Evaluation of Dike Construction in Cambodia

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ABSTRACT

Each year during the rainy season, huge amounts of water flow down the Mekong River, causing flooding downstream of Kompong Cham, Cambodia. The construction of a dike is considered as one means of protecting crops and property against flooding. This study approximately evaluates the construction of dikes through a cost-benefit approach. The target zone between Kompong Cham and Phnom Penh in the Mekong River was selected. The flood discharge quantity between Kompong Cham and Phnom Penh was estimated from monthly discharge data, and the rise in water level at Phnom Penh after constructing the dike was approximated by flood discharge quantity and H-Q curve. For the cost-benefit analysis, the expected benefit after constructing the dikes was estimated based on the inundation area downstream of Kompong Cham station and water levels at Kompong Cham station. The cost of dike construction given in JICA's report was used. As a result, it was shown to be very difficult to construct dikes between these two stations under present conditions. By changing the construction cost or discount ratio, however, the construction of dikes may be feasible.

Keywords: Mekong river, flood, dike construction, cost-benefit analysis

1. INTRODUCTION

The Mekong River, which runs through the six countries of China, Myanmar, Laos, Thailand, Cambodia and Vietnam, is one of the biggest international rivers in Southeast Asia (**Fig. 1**). The total basin area and length of this river are 795,500 km^2 and 4,620 km respectively, and the catchment area in Laos and Cambodia covers more than 80% of each country (Hori, 2000). Each year during the rainy season (September or October), huge amounts of water flow down the river and cause flooding and major damage downstream of Kompong Cham, Cambodia. According to Relief Web, which is a project of the United Nations Office for the Coordination of Humanitarian Affairs (2000), the flood in 2000 caused damage to crops and property in Cambodia estimated to exceed US$50 million,

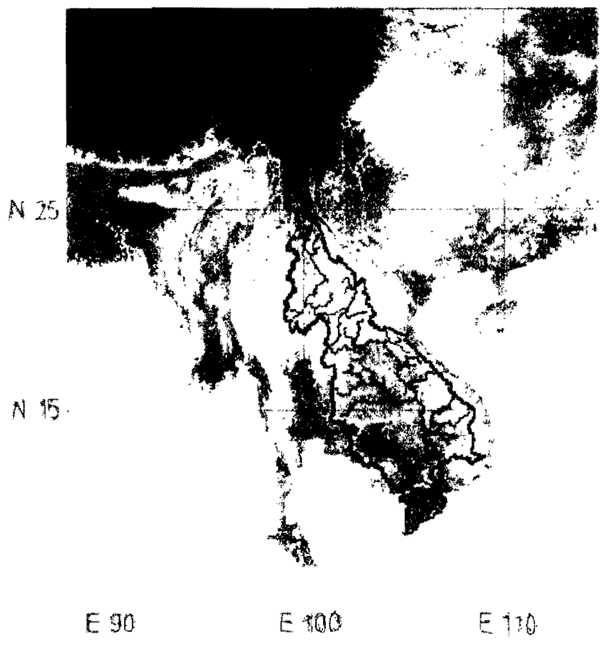

Fig. 1 Location of Mekong River Basin

excluding widespread damage to the nation's infrastructure. Yet even though floods occur every year, there have been few studies on flood water quantities and related matters because of the lack of hydrology and meteorology data following civil strife until 1998. This study aims to grasp discharge characteristics from monthly discharge data, and to estimate the flood water amount and cost-benefit of constructing dikes.

2. STUDY AREA

The study area is shown in **Fig. 2**. The Mekong, Tonle Sap and Bassac Rivers meet in a uniquely shaped crooked X at Phnom Penh, called the "Four Arms". Hydrologic stations of Kompong Cham, Phnom Penh and Neak Loung are located along the main stream of the Mekong River. On the section of the Tonle Sap River through Tonle Sap Lake to above the Phnom Penh station is the Prek Kdam station. The Bassac station is located on a tributary of the Mekong River called the Bassac River. During the rainy season, flooding occurs in the direction of the dotted arrows shown in **Fig. 2**. Note that the Tonle Sap River flows in the direction from Phnom Penh to Tonle Sap Lake, which is the opposite to that during the dry season.

