribution of inundation water, it is necessary to introduce several conditions in the model, e.g., which area in a paddy field is currently less inundated or severely inundated, and how much is the current inundation volume and whether it is possible to distribute the inundation volume from the areas with severe inundation to the area with less inundation and so on.
- Although the above-mentioned simulation model can reflect such conditions in a certain level, the model is not so flexible to fully present

such conditions, because the major purpose of the simulation model is to present basin-wide flood condition covering the wide area of 160,000 km^2.

In this study, the effectiveness of distribution system improvement in the present paddy field is roughly evaluated. The possibility to mitigate flood damage in the paddy field by improvement of flow control facilities and drainage facilities as well as change of cropping pattern is also evaluated.

At first the natural retarding effect focusing on the present paddy field is roughly evaluated as follows:

(a) Rough Evaluation of Retarding Effect of Present Paddy Field

The inundation volume, inundation area and damage in each flood are summarized in Table 3.3.1, including the peak flood discharge at Nakon Sawan, Ayuthaya and Bang Sai and the peak water level at Bangkok. As identified from the comparison of peak discharge between Nakon Sawan and Bang Sai in the table, the present paddy field contributes to mitigation of peak discharge in the Chao Phraya River (e.g., from 4,600 m^3/s at Nakon Sawan to 4,150 m^3/s at Bang Sai in the 1995 flood).

The area of paddy field, which plays the role of natural retarding basin, roughly amounts to 20,500 km^2 in the whole basin and 5,600 km^2 in the lower delta area. Assuming that the water depth stored in the paddy field without damage is about 30 cm on an average, the water volume stored in the whole basin is about 6.2 billion m^3, while that in the lower delta area is about 1.7 billion m^3.

However, the paddy field will suffer from flood damage when the inundation volume amounts to such level. In case of the 1995 flood, the total inundation volume in the whole basin would amount to about 16 billion m^3.

Consequently, in case of such a relatively big flood, it may be difficult to enhance the natural retarding effect to further mitigate the peak discharge in the Chao Phraya River, which results in more flood damage to the paddy field. The possibility to minimize the flood damage in the paddy field, maintaining the present natural retarding effect, should be examined.

(b) Conceivable Mitigation Measures against Flood Damage

As the measures to mitigate flood damage in paddy fields, the following are conceived:

- Distribution of inundation water in paddy field from the area with serious inundation to that with less serious inundation through the distribution system improvement.

- Prompt drainage of inundation water to reduce the inundation volume and water level and to shorten the duration through drainage system improvement.
- Change of cropping pattern to avoid the period suffering from flood damage.

(c) Examination of Possibility to Minimize Flood Damage through Distribution of Inundation Water

The possibility to minimize the flood damage in the paddy field through distribution of inundation water is examined in the following procedure:

- Division of paddy field in inundation area of 20,500 km^2 into 18 blocks (refer to Fig. 3.3.7.)
- Analysis of inundation condition of divided blocks based on the 1995 flood
- Examination of effectiveness to mitigate flood damage

(i) Analysis based on 1995 Flood

In the procedure, the analysis of inundation condition in 1995 flood is as follows:

The inundation condition and possibility of distribution of inundation water are summarized as follows (refer to Fig. 3.3.7):

- In Block 1 (Pitchit Province), the paddy field is divided into two (2) areas: area with inundation where traditional variety (TV) is mainly cultivated; and area without inundation where high yield variety (HYV) is cultivated. Judging from the condition, there is a possibility to distribute inundation water from the area with inundation to the area without inundation.
- In Block 2 (Nakon Sawan Province), inundation is observed in the lowland along the river course, and there may be less possibility to distribute inundation water in the present inundation area to the other area from the topographic point of view.
- In Block 3 (Uthai Thani Province), the inundation condition is similar to Block 2, and there may be less possibility to distribute inundation water.
- In Block 4 (Chainat Province), the inundation is mainly observed in the paddy field in left bank along the Chao Phraya river, while it is not observed in the paddy field in the right bank. In both areas, HYV is mainly cultivated. Consequently, it may be possible to distribute inundation water in the left bank area to the right bank area.
- In Block 5 (Suphanburi Province), the inundation is observed in the southern edge, while the northern and middle parts are

free from inundation which is attributed to the topographic condition. In this block, there may be less possibility to distribute inundation water.

