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Operation Analysis of Multi-Purpose Reservoirs in the Chao Phraya River Basin

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Abstract

The purpose of this study was the development of a model to estimate the effects of various operations on water storage in reservoirs. Investigation area was the Chao Phraya river basin in Thailand. Reservoirs in the water use system are multi-purpose reservoirs. Water distribution for various purposes must be considered. Furthermore the water balance of reservoirs cannot be determined during 1 year. At first a model to estimate future effects of each purpose was developed in this water use system. Next, present operations of reservoirs were evaluated by using the estimation model. Recently water shortage has occurred occasionally in this basin presumably due to operation rules. Evaluation of operation rules showed that the current rules enable to achieve stable water use. The probability of water shortage was estimated at 0.059. Finally relations among effects of purposes were investigated.

Discipline: Irrigation, drainage and reclamation
Additional key words: Thailand, water resources, water use

Introduction

There are many alternatives in operation planning. Managers must select the optimum operation plan among these alternatives. The optimum operation plan is expected to be the most effective for reservoir purposes. Accordingly, it is important to estimate the effect of an operation plan.

The water system investigated in this study is the Chao Phraya delta water use system including Bhumibol reservoir and Sirikit reservoir. The water released from the reservoirs flows through the Chao Phraya river to the Chainat dam and is carried in many irrigation canals or released downstream of the river. The outline and location of this water use system are shown in Table 1 and Fig. 1.

Bhumibol reservoir and Sirikit reservoir have 2 main characteristics.

First, they are multipurpose reservoirs. These reservoirs store water for domestic, industrial and irrigation purposes, salinity control, flood mitigation, power generation, etc. These purposes sometimes conflict with each other. Some operation rules are thus set up in the water use system.

Second, the operations affect the water storage of reservoirs for a long time. The average inflow into both reservoirs is about half of the effective storage and the influence of operations must be considered for many years.

After the construction of the reservoirs, rice cropping in the dry season began and the area under cultivation increased. However water shortage which

Table 1. Characteristics of reservoirs

	Bhumibol	Sirikit
Gross storage capacity (million m^3)	13,462	9,510
Sediment capacity (million m^3)	3,800	2,850
Effective storage capacity (million m^3)	9,662	6,660
Catchment area (km^2)	26,386	13,130
Normal discharge (m^3/s)	561	183
Annual inflow (million m^3)	4,250	4,090

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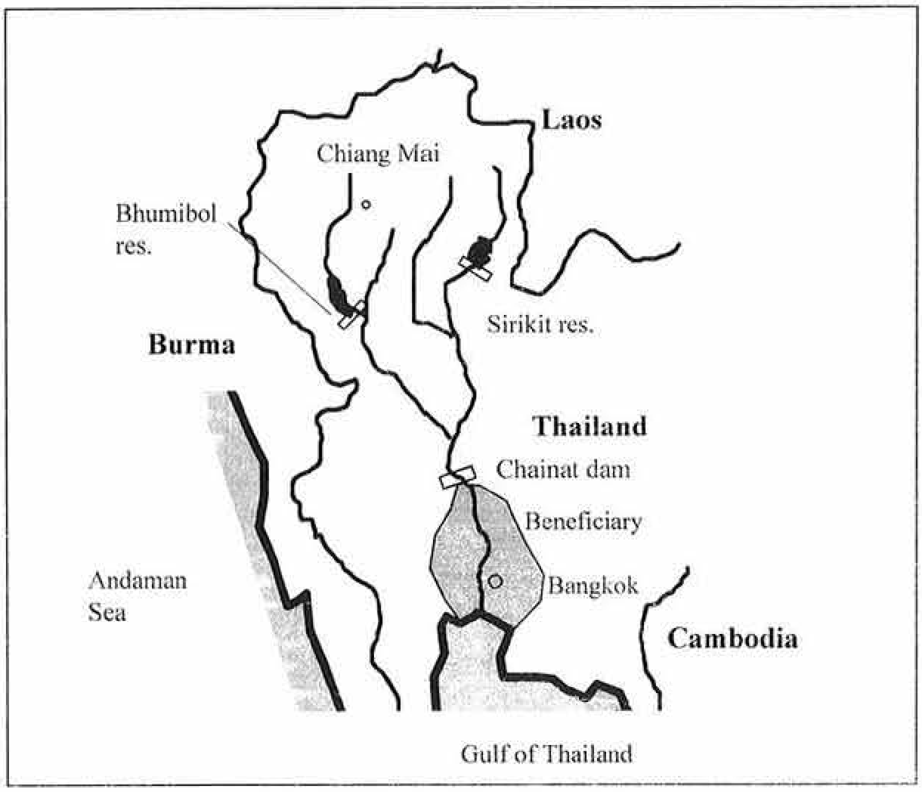