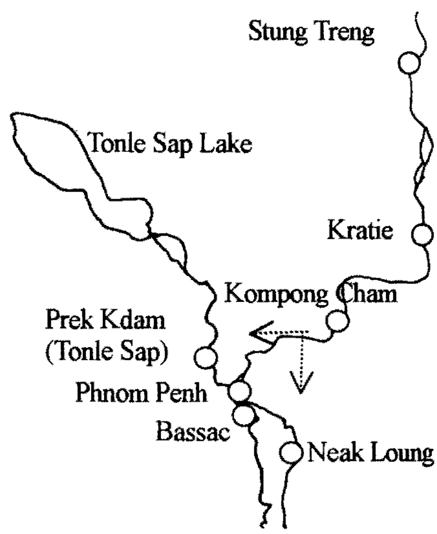

Fig. 2 Outline of hydrologic stations

3. METHODOLOGY

3.1 Determination of River Discharge Characteristics

There is limited data available for flood analysis in Cambodia. The "Year Book" published by MRC (Mekong River Commission) gives only daily discharge and water level data. There is scarcely any discharge data for 1965 to 1971 in this book, and not enough for daily analysis. For this period, therefore, monthly discharge data converted from daily discharge data were used.

3.2 Estimation of Cost-Benefit for Dike Construction

In order to estimate the cost-benefit of constructing dikes, many data sets are needed and detailed investigations and analyses should be done. However, an approximate cost-benefit analysis was sufficient for this study, so JICA's reports (1999) were mainly used for calculating the cost-benefit of dike construction.

3.3 Nonparametric Regression Method (Super Smoother)

Using some references (Friedman, 1984; Jeffrey, 1999; Herbert, 2000), nonparametric regression models are explained simply as follows. In this case, Super Smoother is used for analysis. Super Smoother is based on local linear k-NN fits in a variable neighborhood of the estimation point X. Local cross-validation is applied to estimate the optimal span as a function of the predictor variable. The basic idea of Super Smoother is to attempt to minimize the local mean squared error. The concept of nonparametric regression is to use models as shown by the following equation:

$$y_i = m(x_i) + \varepsilon_i$$

where m(x) is conditional expected value (m(x)=E(Y|X=x), and ε is iid additive error with mean zero and constant variance. The advantage of nonparametric regression over simpler parametric models (such as spline regression line as shown in **Fig. 3**) is that the assumptions of the model can be flexibly varied.

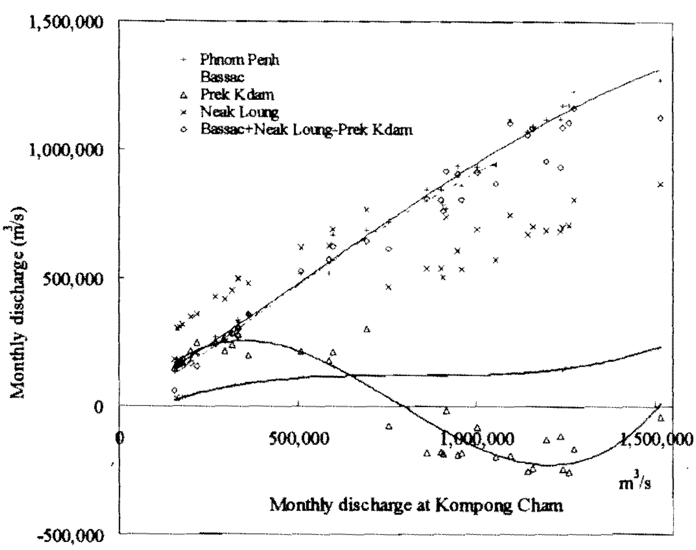

Fig. 3 Comparison between Kompong Cham monthly discharge and each station (spline regression result)