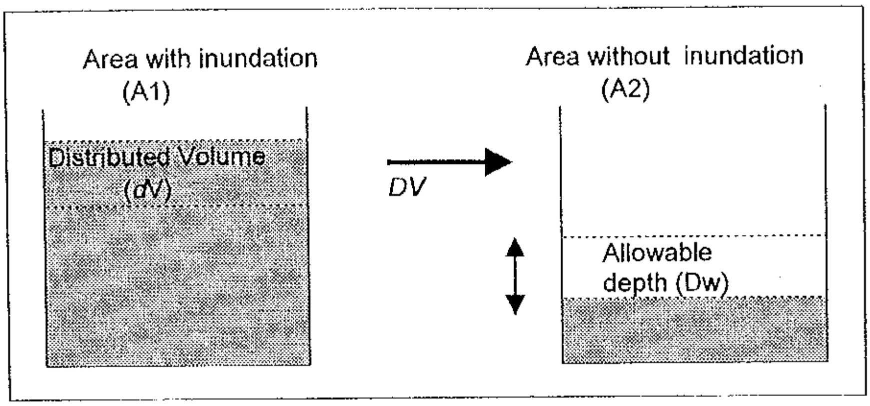
- In Block 6 (Sing Buri Province), the inundation widely spread in both left and right banks of the Chao Phraya river course. However, there may still be a possibility to distribute inundation water to the paddy field in the right bank. The major land use in the area is composed of HYV and floating rice (FR).
- In Block 7 (Lopburi Province), inundation widely spreads and there may be a minor possibility to distribute the inundation water to the area with relatively less inundation. The major land use is composed of FR and deep-water rice (DR).
- In Block 8 (Angthong Province), inundation widely spreads in the whole block, and there may be a minor possibility to distribute the inundation water to the area with less inundation.
- In Block 9 (Ayuthaya Province), inundation condition is more severe than in Block 8 and there may be less possibility to distribute the inundation water somewhere in the block.
- In Block 10 (Saraburi Province), inundation condition is observed in the area adjacent to the Chao Phraya River, while it is not observed in the remote area from the Chao Phraya River. Judging from the topographic condition, it may be difficult to distribute the inundation water to such a remote area.
- In Block 11 (Phathun Thani Province), inundation condition is observed in the wide area, especially that adjacent to the Chao Phraya River. Judging from the current inundation condition, there may not be a possibility to distribute inundation water to the area with less inundation.
- In Block 12 (Nakohon Pathom Province), the situation is the same as in Block 10, and it may be difficult to distribute the inundation water to the remote area.
- In Block 13 (Nonthaburi Province), the inundation water spreads in the whole block, and there may be less possibility to distribute the inundation water to the other area.
- In Block 14 (Bangkok Metropolitan Area), there may be less possibility to distribute the inundation water, since most of the area is not paddy field to serve as a natural retarding basin but designated as urban area.
- In Block 15 (Chachoengsao Province), Block 16 (Samut Songklar Province) and Block 17 (Samut Sakhon Province), the situation is similar to that in Block 12, and it may be difficult to distribute inundation water to the remote area.

- In Block 18 (Phathun Thani), there may be less possibility to distribute the inundation water to the other area, since most of the paddy field is inundated.

In general, there may still be a possibility to mitigate flood damage in the paddy field through distribution of inundation water to the area with less inundation damage.

The possibility of mitigation of flood damage in paddy field is roughly calculated as follows:

- The water volume (dV) distributed from the area with inundation (A_1) to the other area without inundation (A_2) is calculated by multiplying area without inundation with the allowable water depth (D_w).
- The area without inundation (A_2) is delineated based on the simulation results (refer to Fig. 3.3.5.).
- As the allowable water depth (D_w), 20 cm for the paddy field of HYV, 50 cm for TD, DR and FR are applied considering the damage ratio by water level, to minimize the damage in the area (A_2) when inundation water is distributed.
- In principle, the distribution of water is considered from area of HYV to area of HYV, TD, DR and FR, or from TD, DR and FR to TD, DR and FR. However, distribution from TD, DR and FR to HYV is not considered, since HYV is more vulnerable to inundation and higher productivity compared with the TD, DR and FR.
- Flood damage in the (A_1) area is expected to decrease with the amount of (dD_1) through distribution of water volume (dV) to the (A_2) area. The reduction of damage is estimated based on the relation between inundation volume and damage in the block, applying the inundation volume (V_1) after reduction of (dV) in the (A_2) area.
- On the other hand, flood damage on the (A_2) area is expected to increase with the amount of (dD_2) by distribution of the water volume (dV) from the (A_1) area. The increase of damage is similarly estimated based on the relation between inundation volume and damage in the block.
- The effect of natural retarding basin is finally calculated accumulating the damage reduced (dD_1) and increased (dD_2) in each block.



The inundation volume and effect of the natural retarding basin is shown in Table 3.3.4.

By this distribution, the effectiveness to mitigate flood damage is summarized as follows:

- The effectiveness to mitigate flood damage is not much. For the 1995 flood, it is only about 3% of damage reduction for the damage in blocks in which the inundation water can be distributed.
- The percentage of damage reduction tends to decrease in proportion to the scale of flood because of the inundation volume to be distributed, although the percentage is not large as expected for such a relatively large scale flood.
- However, it is natural that the effectiveness will increase for relatively small scale floods, since the area to distribute the inundation water will increase while the inundation volume decreases.
- Thus, it is expected that this measure is effective to mitigate the flood damage for small-scale floods.
- Practically, the area to distribute the inundation volume should be narrowed down to the area with high possibility of distribution. Judging from the flood inundation condition, the area from Block 4 to 11 with 5,600 km^2 is delineated.

(ii) Planning of Inundation Water Distribution to Mitigate Flood Damage

The inundation condition differs depending on the flood. Therefore, practically, the utilization of paddy field as natural retarding basin also differs depending on the flood, which is regarded as an issue for the operation of a retarding basin. On the other hand, from the planning point of view, it is necessary to generalize the utilization of paddy field as the natural retarding basin, preparing a guideline for the purpose. The effect of the natural retarding basin is evaluated by applying the guideline to several floods.

The guideline is assumed to be as follows:

- Paddy field of 5,600 km^2 for natural retarding basin is divided into several blocks as discussed above and the priority for distribution of inundation water is defined considering the current inundation condition, land use, their productivity and so on (refer to Fig. 3.3.7, as an example).
- When flood is expected, the water retarded in the paddy field is discharged into the Chao Phraya River in advance to assure the retarding capacity of the paddy field, considering the features of flood runoff.
- Excess flood discharge flowing down from upstream is reserved in a block with a high priority.
- After such a block is filled with inundation water up to the level in which flood damage will be detected, further excess water is distributed to the other blocks in accordance with the priority.
- When all blocks are filled with inundation water up to the level in which flood damage will be detected, further excess water is reserved up to the maximum retarding capacity in accordance with the priority. Such maximum retarding capacity is assumed up to the level where flood damage can be compensated.