Fig. 1. Water use system in the Chao Phraya river basin beneficiary

has occurred recently restricts dry season rice cropping. Excessive cultivation of rice in the dry season and excessive release of water for power generation are considered to be the main reasons for water shortage, in addition to the decrease of the inflow into the reservoirs.

The purpose of this study is to develop a model to estimate the effects of operations on reservoir storage and to evaluate alternative operation rules for the Chao Phraya river basin.

A probability estimation of reservoir operations which includes the Markov process was first described by Moran[1] and has been examined by several authors. If various operations are decided at different intervals, the size of the transition matrix increases. In this study case, release from reservoirs is decided at an interval of a few days, while the planting area is decided at an interval of 1 year.

A random linear alignment which is a kind of simulation model was suggested[2] to decrease the amount of calculations but this method limits the possibility of storage changes.

In this paper a discrete Markov process model and a simulation model were combined and an estimation model was developed.

Following investigations were carried out:

1) Development of a water use model to simulate reservoir storage changes and estimate effects of operations.
2) Development of an estimation model by using the water use model.
3) Evaluation of operation rules. There are operation rule alternatives for the water use system.

At first the present operation rules were evaluated by using the estimation model obtained above. Next the effect of operation rules on each purpose was investigated.

Development of water use model

1) Outline

It is necessary to forecast changes in the storage volume in the Bhumibol reservoir and Sirikit reservoir for the estimation of effects of operations in future. The water use model simulates storage volume changes caused by a certain operation under the same hydrological conditions as previous ones. To simulate the changes of storage in reservoirs, the water balance was calculated as follows.

Firstly, the volume of required water which is taken into the canals and the volume of water released from the Chainat dam were calculated. Secondly the river discharge at the Chainat dam was compared with the sum of release and intake from the Chainat dam and a difference was obtained. Thirdly the difference and release for power generation were compared with each other and the larger value was used to represent the release from reservoirs. Finally storage increment was calculated from the volume of inflow and release.

Volume of water release from the Chainat dam, required intake and release for power generation were calculated in sub-models. A set of operations was dealt with for operation rules.

2) Operation rules

Purposes of Bhumibol reservoir and Sirikit reservoir are classified into 4 groups i.e. flood mitigation, power generation, water supply for rice cropping in the dry season and others (water supply for domestic use, irrigation water in the wet season and salinity control). There are some rules for the distribution of water stored in reservoirs.

(1) Upper rule curve

Bhumibol reservoir and Sirikit reservoir have a set of storage systems represented by the so-called upper rule curve determined each month. These systems are set up for flood mitigation, to keep the water volume below a certain level. In the model, water is released depending on the capacity of each reservoir when the water volume exceeds that indicated by the upper rule curve.

(2) Lower rule curve

Reservoirs have also a set of storage systems represented by the so-called lower rule curve determined each month. These systems are set up for avoiding water shortage for domestic use, etc. Water storage should exceed this volume. Restriction on release for power generation is imposed when the water storage volume is less than the volume indicated by the lower rule curve. Fig. 2 shows the rule curves. The storage volume used later is the sum of the volumes of the 2 reservoirs.

(3) Rule for planting area of rice in the dry season

When water storage decreases at the beginning of the dry season the planting area of rice in the dry season is restricted or planting is prohibited. The rule for the planting area of rice in the dry season is expressed by the relation between the water storage volume and planting area. Records observed are shown in Fig. 3.