4. RESULTS AND DISCUSSIONS

4.1 Characteristics of Monthly Discharge at Each Station

By using the nonparametric regression model, the relation of monthly discharge data at Kompong Cham station and each station at Phnom Penh, Bassac, Prek Kdam and Neak Loung were analyzed as shown in **Fig. 4**. The X-axis shows monthly discharge data at Kompong Cham and the Y-axis shows the discharge of each station. From the above line, the first line is Phnom Penh, the second line is Neak Loung + Bassac – Prek Kdam, the third line is Neak Loung, the fourth line is Bassac and the lowest line is Prek Kdam. From this figure, it is clear that: (1) the monthly discharge of Prek Kdam goes negative when the monthly discharge of Kompong Cham exceeds 750,000 – 800,000 $m^3 \cdot s^{-1}$. This indicates that the period of backflow of the Prek Kdam River can be estimated from the accumulated discharge of Kompong Cham. In addition, the monthly discharge of Phnom Penh becomes less than that of Kompong Cham around this period due to flooding; (2) The sum of discharges at Prek Kdam, Bassac and Neak Loung moves similar to the discharge of Phnom Penh and starts to decrease when the discharge of Kompong Cham exceeds 1,000,000 $m^3 \cdot s^{-1}$; and (3) The discharge behavior at Neak Loung and Bassac are very similar to each other when the backflow from Phnom Penh to Tonle Sap Lake begins.

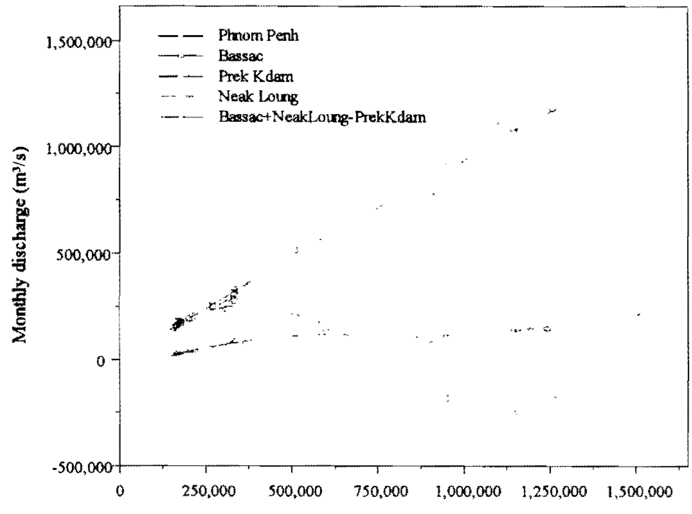

Fig. 4 Comparison between Kompong Cham monthly discharge and each station (Nonparametric regression result)

4.2 Approximation of Monthly Flooding Discharge Water

The monthly flooding discharge water between Kompong Cham and Phnom Penh during the rainy season was approximated as shown in **Fig. 5**. This figure was made by tracing the lines of nonparametric regression (**Fig. 4**) and expressing them as a sequential line graph (aggregation of linear expression). In this case, daily evaporation during the flood period is assumed to be negligible because the ratio of the sub-basin to the whole upper basin is very small. Thus, monthly flooding discharge water between these two stations was estimated from the monthly discharge water at Kompong Cham minus that at Phnom Penh. The monthly discharge water of 1,500,000 $m^3 \cdot s^{-1}$ at Kompong Cham is an example. The discharge at Kompong Cham ($y = x$) minus the discharge at Phnom Penh ($y = 4/5x + 160000$, where: $x \geq 1{,}050{,}000$ $m^3 \cdot s^{-1}$) was considered to be the flooding discharge water, which was 140,000 $m^3 \cdot s^{-1}$.