(iii) Mitigation of Flood Damage based on the Guideline

Based on this guideline, the possibility to minimize the flood damage is examined in the following steps:

- As the first step, the retarding capacity without flood damage in the paddy field of 5,600 km^2 was calculated, applying different allowable depths without any flood damage to FR (Floating Rice), DWR (Deep Water Rice) and HYV (High Yield Variety) areas. This harmless retarding capacity was estimated at 2,100 million m^3.
- Considering the production values and flood damage rates of rice varieties, FR is the most tolerable against flood inundation. In other words flood damage of FR under a certain water depth is less than the other varieties, and excessive flood water over the harmless capacity should be distributed into the FR area at first. The FR area possibly accommodates 600 million m^3 with a damage of 350 million baht.
- The second priority is the DWR (Deep Water Rice) area which is the second most economical against flood inundation. This area can accommodate 3,900 million m^3 with damage at 4,700 million baht. After the FR area becomes full, the floodwater should be withdrawn into this DWR area. Withdrawing the excessive floodwater into the HYV (high yield variety) is the last step which should be done only after the DWR area is already full.

The relation between the retarding capacity (inundation water volume) and flood damage is shown in Fig. 3.3.6, and the priority area to distribute the inundation water is shown in Fig. 3.3.7. In general, flood damage with some inundation volume is more than that on the relation, since inundation causes flood damage at random. Consequently, the relation shows the least flood damage for inundation volume in paddy field when inundation occurs in the retarding basin. Based on the relation, the flood damage for 45 floods is estimated and compared with the flood damage based on the simulation results (refer to Table 3.3.5). As noted from the table, it is expected to mitigate the flood damage within a certain range, and it is especially very effective for small-scale flood. The rate of damage mitigation is 30% on the average.

(d) Prompt Drainage of Inundation Water

In the Chao Phraya Delta, inundation water remains for a long time until water level in the Chao Phraya River lowers, resulting in huge flood damage. In this connection, it is considered to reduce the flood damage through improvement of the drainage system. However, drainage to the Chao Phraya River in the flood season is substantially difficult, because the water level almost reaches up to the bank height. In this study, the drainage system improvement is proposed to drain the inland water to the sea, providing the drainage channel with gate in the delta area (refer to Fig. 3.3.8).

The effectiveness of the drainage system improvement is examined by applying the simulation model to the 1983, 1995 and 1996 floods with several cases of drainage capacity of between 100 m^3/s and 300 m^3/s.

According to the results, improvement of the drainage system is effective to mitigate inundation duration and water volume so that flood damage is mitigated, although the water depth is not drastically lowered. The effectiveness is higher when the inundation volume is less, which is noted through the comparison of effectiveness among three floods (refer to Table 3.3.6 and Fig. 3.3.9).

Among the comparison of several cases of drainage capacity, the cost-effectiveness shows that the case of the capacity of 75 m^3/s has an economic advantage (refer to Table 3.3.8 and Fig. 3.3.10). The inundation damage in agricultural areas is mitigated and effectiveness is about 30 % on the average for damage by the three floods.

(e) Change of Cropping Pattern

To minimize the flood damage in paddy field, it is considered to change the cropping pattern, i.e., change of cultivation schedule and variety.

At present, the flood damage is widely observed at cultivation areas of floating rice, deep-water rice and high yield variety. Judging from the current practice of cultivation, it may difficult to change the cropping pattern from the following reasons:

- The current cultivation schedule of high yield variety is arranged so as to minimize the flood damage avoiding the flood season, and schedules for floating rice and deep water rice are arranged to use enough water in the flood season.
- The varieties currently practiced seem to be the most suitable ones to maximize the production amount; namely, in the habitual inundation areas, flood tolerable varieties are cultivated, while in the other areas, high yield variety is practiced.
- Consequently, it may be difficult to rearrange the cultivation schedule and to change the variety, unless the production amount is sacrificed to avoid flood damage.

(f) Estimation of Cost for Distribution System Improvement

Distribution system improvement requires some amount of cost to smoothly distribute inundation water to the area with less inundation. The cost for improvement of the distribution system of inundation water is roughly estimated, assuming the construction or improvement of the following items:

- Construction of connection canal to distribute inundation water
- Expansion of existing main canal
- Construction of siphon to cross the main river
- Gate and regulator to operate the distribution system

The cost is shown in Table 3.3.6.

(g) Applicability of Distribution System Improvement

As identified in the above, the flood damage in the paddy field can be mitigated through distribution of inundation water and drainage system improvement, preserving the current natural retarding effect. Accordingly, the distribution system improvement is applicable especially for small-scale floods, through the provision of guideline as well as improvement of drainage facilities and flow control facilities.

(5) Retarding Basin (Artificial Retarding Basin)

In this study, three alternative cases for the area of artificial retarding basin were proposed. For these alternative cases, the effectiveness of the artificial retarding basin is evaluated in the following procedure:

(a) Study Cases of Artificial Retarding Basin and Simulation Results

Cases of area of retarding basin; namely, 1,000 km^2, 2,000 km^2 and 3,000 km^2 are examined and as the result, it was identified that the 3,000 km^2 retarding basin is effective at the 1995 flood to reduce the discharge at Bang Sai by 300 m^3/s and the water level at Memorial Bridge in Bangkok by 4 cm.

(b) Relation between Cost and Effectiveness

The cost of retarding basin includes cost of facilities for intake from river and drainage to river, dikes, relocation of houses, and raising of existing road (refer to Table 3.3.7). It also includes the cost of land for the retarding basin and it is assumed that this is rental cost.