3) Sub-model

(1) Intake

Intake water from the Chainat dam is used for irrigation mainly. The characteristics of irrigation supply in the dry season and in the wet season are as follows:

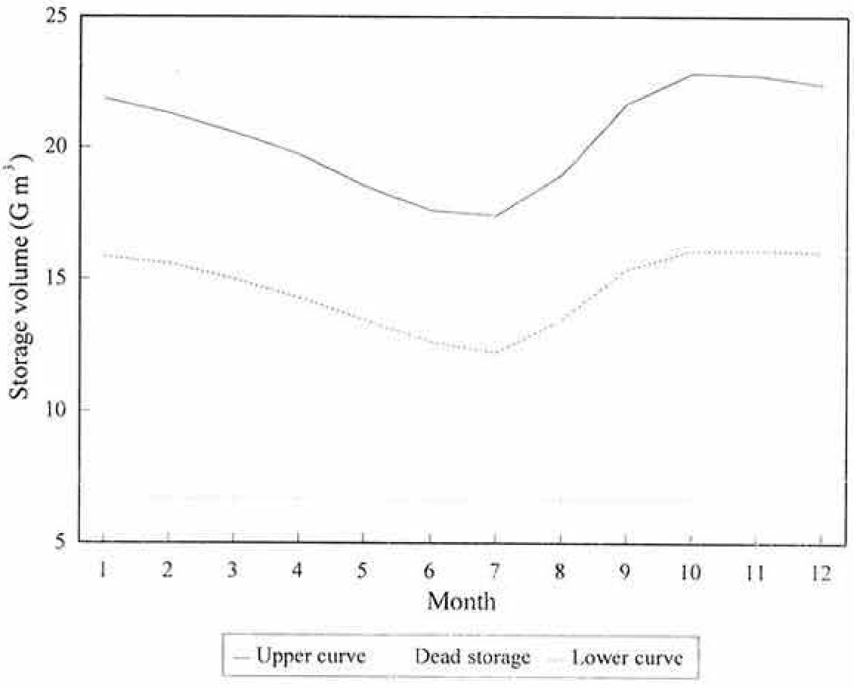

Fig. 2. Rule curves

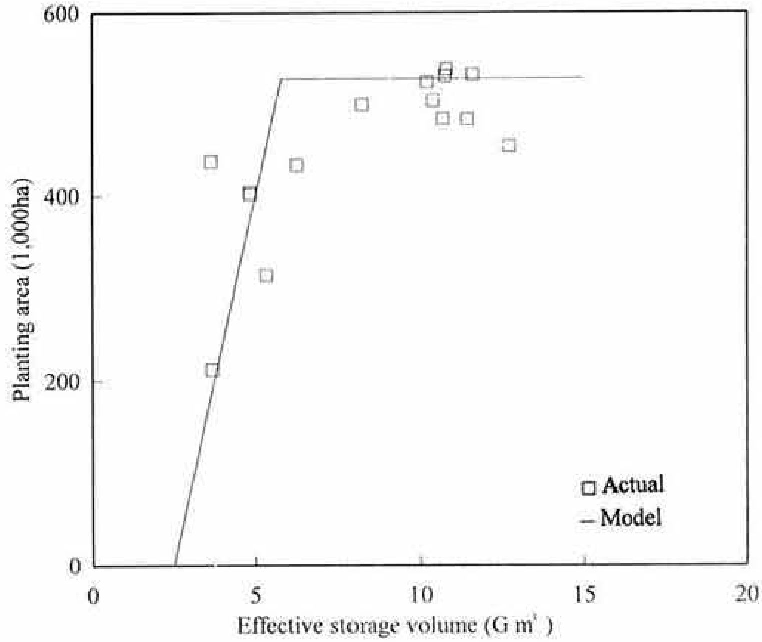

Fig. 3. Relationship between planting area reduction in the dry season as storage volume

• Wet season (May – December)

It is assumed that the amount of irrigation water in the wet season is related to rainfall. In this calculation, data observed represent the irrigation water required (water demand).

• Dry season (January – April)

It is assumed that the planting area in the dry season depends on the water volume in the reservoirs at the beginning of the dry season. The variation in the amount of rainfall with years does not seem to be important. Accordingly, the estimation of required irrigation water must be considered as a function of the cropping area. The amount of water required for every 10-day periods which is calculated from past intake records is shown in Table 2.