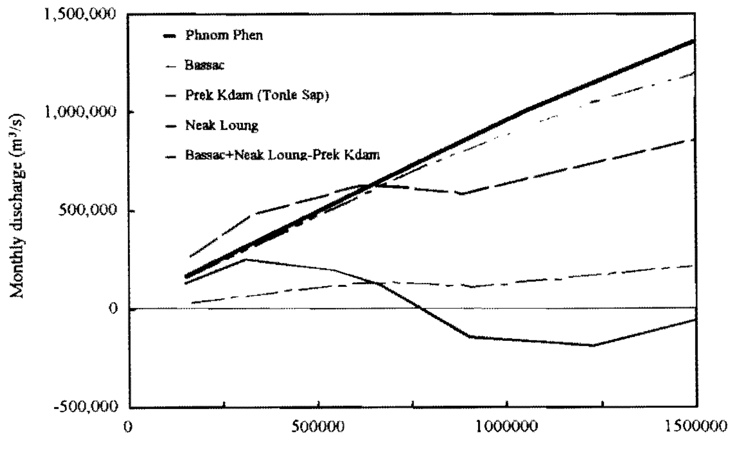

Fig. 5 Sequential line estimated by nonparametric regression graph

4.3 Estimated Rise in Water Level at Phnom Penh in A Special Case

The rise in water level at Phnom Penh was estimated in the case that the flooding discharge water calculated in section 4.2 does not flood over the banks between Kompong Cham and Phnom Penh stations. To calculate the water level, the monthly value was converted to a daily value (4,667 $m^3 \cdot s^{-1}$). One month is assumed to be 30 days for converting the values. In the case of a monthly discharge of 1,500,000 $m^3 \cdot s^{-1}$ at Kompong Cham, the monthly discharge at Phnom Penh is 1,360,000 $m^3 \cdot s^{-1}$ and the daily discharge is 45,333 $m^3 \cdot s^{-1}$. This daily discharge was converted to water level by using the H-Q curve ($Q=1731H^{1.436}$) calculated from the discharge and water level at Phnom Penh given in the Year Book (1965). From this curve, the daily discharge, 45,333 $m^3 \cdot s^{-1}$, is equivalent to roughly 9.7 m. In the case of no flooding between the two stations, the daily discharge and water level were estimated to be 50,000 $m^3 \cdot s^{-1}$ and 10.4 m, respectively. As a result, the rise in water level at Phnom Penh is estimated to be about 0.7 m.

4.4 Approximate Evaluation of Cost-Benefit for Dike Construction

In order to estimate the cost-benefit of dike construction, some assumptions were set up. First, the cost of damage caused by flooding was assumed to be US$50 million based on the cost of damage caused in the year 2000. Second, data of the inundation area downstream of Kompong Cham and water level at Kompong Cham station were taken from 2002 and 2003. Third, dike construction cost per unit distance and probable water level at Phnom Penh were taken from a report compiled by JICA. Forth, flood frequency is 50 years and the evaluation period of dikes is 50 years (construction is for 3 years and discount ratio is 10%). Finally, the dike distance required to be constructed is 180 km (both sides of river between Kompong Cham and Phnom Penh). The relationship between water level at Kompong Cham and inundation area downstream of Kompong Cham station was expressed as shown in **Fig. 6**. By using this relationship, an approximated function of expected benefit was made as shown in **Fig. 7**. The damage cost by flooding for each flood frequency (year) was estimated from **Fig. 5**, **Fig. 7**, **Table 1** and the H-Q Curve of 1966 ($Q=1731H^{1.436}$). The expected benefit by dike construction was estimated based on a flood control manual (River Bureau, 2000). The construction cost was estimated to be US$1 million/km (distance)/m (height). The average dike height needed to be constructed for preventing floods of 50-year frequency was estimated to be 2.2 m from the DEM data (source:

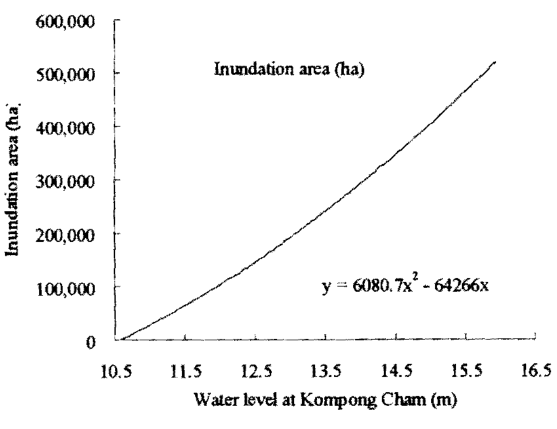

Fig. 6 Relationship between inundation area and water level at Kompong Cham

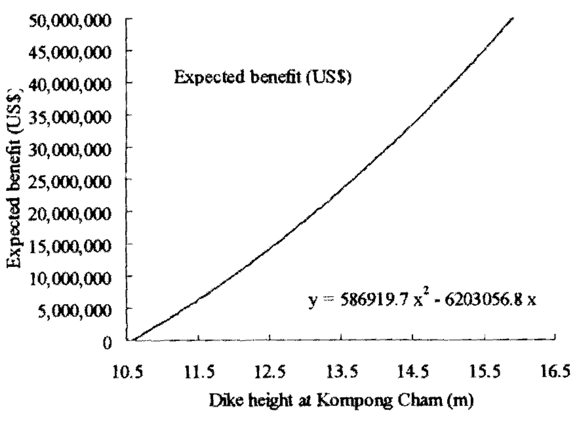

Fig. 7 Relationship between expected benefit and dike height at Kompong Cham

Hydro1k), hence the relationship between dike construction cost and dike height was derived (**Fig. 8**). As a result, the relationship between cost-benefit ratio (B/C) and dike height is shown in **Fig. 9**. This figure shows that dike construction will not pay between these two stations under present conditions.

Table 1 Probable water level at Chaktomuk (Phnom Penh) hydrologic station

Flood frequency (year)	Water level (EL m, NGK)
2	8.9
5	9.4
10	9.7
20	9.9
30	10
50	10.1

(source: JICA, 1999)

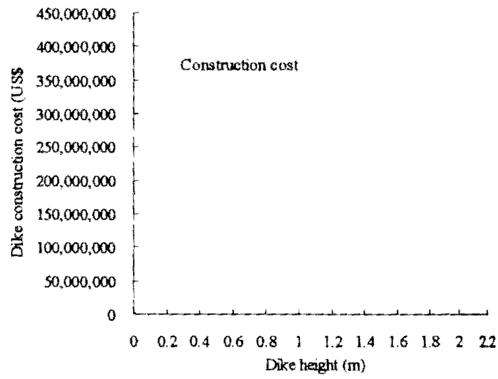

Fig. 8 Relationship between dike construction c
and dike height

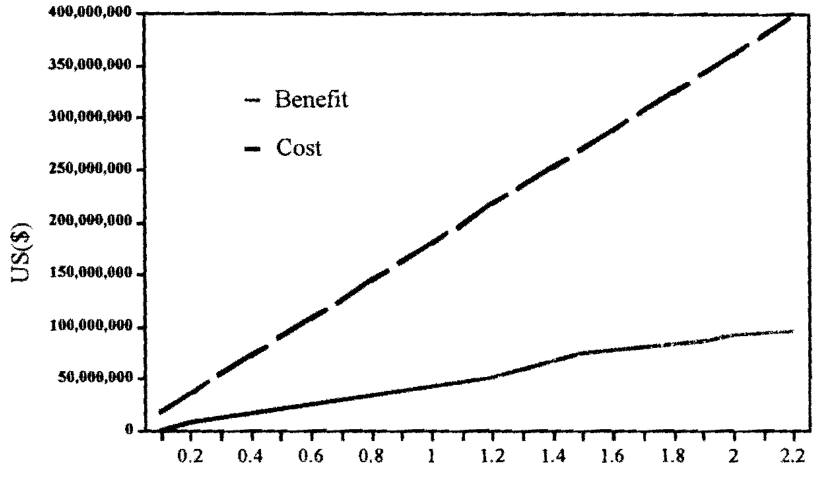

Fig. 9 Result of cost-benefit and dike height

As a next step, sensitivity analyses were done. When the benefit of constructing dikes is calculated, an arbitrary discount ratio is usually used. As this discount ratio is determined by each numerator, the benefit will change depending on this value. Thus, differences of benefit line were checked by changing the discount ratio. In addition, differences of cost line were checked. Because this cost line is made from JICA's report for protecting Phnom Penh city, the cost will be estimated higher than under general conditions, and so may not be applicable to agricultural areas such as that between these two stations. Additionally, since most of the cost is accounted for by fuel, the cost may change with fuel prices. The result of the two sensitivity analyses is shown in **Fig. 10**. From this figure, the cost-benefit will pay if the cost can be reduced by 30 to 50% and assuming a discount ratio of 3%.

Next, the reduction of flooding area by constructing dikes was considered as a benefit. The reduction of flooding area by building dikes is shown in **Fig. 11**. Note that the water level rises very slowly during the flood season and the water velocity is also very low in the Mekong River unlike in rivers in Japan.