Based on the cost of retarding basin, the relation between cost and effectiveness, expressed in a manner of reduction of water level and inundation volume, is as shown in Table 3.3.1. The ratio between cost and effectiveness is also included in Table 3.3.1.

According to the evaluation, the area of 3,000 km^2 shows a higher ratio between cost and effectiveness. However, compared with the other measures, especially diversion channel, the ratio is low due to the huge cost.

(c) Applicability of Artificial Retarding Basin

Based on the above results, the applicability of artificial retarding basin is considered as follows:

(i) Effective Area of Flood Mitigation

The effectiveness of artificial retarding basin for the reduction of water level is limited to the area downstream where it is provided. For the mitigation of flood damage in the other areas, it is necessary to combine it with the other measures such as dam, river training and flood diversion channel works.

(ii) Applicable Size of Retarding Basin

To decrease the water level at Bangkok up to MSL+2.3 m, the artificial retarding basin is not applicable as shown in Table 3.3.1. The most economical size of artificial retarding basin is 3,000 km^2, judging from the cost and benefit ratio.

In this connection, to optimize the size of artificial retarding basin, it is necessary to examine the case further in combination with the other measures such as dam and river training works. However, the priority of application of artificial retarding basin is very low judging from the economic comparison. Thus, the further study on artificial retarding basin is not undertaken in this study. (Refer to Fig. 3.3.10.)

3.4 Preliminary Selection of Applicable Measures for Further Study

3.4.1 Confirmation of Applicability and Necessity of Further Study

In Section 3.1, 3.2 and 3.3, the applicability of measures including structural and nonstructural measures is discussed and confirmed. The necessity of further study on some measures in combination with the other measures is also examined. The following measures require further study in combination with the other measures:

- *Non-Structural Measures:* Modification of Reservoir Operation Rule
- *Structural Measures:* River Training, Diversion Channel, Distribution and Drainage System Improvement

The alternative cases of combination of these measures are discussed in Section 4.2.

3.4.2 Priority Order of Combination of Applicable Measures

The relations between cost and effectiveness are shown in Fig. 3.3.10. As shown in this figure, the economic advantages of measures are in the following order: (*1st*) modification of reservoir operation rule; (*2nd*) distribution and drainage system improvement; (*3rd*) river improvement works and (*4th*) diversion channel. Therefore, the alternative cases of combination of these measures are set according to this order.

4. FORMULATION OF THE MASTER PLAN

4.1 Selection of Applicable Measures

Based on the evaluation results, the applicable measures are selected for the formulation of the Master Plan.

4.1.1 Upper Central Plain and Nakhon Sawan Area

In these areas, it seems not necessary to discuss the applicability of the nonstructural measures judging from features and effectiveness, except for the modification of reservoir operation rule. Besides, it is necessary to confirm the applicability of river improvement. Consequently, the applicability of modification of reservoir operation rule and river improvement is examined herein in a quantitative manner:

(1) Modification of Reservoir Operation Rule

To evaluate the effectiveness in a quantitative manner, modification of the reservoir operation rule of Sirikit, Kwae Noi, Kaeng Sua Ten and Pasask dams is examined in three cases of flood control capacity: 7,400 million m^3, 10,700 million m^3 and 14,600 million m^3. This measure brings about the effectiveness in a manner of mitigation of flood discharge as the benefit, while it affects the reservoir operation for irrigation purposes and hydropower generation, resulting in the reduction of irrigation area and hydropower generation that must be compensated as the cost.

Since this measure has the effectiveness to mitigate flood damage not only in these areas but also the higher and lower delta in the lower central plain, the applicability cannot be identified from the effectiveness in these areas. However, as shown in Table 3.3.1, the effectiveness of the measure is high, judging from the cost-effectiveness. Eventually, the measure in case of 14,600 m^3 flood control capacity is selected for the Master Plan.

(2) River Improvement

To identify the applicability of river improvement, the design discharge distribution in river channel is examined in several cases of return period and also in case of consideration with and without effect of natural retarding basin. The design discharge distribution is obtained based on the simulation results for 45 floods (refer to Fig. 4.1.1).

As shown in these figures, the adverse influence in a manner of increase of flood discharge to the downstream is quite large; i.e., from 3,100 m^3/s at present to 4,400 m^3/s by river improvement with 5-year return period. Consequently, it is necessary to provide measures to absorb the increase of flood discharge. As the measures to absorb such influence, the artificial retarding basin and the diversion channel are considered. However, they require a huge cost or huge sacrifice in the area downstream to absorb about 1,300 m^3/s of discharge increase. Therefore, it is not practically feasible to apply the river improvement in these areas together with the measures to absorb the adverse influence.

4.1.2 Higher Delta in Lower Central Plain

In this area, it is not necessary to discuss the necessity of nonstructural measures including modification of reservoir operation rule. The applicability of the following structural measures is examined in a quantitative manner: river improvement, diversion channel, and mitigation measures against damage in paddy fields.

(1) River Improvement

Based on the design discharge distribution shown in Fig. 4.1.1(2/2), river improvement within an allowable extent so as not to cause serious adverse influence to the downstream is discussed.

As for such allowable extent, the flow capacity at Bangkok of about 3,600 m^3/s after construction of the flood barrier is adopted as an indicator. Comparing the design discharge distribution to the flow capacity at Bangkok, only the case of river improvement with a scale of 10-year return period considering the natural retarding effect coincides (refer to Fig. 4.1.1(2/2). For the purpose, it is necessary to partially increase the flow capacity of the present river channel to about 800 m^3/s at maximum.

Furthermore, it is considered to improve the river channel from the 10-year to 25-year level. In this case, it is also necessary to provide measures to absorb the adverse influence in the downstream of about 300 m^3/s of discharge over the flow capacity at Bangkok by diversion channel (Ayuthaya-East Bank-Sea Route; refer to Fig. 3.1.2).