Table 2. Amount of water required in the dry season

Month	Day	Water required (m^3/ha/10 days)
January	1 – 10	53.2
	11 – 20	10.0
	21 – 31	122.5
February	1 – 10	414.4
	11 – 20	430.6
	21 – 28	600.6
March	1 – 10	772.5
	11 – 20	942.5
	21 – 31	1,048.8
April	1 – 10	881.3
	11 – 20	743.1
	21 – 30	726.3

(2) Release from the Chainat dam

Water for domestic purpose, etc. is released from the Chainat dam downstream of the river. The required release including the water management requirement from the Chainat dam was estimated at 95 m^3/s.

(3) Release for power generation

When the storage volume level corresponds to the middle part of the volumes given by the 2 rule curves, release for power generation increases with the storage volume in the reservoirs. The minimum amount of water (141 million m^3 during 1 month) is released all the time.

Development of the estimation model

1) Simulation during 1 year

Simulations were executed for 1 year under the operation rule alternatives to obtain the relation between the storage volume at the beginning of the year and the storage volume at the end of the year. The effects of operations were also analyzed in the course of simulations. Effects are denoted as expectations or probabilities. Expectation is suitable for expressing the harvested area in the dry season and the amount of power generation. Probability is used to express water shortages and floods.

2) Transition matrix

At first it is necessary to carry out discrete programming for the water storage volume. In this study the storage volume was divided into 500 million m^3 series to carry out discrete Markov programming. As the sum of the effective storage volume of the Bhumibol reservoir and Sirikit reservoir is 16,322 million m^3, the storage was divided into 34 units. Occurrence probabilities are assigned to each unit at the beginning of the year and enable to derive the probability distribution vector x_i. The subscript i stands for the number of years after onset.

The 34th order square matrix with elements reflecting probabilities was used as a transition matrix P. The element p_{jk} stands for the probability in which k-th storage volume in the reservoirs changes to j-th storage volume after 1 year.

The relation between the probability distribution in a certain year x_i and that after 1 year x_{i+1} is derived in the equation below.

$$x_{i+1} = Px_i$$

It is assumed in this study that the state of the next stage depends only on the state of this stage and is not related to former states or former decisions. The stochastic process which controls this assumption is referred to as Markov process.

After a transition matrix is obtained, probability distribution in m years onward is derived by the equation below.

$$x_m = P^m x_0$$

The vector x_0 is the initial probability distribution.

Once the probability distribution of reservoir storage is determined for m years onward, other predictions during m years after the present year can be deduced as follows:

- Expectation of harvested area of rice in the dry season.
- Probability of restriction on planting area in the dry season.
- Probability of water shortage for domestic use, etc.
- Probability of flood occurrence.
- Expectation of output of annual power generation.

3) Example

Based on the estimation model, forecasts of the expectation of the harvested area and of the water shortage probability are presented in Figs. 4 and 5 as examples. The operation rule used is the present rule. Initial storage volumes are set up at 7,150 million m^3, 9,150 million m^3, 11,650 million m^3, 14,150 million m^3, 16,650 million m^3. The probability of water shortage in the near future depends on the initial storage volume. However reservoir storage shows an inherent capacity of recovery. Even if, the reservoir storage volume fluctuates for some reasons, stationary storage can be recovered within 6 or 8 years.

The expectations of harvested area show the same trend as the water shortage probability.

Evaluation of operations

1) Method

As mentioned above we can forecast the effects of operations in future based on present reservoir storage by using a transition matrix. The estimation model enables to forecast effects and evaluate the operation rules, since a limit value of expectation or probabilities is not related to the initial storage. A limit value can be used as indexes to evaluate the operation rules.

2) Evaluation of present operations

The evaluation of the present operation rules can be described as follows, based on limit values.

- The expectation of harvested area in the dry season is 94% of field.
- The probability of restriction on planting area in the dry season is 15% (once in 6 or 7 years).
- The probability of water shortages is 6% (once in 16 or 17 years).
- The water storage probability within 1 year, when effective initial storage is 5,000 million m^3, is 25%.
- The 90% rank storage and 75% rank storage are 11,500 million m^3 and 13,500 million m^3, respectively.