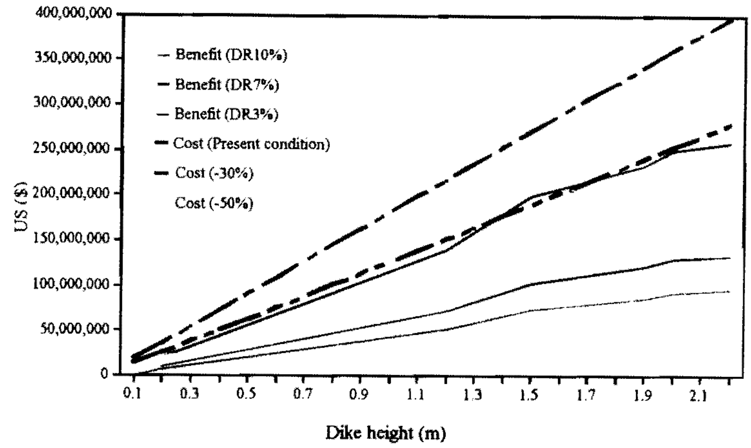

Fig. 10 Sensitivity analysis for cost-benefit with change in discount ratio and dike construction cost

By delaying the timing of flooding, the flooding area may be reduced and not all crops will be damaged. The result of such a time delay is shown in **Fig. 12**. It is clear that delaying flooding, which is one of the functions of dikes, increases the benefit.

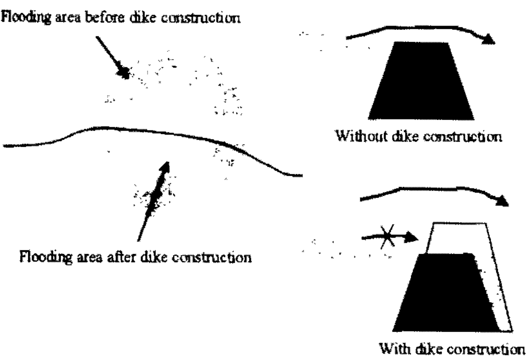

Fig. 11 Reduction of flooding area by dike construction

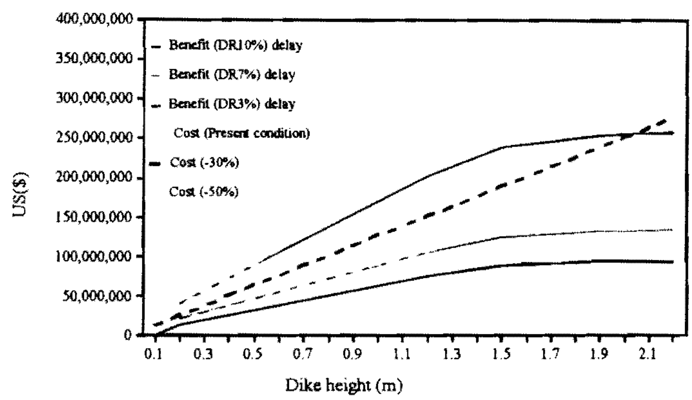

Fig. 12 Sensitivity analysis for cost-benefit with dike construction

Finally, the change of property values was considered. At present, the land between these two stations is mainly used for agriculture, according to the land use map. However, land use will change as the population increases and economy grows. According to The World Bank (1999) and UN (1994), the population of Cambodia is estimated to double from 1997 to 2025. Furthermore, according to the UN (1994), the urban population of Cambodia is estimated to increase by 183% from 2000 to 2025. By using these estimations, the future benefit could be estimated. As the present value of flood damage at Phnom Penh is estimated to be US$32 million according to JICA's report (1999), it is estimated that two cities of the same scale as Phnom Penh will develop, one by 2012 and the other by 2025. As a result, considering the population increase by 2012, the cost-benefit will pay with a discount ratio of 7% and cost reduction of 30% (**Fig. 13**). Furthermore, in view of the population increase by 2025, the cost-benefit will pay with a discount ratio of less than 7% (**Fig. 14**). The comparison between 2012 and 2025 shown in **Fig. 15**, anticipating that the population increases up to 2025, shows that the construction of dikes between these two stations may be feasible.