However, such diversion only to mitigate the flood damage in agricultural areas is not at all attractive from the economical point of view, and it may cause a huge social problem. On the other hand, as discussed later, when such diversion is used to mitigate the flood damage to both the agricultural area and Bangkok, it can be applicable even from the economical point of view.

(2) Diversion Channel

As the alternative case to river improvement, it is considered to apply only the diversion channel with the capacity of about 800 m^3/s to mitigate flood damage in agricultural areas. The route of the diversion channel is considered to be the Chianat-Pasak-Raphipat-Sea Route.

Since the diversion channel is also effective to enhance the safety level at Bangkok, the effectiveness considering such aspect should be examined to identify applicability. However, the applicability of the diversion channel may be low considering the cost and effectiveness compared with the case of river improvement (refer to Tables 4.1.1 and 4.1.2).

(3) Mitigation Measures of Flood Damage in Paddy Field

The natural retarding area, especially the agricultural area contributes to mitigation of the flood peak discharge in the Chao Phraya River (e.g., from 4,600 m^3/s at Nakon Sawan to 4,150 m^3/s in the 1995 flood with the extensive inundation). On the other hand, the paddy field suffers from habitual inundation, resulting in serious flood damage.

To mitigate such flood damage in paddy field, it is considered to improve the inundation water distribution system. Through the improvement of such system, about 30% of the present flood damage would be mitigated.

4.1.3 Lower Delta in Lower Central Plain

In the area, it is also not necessary to discuss the necessity of nonstructural measures and measures for flood damage mitigation in agricultural areas. The applicability of the following measures or options is discussed in a quantitative or qualitative manner.

(1) Mitigation of Adverse Influence due to Protection Works in Urban Areas

To assure the safety level at Bangkok, six options are conceived (refer to Figs. 4.1.2 and 4.1.3). The advantage and disadvantage are considered as follows (refer to Table 4.1.3):

(a) *Option 1:* To maintain the present condition of Pathum Thani and Nontaburi (Not to implement Protection Works)

As noted from the title, the option is not to implement protection works for these urban areas. From the situation, the present safety level evaluated as about a 2 to3-year return period will be maintained in the future, while the safety level at Bangkok is about a 125-year return period because of effectiveness by loop-cut. For this option, the following advantage and disadvantage are conceived:

- As the advantage, from technical, economical and environmental points of view, there may be no issue derived from the option.
- However, from the social point of view, inhabitants in the urban areas of Pathum Thani and Nonthaburi will not accept maintenance of the present safety level in the future.
- Besides, the option cannot cope with the situation to enhance the protection level of agricultural area in the upstream in the future. (Under this option, it is almost impossible to enhance the safety level of agricultural area from 10-year return period to 25-year return period.)

(b) *Option -2:* To enhance the safety level only up to the level in which an adverse influence to Bangkok is not expected so much

Since the protection level at Bangkok is slightly higher than a 100-year return period (125-year return period), it may be possible to enhance the safety level at Pathum Thani and Nonthaburi by lowering the safety level at Bangkok from 125-year return period to 100-year return period. According to the rough estimation results, the safety level at Pathum Thani and Nonthaburi can be enhanced up to a 5-year return period from 2- to3-year return period, although Bangkok will have a 100-year return period. For this option, the advantage and disadvantage are the same as in Option 1.

(c) *Option 3:* To lower the safety level at Bangkok from 125-year return period to a certain level, e.g., 50-year return period, and slightly enhance the safety level for Pathum Thani and Nonthaburi

By lowering the safety level at Bangkok to a 50-year return period, that of Pathum Thani and Nonthaburi can be enhanced up to a 7-year return period. From the situation, however, the advantage and disadvantage are still similar to those of Option 1 and Option 2.

(d) *Option 4:* To narrow down the protection area for Pathum Thani and Nonthaburi

To narrow down the protection area to only a part of Nonthaburi, it is possible to protect the narrowed area with a 100-year return period without causing a serious adverse influence to Bangkok. However, the remaining area of Pathum Thani and Nonthaburi will maintain the present safety level in the future. From the situation, the advantage and disadvantage are still similar to those in the above options.

(f) *Option 5:* To heighten the flood barrier at Bangkok

To heighten the flood barrier at Bangkok for about 30 cm, it is possible to absorb the adverse influence due to protection works at Phatum Thani and Nonthaburi. The option involves the following advantage and disadvantage:

- From the technical point of view, the works will not involve serious issues, since heightening of flood barrier can be done through piling any material on top of the present flood barrier.
- From the economical point of view, the works can be done with relatively less cost compared with the diversion channel as discussed later.
- From the environmental and social points of view, however, this option will cause serious issues judging from the difficulty of construction to the currently proposed flood barrier. (This option will hamper the daily activities of inhabitants who fully use the Chao Phraya River for daily activities, and heightening the barrier will interfere with the inhabitants and tourists from enjoying the scenery of the Chao Phraya River.)
- Also, the option cannot cope with the situation to enhance the protection level for agricultural areas upstream in the future.

(g) *Option 6:* To provide a diversion channel

Through the construction of a diversion channel with the capacity of 800 m^3/s, it is possible to absorb the adverse influence due to protection works of Pathum Thani and Nonthaburi as shown in Table 4.1.5. For the option, the following advantage and disadvantage are conceived:

- From the technical point of view, the works will not involve serious issues, since diversion is a traditional earth work that is often undertaken in this country, although the project scale is quite large.
- From the environmental point of view, issues derived from the works may be solved, although it may not be an easy work.
- From the economical point of view, however, the works will require a huge financial burden to the country.
- Also from the social point of view, this option will cause issues on land acquisition and house evacuation.
- As for the enhancement of protection level for agricultural areas in the upstream in the future, this option can cope with this by expanding the capacity as discussed in Subsection 5.3.2. (To enhance the safety level in agricultural areas in higher and lower delta from a 10-year return period to 25-year return period, it is necessary to further expand the capacity of diversion channel from 800 to 1,100 m^3/s as shown in Table 4.1.5.)