The probability of water shortage is very low and the storage volume of 90% rank is comparatively large. Therefore, it is important for stable water use to keep a high storage level.

3) Influence of water operation rules

(1) Influence of planted area rule in the dry season

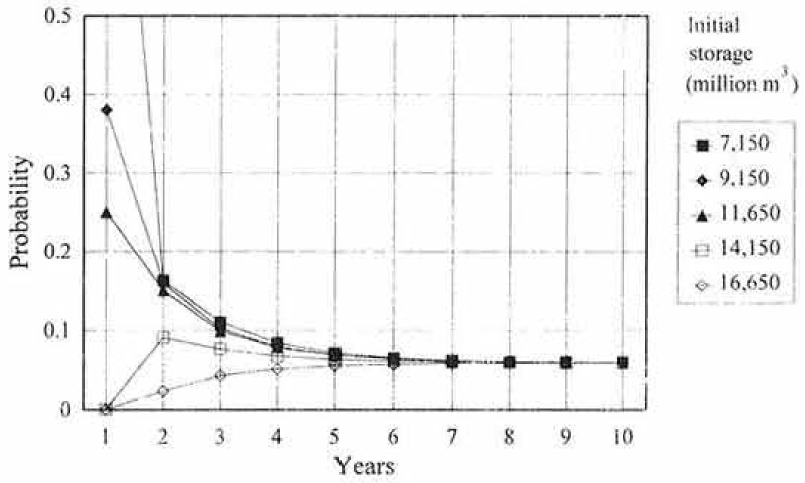

Fig. 4. Change in probability of water shortage

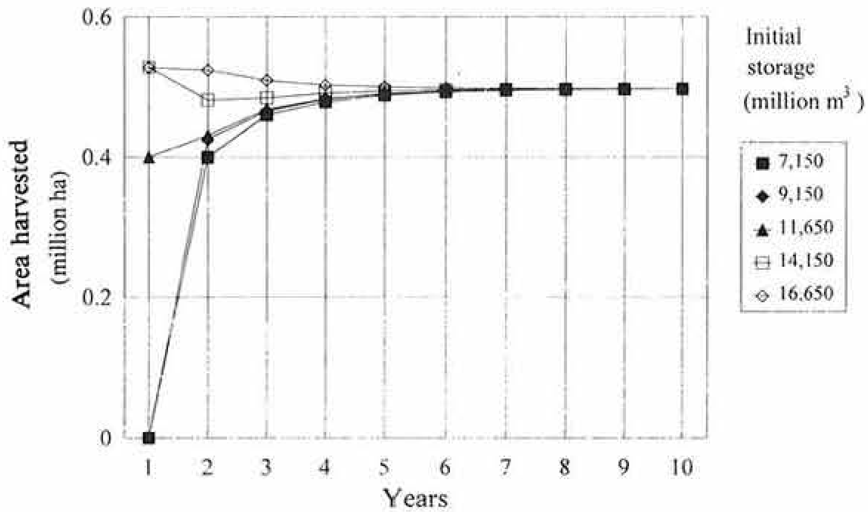

Fig. 5. Change in harvested area

Table 3. Planting area rule

Effective storage (million m^3)	Planting area (1,000 ha)					
	Present	Case 1	Case 2	Case 3	Case 4	Case 5
Less than 1,500	0	0	0	0	0	530
2,000	0	0	0	0	80	530
2,500	0	0	0	80	150	530
3,000	80	0	0	160	240	530
3,500	160	0	80	240	320	530
4,000	240	110	160	320	400	530
4,500	320	190	240	400	480	530
5,000	400	1.6	320	480	530	530
5,500	480	340	400	530	530	530
6,000	530	420	480	530	530	530
6,500	530	480	530	530	530	530
More than 7,000	530	530	530	530	530	530

By varying the planting area rule, changes of effects were investigated. Five rules were suggested and calculated (the 5 rules are referred to as case 1 to case 5) as shown in Table 3.