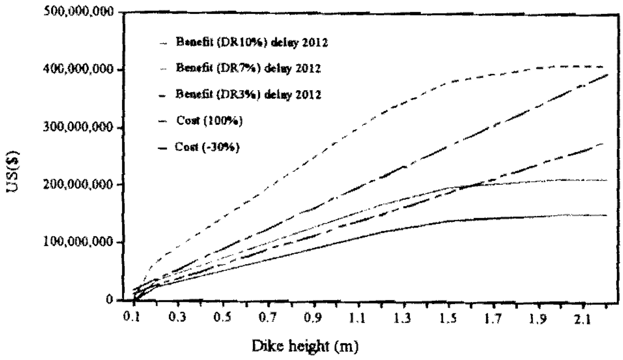

Fig. 13 Benefit line at 2012

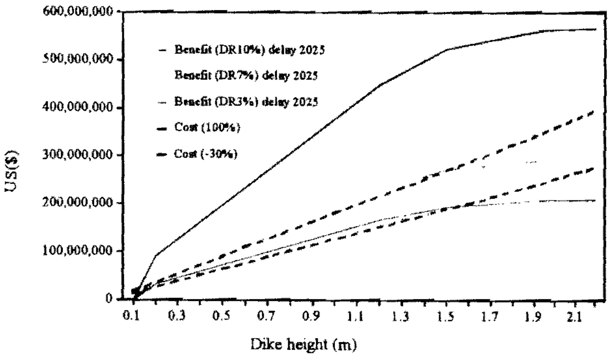

Fig. 14 Benefit line at 2025

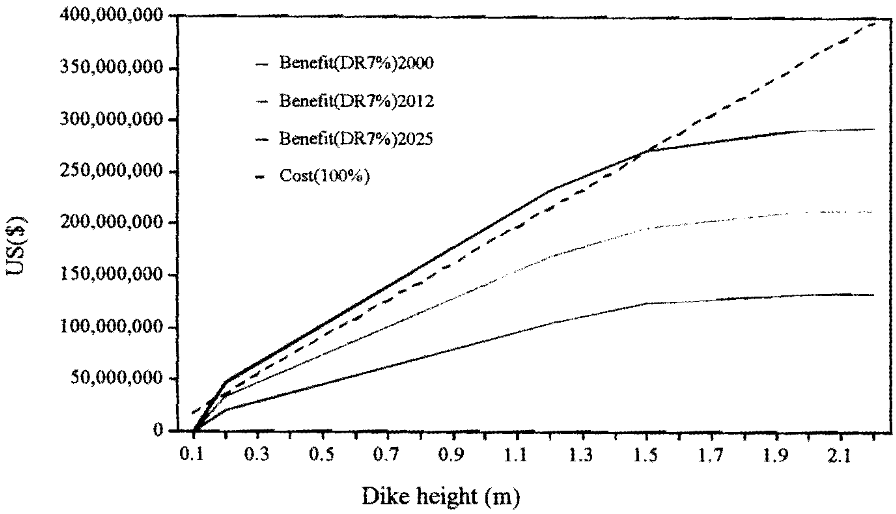

Fig. 15 Difference of benefit line by year

5. CONCLUSIONS

In this study, the amount of flood discharge and rise in water level were approximately estimated. Although hydrologic models are usually used to estimate these values, much time and effort would be required to create such models for an area like the Mekong River Basin where there is little data. In spite of the very rough method used to derive the results of this study, the effects of discharge downstream of Kompong Cham were estimated relatively easily by a primary approximate expression. In addition to these, evaluation of constructing dikes was considered. The results are summarized as follows.

- Monthly discharge characteristics were grasped.
- The monthly discharge water between Kompong Cham and Phnom Penh was estimated to be about 140,000 $m^3 \cdot s^{-1}$.
- The rise in water level at Phnom Penh in the case without flood water between Kompong Cham and Phnom Penh was estimated to be about 0.7 m.
- Sensitivity analyses showed that it is very difficult to construct dikes between these two stations under present conditions. It might be possible, however, to consider the construction of dikes by changing the construction cost or discount ratio.

- The increase in benefit as the population increases in the near future (2012 and 2025) suggests that dike construction may be feasible under present conditions.

In future studies, the benefit of constructing agricultural channels such as colmatages between these two stations should be considered, because agricultural productivity will increase when flood water is transferred to agricultural areas for irrigation. The cost-benefit relationship related to the construction of dikes and channels may thus be clarified.

ACKNOWLEDGEMENT

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