To select the suitable option among these options, it is necessary to thoroughly discuss it with the agencies concerned. In this study, Option 4 (partial protection of Pathum Thani and Nonthaburi) is proposed as Alternative 1, and Pption 5 (heightening of flood barrier) and Option 6 (diversion channel) are proposed as Alternative 2-1 and Alternative 2-2, respectively, from the following reasons:

- Considering the current urbanization and future development in these areas, it is necessary to assure the safety level for the protection of urban areas in the future, and it may be difficult to have varying protection levels among these urban areas. (for Option 1, 2 and 3)
- Although it may be difficult to delineate areas to be protected and not to be protected in Pathum Thani and Nonthaburi, this option can enhance the protection level of urban areas without serious adverse influence to the downstream and with less cost. (for Option 4)
- Although it is also difficult to implement heightening of the flood barrier from the social and environmental viewpoints, it may not involve seriouse issues from the economical and technical points of view. (for Option 5)
- Construction of diversion channel is not an easy work from economical and social viewpoints. However, this measure can also be used to enhance the saftey level for agricultural areas. This seems to be the ultimate solution to enhance the safety level for urban areas including Bangkok and agricultural areas. (for Option 6)

(2) Mitigation Measures of Flood Damage in Paddy Field

As in the higher delta, it is necessary to mitigate flood damage in the paddy fields. In these areas, it is possible to mitigate the damage through drainage system improvement, although it may be difficult to further distribute the inundation water to mitigate the flood damage. Since drainage to the Chao Phraya River in the flood season is substantially difficult, it is considered to drain the inundation water to the sea.

To identify the effectiveness of the drainage system improvement, several alternative cases of drainage system improvement by widening and deepening the present channels were examined by applying the simulation model to the 1983, 1995 and 1996 floods (refer to Fig. 3.3.8).

According to the simulation results, the improvement of drainage system is considerably effective to mitigate inundation volume and duration, so that flood damage could be mitigated, although the water depth is not drastically lowered in floods as big as the 1983 flood.

The longer channel can reduce inundation in the upper deep inundation areas. However, in terms of economic effectiveness expressed by the ratio of decrease of flood damage with cost, the shorter and smaller channel is advantageous.

Eventually, the smallest capacity of 75 m^3/s is applied as a suitable case. By this drainage system improvement, about 30% of the damage in the area can be mitigated.

4.1.4 Summary of Measures Applied to the Master Plan

As the results, the following measures are employed for the Master Plan (refer to Table 4.1.5 and 4.1.6 and Figs. 4.1.4, 4.1.5 and 4.1.6).

(1) Upper Central Plain and Nakhon Sawan Area

(a) Nonstructural Measures

The following nonstructural measures are employed for the Master Plan:

- Land use control and guidance
- Modification of reservoir operation rule
- Other nonstructural measures (flood forecasting and warning system, flood fighting, disaster recovery, subsidy, flood insurance, watershed management, and institutional and organizational arrangement)

(b) Structural Measurers

In the area, no structural measure is included in the Master Plan, except protection works for urban areas by PWD.

(2) Higher Delta in Lower Central Plain

(a) Nonstructural Measures

The nonstructural measures adopted in the higher central plain and Nakhon Sawan area are all employed for the Master Plan.

(b) Structural Measurers

In the area, river improvement and measures for damage reduction in paddy fields as well as protection works for urban areas are applied. As for the diversion channel, the implementation is subject to change of option applied in the lower delta. In case of Alternative 1 [Option 4], partial protection of Phatum Thani and Nonthaburi and Alternative 2-1 [Option 5], heightening of flood barrier, only the ring levee is applied. On the other hand, in case of Alternative 2-2 [Option 6], expansion of the diversion channel is considered.

Under the situation, the following considerations are made:

(i) River improvement

River improvement is undertaken in two (2) stages. Stage 1 is prompt implementation with a 10-year return period. Implementation of Stage 2, the purpose of which is to enhance the safety level to 25-year return period, depends on the selection of options. In case of Alternative 1 and Alternative 2-1, river improvement is terminated with Stage 1. In case of Alternative 2-2, the river improvement is expanded in Stage 2 to the safety level of 25-year return period. However, the implementation of Stage 2 is proposed after the diversion channel is ready to absorb the adverse influence.

(ii) Diversion Channel

Diversion channel is considered only in case of Alternative 2-2.

In this case, diversion channel is also undertaken in two stages: Stage 1 is implemented to absorb the adverse influence by protection works in urban areas of Pathum Tani and Nonthaburi, and Stage 2 is to cope with the adverse influence due to river improvement for protection of agricultural areas. As for flood mitigation measures in this area, the latter stage (Stage 2) is concerned.

(3) Lower Delta in Lower Central Plain

(a) Nonstructural Measures

The nonstructural measures adopted in the higher central plain and Nakhon Sawan area are all employed for the Master Plan and, furthermore, control of groundwater extraction is added.

(b) Structural Measurers

In the area, the measures for damage reduction in paddy field as well as protection works for urban areas are employed. As for the measures to absorb the influence of increase of discharge to Bangkok due to protection works for Pathum Thani and Nonthaburi, two options, Alternative 2-1 and Alternative 2-2 are considered, while partial protection for these areas does not need measures to absorb the influence.