The relation between the expectation of the harvested area and the probability of water shortage based on limit values is shown in Fig. 6. The relation between the expectation of the harvested area and the expectation of power generation based on limit values is shown in Fig. 7. The harvested area is the trade off, in case of water shortage, for water for domestic use, etc. and the amount of power generation. These figures are used to determine rules among these alternatives.

(2) Influence of the lower rule curve

Four operation rules are suggested here. The volume indicated by the lower rule curve decreases by 1,000 million m^3 uniformly in case 6, by 2,000 million m^3 in case 7, increases to 1,000 million m^3 in case 8 and to 2,000 million m^3 in case 9. Calculated expectations of the harvested area in the dry season based on limit values, probability of water shortages and the output of power generation are shown in Table 4.

The table indicates that the rise of the lower rule curve results in the increase of the harvested area in the dry season, decrease of water shortage probability, increase of power generation. The rise of the lower rule curve is effective for these 3 purposes. However, in this study the stability of the output of power generation was not evaluated. It is thus necessary to confirm the stability of the electricity supply to obtain actual estimations.

Conclusion

A water use model and estimation model of operations were developed in the Chao Phraya water use system. The estimation model enables to predict the storage volume, water shortage, harvested area in the dry season, annual output of power generation in future from the present storage volume under a certain operation.

Using this model, we can also obtain the evaluation indexes of operations or operation rules. The present operation rules were evaluated as follows: the present operation rules indicate stable water use. However it is important to save water when the reservoir storage volume is sufficient.

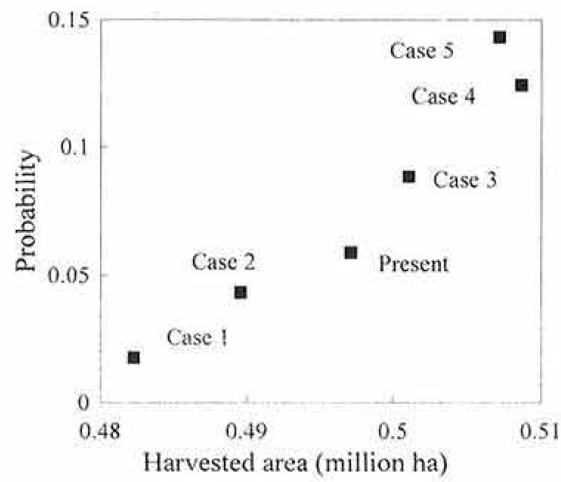

Fig. 6. Harvested area and water shortage

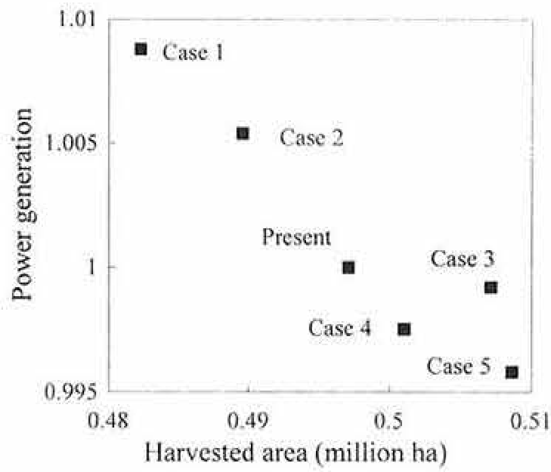

Fig. 7. Harvested area and power generation

Table 4. Influence of lower rule curve

	Curve shift (million m^3)	Harvested area (1,000 ha)	Probability of water shortage	Power generation (standard present)
Case 7	− 2,000	480	8.3%	0.986
Case 6	− 1,000	490	7.0%	0.983
Present	0	497	5.9%	1.0
Case 8	+ 1,000	502	4.8%	1.011
Case 9	+ 2,000	506	4.2%	0.995

The purposes of water release from the Bhumibol reservoir and Sirikit reservoir are divided into several groups i.e. irrigation water in the dry season, release for power generation, water supply for other purposes (domestic water, salinity control, irrigation water in the wet season). The storage of reservoir is distributed for these water uses based on some rules. The change of the rules results in changes in distribution. The influence of these rules and relation among the 3 types of water supply were investigated for the adoption of operation rules among alternatives.

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