In the case of Alternative 2-1, the measure is heightening of flood barrier, while in the case of Alternative 2-2, the measure is diversion channel which is to be implemented in two (2) stages. However, only Stage 1 is concerned in flood damage mitigation in this area.

4.2 Formulation of the Master Plan

In this study, the Master Plan is formulated consisting of structural and nonstructural measures as shown in Fig.4.2.1. In the Master Plan, for flood mitigation in the urban areas of Pathum Thani, Nonthaburi and Bangkok, three (3) alternatives are provided; namely, Alternative 1, partial protection of Pathum Thani and Nonthaburi; Alternative 2-1, heightening of flood barrier at Bangkok; and Alternative 2-2, construction of diversion channel.

The difference of the measures applied in these alternatives is only the way of flood mitigation in these urban areas, and the other measures are commonly applied to these three options (refer to Table 4.2.1)

4.2.1 Alternative 1: Partial Protection of Pathum Thani and Nonthaburi

(1) Cost, Preliminary Design and Implementation Schedule

(a) Economic Cost and Benefit

It is possible to estimate the economic cost and benefit for only for following components (refer to Table 4.2.1). The other components are difficult to be evaluated in monetary term.

Project Components	Cost (mil. Baht)	Benefit (mil. Baht)
Modification of Dam Operation Rule	40 as initial cost and 394 as annual cost	3,268/year
Distribution and drainage system improvement	5,633 as initial cost and 39 as annual cost	
River improvement	1,227 as initial cost and 31 as annual cost	
Others	-	-

(b) Preliminary Design and Implementation Schedule

(i) Preliminary Design

Among the project components, preliminary design is prepared for only structural measures; namely, the river improvement and distribution and drainage system improvement. As for the distribution and drainage system improvement, only the area is shown in Fig. 3.3.7 and 3.3.8.

Preliminary design of river improvement is made in the following manner:

Alignment

The alignment of the river improvement is set based on the existing channel. As for the alignment of dike for agricultural areas along the river channel, the following cases are conceived:

- *Case 1:* Alignment based on the bank of existing channel, in which PWD is to provide ring levee for the protection of urban areas.
- *Case 2:* Alignment based on the dike of irrigation channel or road which play the role of dike, locating in parallel with the existing channel.
- *Case 3:* Combination of Case 1 and Case 2.

The major difference among these 3 cases is the river width, which influences the number of house relocation and decision of design water height.

In this study, Case 2 is adopted to minimize the number of house relocation, while there is not much difference in the decision for design water level, since the design discharge is not so large to require a change in design water level (refer to Fig. 4.2.1).

Longitudinal Profile

The longitudinal profile is set based on that of the existing channel.

Design water level is set based on the water level calculated by non-uniform calculation applying the design discharge (refer to Fig. 4.2.2.).

Cross Section

The cross section is based on the existing channel, but requires heightening of the dike up to the design dike height consisting of design water level and clearance (refer to Fig. 4.2.1 and 4.2.3).

(ii) Implementation Schedule

In principle, the implementation schedule is prepared considering the following points:

- Flood damage in paddy field playing a natural retarding function can be mitigated with less cost as long as detailed study for preparation of guideline and improvement of necessary facilities are finished. Thus, high priority is given to the implementation.
- River improvement can be implemented up to the level with 10-year return period by minimizing the adverse influence to Bangkok through the utilization of effectiveness of natural retarding basin. Thus river improvement can be given higher priority. (In case the river improvement is implemented without the natural retarding basin including distribution system improvement, it is necessary to provide a fuse to minimize the adverse influence by the river improvement.)
- The partial protection works of Pathum Thani and Nonthaburi should be undertaken considering the progress of loop-cut at Bangkok Port by RID.

Under the above considerations, the implementation schedule is prepared, as shown in Fig. 4.2.4.

(2) Evaluation of the Master Plan

(a) Economic Evaluation

The economic evaluation is made only for project components that can be evaluated in monetary term based on the economic cost and benefit mentioned above. The evaluation is made in a manner of EIRR, B-C and B/C, as shown below (refer to Table 4.2.2):

- EIRR = 21.1 %
- B-C = 5,875 million Baht
- B/C = 2.4

As identified, the economic viability evaluated by EIRR is high enough at over 12%.

Also, the project brings about many intangible benefits such as stabilization of people's living condition, decrease of waterborne diseases, increase of work opportunity and so on.

From the financial point of view, the project requires about 1.1 billion Baht per annum for the implementation within 20 years, which roughly corresponds to 1.2% of the total annual budget of 96.5 billion Baht for RID (44.4 billion Baht), PWD (39.8 billion Baht) and BMA (12.3 billion Baht). Although it may be difficult to designate the allowable percentage of allocation of the total budget, it seems to be still within the financial affordability of these agencies, judging from the figure (refer to Table 4.2.3).

(b) Technical Soundness and Social Acceptability

The project components are based on the conventional structural measures such as earth works. These measures do not face any technical difficulty.

On the other hand, river improvement may have social issues due to relocation of inhabitants in the areas where these measures are proposed. In this connection, it is natural to obtain a favorable public opinion for the decision of project implementation through meetings and seminar, so that the inhabitants can fully understand the significance and necessity of the project. By this, it seems to be possible to receive social acceptability.

(c) Environmental Sustainability

Initial Environmental Examination (IEE) has been conducted for the structural measures of project components to confirm the environmental sustainability of the Master Plan, i.e., the river improvement and the distribution and drainage systems improvement. IEE was conducted based on the customized parameters prepared in this study.

As the result, the IEE found that these measures will not have significant impacts from the ecological point of view, but may have impacts on sites and the surroundings from the social point of view. Therefore, it is crucial to pay attention to soften such social impacts and it is assumed that the solution is obtainable through continuous communication with affected people.

4.2.2 Alternative 2-1: Heightening of Flood Barrier at Bangkok

(1) Cost, Preliminary Design and Implementation Schedule

(a) Economic Cost and Benefit

It is possible to estimate economic cost and benefit for only for following components (refer to Table 4.2.1). The other components are difficult to be evaluated in monetary term.

Project Components	Cost (mil. Baht)	Benefit (mil. Baht)
Modification of Dam Operation Rule	40 as initial cost and 394 as annual cost	4,838/year
Distribution and Drainage System Improvement	5,633 as initial cost and 39 as annual cost	
Heightening of Flood Barrier	1,493 as initial cost and 12 as annual cost	
River Improvement	1,227 as initial cost and 31 as annual cost	
Others	-	-

(b) Preliminary Design and Implementation Schedule

(i) Preliminary Design

Among the project components, preliminary design is prepared for only structural measures, i.e., the river improvement. As for the distribution and drainage system improvement, only the area is shown in Figs. 3.3.7 and 3.3.8.

Preliminary design of river improvement is made in the following manner:

Alignment

The alignment of the river improvement is set based on the existing channel. As for alignment of dike for agricultural areas along the river channel, the following cases are conceived:

- *Case 1:* Alignment based on the bank of existing channel, in which PWD is to provide ring levee for protection of urban areas.
- *Case 2:* Alignment based on the dike of irrigation channel or road which play the role of dike, locating in parallel with the existing channel.
- *Case 3:* Combination of Case 1 and Case 2.

The major difference among these 3 cases is the river width, which influences the number of house relocation and decision on design water height.

In this study, Case 1 is adopted to minimize the number of house relocation, while there is not much difference in the decision for design water level, since the design discharge is not so large to require a change in the design water level (refer to Fig. 4.2.1).

Longitudinal Profile

The longitudinal profile is set based on that of the existing channel.

Design water level is set based on the water level calculated by non-uniform calculation applying the design discharge (refer to Fig. 4.2.2).

Cross Section

The cross section is based on the existing channel, but requires heightening of the dike up to the design dike height consisting of design water level and clearance (refer to Fig. 4.2.3).

(ii) Implementation Schedule

In principle, the implementation schedule is prepared considering the following points:

- Flood damage in paddy fields playing a natural retarding function can be mitigated with less cost as long as detailed study for preparation of guideline and improvement of necessary facilities are finished. Thus, high priority is given to the implementation.
- River improvement can be implemented up to the level with 10-year return period by minimizing the adverse influence to Bangkok through the utilization of effectiveness of natural retarding basin. Thus it can be given higher priority. (In case the river improvement is implemented without the distribution system improvement, it is necessary to provide a fuse to minimize the adverse influence by the river improvement.)
- Currently proposed heightening of flood barrier by BMA is ongoing and is to be completed by 2002. Consequently, further heightening should be undertaken after the current heightening of barrier is almost complete.
- In this connection, the protection works of Pathum Thani and Nonthaburi should be undertaken considering the progress of heightening of flood barrier at Bangkok.

Under the above considerations, the implementation schedule is prepared, as shown in Fig. 4.2.4.

(2) Evaluation of the Master Plan

(a) Economic Evaluation

The economic evaluation is made only for project components that can be evaluated in monetary term based on the economic cost and benefit mentioned above. The evaluation is made in a manner of EIRR, B-C and B/C, as shown below (refer to Table 4.2.2):

- EIRR = 24.0%
- B-C = 9,014 million Baht
- B/C = 2.9

As identified, the economic viability evaluated by EIRR is high enough at over 12%.

Also, the project brings about many intangible benefits such as stabilization of people's living condition, decrease of waterborne diseases, increase of work opportunity and so on.

From the financial point of view, the project requires about 1.2 billion Baht per annum for the implementation within 20 years, which roughly corresponds to 1.3% of the total annual budget of 96.5 billion Baht for RID (44.4 billion Baht), PWD (39.8 billion Baht) and BMA (12.3 billion Baht). Although it may be difficult to designate the allowable percentage of allocation of the total budget, it seems to be still within the financial affordability of these agencies, judging from the figure (refer to Table 4.2.3).

(b) Technical Soundness and Social Acceptability

The project components are based on the conventional structural measures such as earth works and piling blocks on top of the present barrier. These measures do not face any technical difficulty.

On the other hand, heightening of flood barrier may have social issues, since the works hamper the daily activities of inhabitants who fully use the Chao Phraya River for daily activities. River improvement also may have social issues due to relocation of inhabitants in the areas where these measures are proposed. In this connection, it is natural to obtain a favorable public opinion for the decision on project implementation through meetings and seminar, so that the inhabitants can fully understand the significance and necessity of the project. By this, it seems to be possible to receive social acceptability.

(c) Environmental Sustainability

Initial Environmental Examination (IEE) has been conducted for the structural measures of project components to confirm the environmental sustainability of the Master Plan, i.e., the river improvement, distribution and drainage systems improvement and heightening of flood barrier. IEE was conducted based on the customized parameters prepared in this study.

As the result, the IEE found that these measures will not have significant impacts from the ecological point of view, but may have impacts on sites and the surroundings from the social point of view. Heightening of the flood barrier, which interfere with inhabitants and tourists from enjoying the nice scenery of the Chao Phraya River, may have serious impacts from the social point of view. Therefore, it is crucial to pay attention to soften such social impacts and it is assumed that the solution is obtainable through continuous communication with the affected people.