Development of Operation Rule for Multipurpose Reservoirs to Secure Water Supply in the Mae Klong River Basin, Thailand

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Abstract

The purpose of this study is to propose an operation rule for the multipurpose reservoirs in the Mae Klong River Basin so that the water users can have a more stable water supply, which creates no adverse influence on hydropower generation. The authors analyze the operation records of water resource systems for the last thirteen years, revealing that a substantial amount of water released from multipurpose reservoirs mainly for power generation was followed by water shortage problems. A new operation rule, which includes rule curves of two seasonal storage lines (an upper and a lower storage line), is proposed. The upper storage line indicates the upper limit for the prevention of water from overflowing during the flood season, while the lower line indicates a minimum amount of water for downstream water uses. A simulation of the reservoir operation shows the effectiveness of the proposed principles.

Keywords: *Multipurpose reservoir, Operation Rule, Water supply stability, Hydropower generation, Mae Klong River basin, Thailand*

1. INTRODUCTION

The Mae Klong River of Thailand has two main tributaries, the Khwai Yai and Khwai Noi, in which the multipurpose reservoirs, Srinagarind (SRN) and Khao Laem (KHL) have been constructed, respectively. The total catchment area of the Mea Klong River is 30,836 km^2, of which SRN and KHL cover 10,880 km^2 and 3,720 km^2, respectively. Just downstream of the junction of the tributaries is the Vajiralongkorn (VJ) diversion dam, from which irrigation water is supplied to 290,000 ha of the Greater Mae Klong River Irrigation Project area. These three hydraulic facilities have joined to control water in the basin since 1985, resulting in the greater availability of water resources.

With its relatively abundant water resources, the basin has been transferring water to the Bangkok Metropolitan area since 1995, and is expected to supply more water in the future (Kositsakulchai et al. 1999). The storage in these reservoirs, however, decreased down to almost nothing during the dry seasons of 1993 and 1994, when the water use sectors downstream experienced a severe water shortage (AIT 1996).

Concerning the reservoir operation in this basin, Yeh (1985) reviewed the reservoir management and operation using simulation models. Sivaarthitkul and Takeuchi (1995) introduced a DP model for reservoir operation in this basin, whose purpose was to increase the amount of hydropower generation. These studies focused only on increasing hydropower generation, but did not provide a solution for satisfying water demand from the downstream area. For more proper water use in this basin, both the demands of the hydropower generation sector and the other water use sectors have to be considered.

This view point and practical solution of the problem is a must in an integrated water resource management for any type of river basins but has been hardly applied in an actual situation. A conflicting relation between the hydropower sector and the other sectors in Japanese multipurpose reservoirs and its solution is reported (Shinzawa 1962), but they are not of a year-to-year carry over type, which is common in the Asian Monsoon region.

The objective of this study is to propose a new reservoir operation rule that is acceptable for both water use and hydropower generation sectors in the Mae Klong

River basin. It has distinct rainy and dry seasons in a year, which are typical hydrological characteristics of the Asian monsoon region.

2. DIFFERENT REQUEST TO RESERVOIR OPERATION FROM WATER USE SECTOR AND HYDROPOWER GENERATION SECTOR

In order to establish a principle of operation, we must first consider the requests from different sectors, the hydropower generation sector and the water use sectors including irrigation, municipalities, navigation, environment, etc. For the hydropower generation sector, in a long scale, it is desirable to release as much water as possible with the water level kept high to get more energy. The share of hydropower generation in total electricity production in Thailand is as much as 9% (EGAT 1996). So more hydropower generation can contribute to reduced consumption of fossil fuels such as natural gas, bunker oil, or lignite. Also in the short term, the release of storage water, in such cases of regulating the capacity of hydropower generation in order to meet the peak load for a single day is needed. On the other hand, other water use sectors including the irrigation sector request mainly stability especially during drought time.

Introducing a concept of seasonal storage requirements has solved this conflicting problem in Japan. In the operation of reservoirs adopting seasonal storage requirements, operation priority is placed on water use sectors when the water level is less than the seasonal storage requirements set for each reservoir.

3. ANALYSIS OF THE RELEASE FROM THE UPSTREAM RESERVOIRS

3.1 Outline of the basin water management

The basic features of SRN and KHL reservoirs are shown in **Table 1**. The records of reservoir operation at SRN and KHL from January 1985 to December 1997 are presented in **Figs. 1** and **2**, where all the data are monthly. The inflows here indicate the net inflow (Real inflow - Evaporation from reservoir surface). **Figure 3** shows the release from the VJ dam from January 1985 to December 1997. From these figures, we know that:

a. There is a large variance in the rainy season (May-Nov.) inflow from year to year.
b. Although the floods at SRN and KHL occurred almost in the same years, they did not always occur simultaneously. This may be because rainfall sources in the SRN and KHL basins are different (Sugiyama et al. 1998).
c. The water storage in the reservoirs largely decreased when the rainy season (from July to November) inflow was relatively low for two successive years.
d. The release from VJ downstream has been almost always larger than $50m^3/s$, which is the minimum requirement to prevent seawater intrusion in the estuary of the river (AIT 1994).

Table 1 Basic features of Srinagarind and Khaolaem reservoirs

	SRN	KHL
Year of completion	1980	1984
Catchment area (km^2)	10,880	3,720
Normal high water level (m, above MSL)	180	155
Storage at normal high water level (MCM)	17,745	8,860
Effective storage (MCM)	7,481	5,848
Annual average inflow (MCM)	4.457	5,161

3.2 Method of Analysis

3.2.1 "Savable Water"

Shinzawa and Okamoto (1985) analyzed a reservoir operation system in the Tone River Basin, Japan, and proposed an operation rule to improve the efficiency of the water resources system. It introduced the concept of "surplus release" from a river system.

There are two sources of surplus release from VJ, which is defined as the amount of released water exceeding $50m^3/s$. One is the release from SRN and KHL, and the other is the side flow occurring between the two storage reservoirs and the VJ diversion dam. Of these, release from SRN and KHL is controllable; however, the side flow is not controllable because it is a natural discharge from the downstream area of the storage reservoirs.

The authors define "Savable Water (*SW*)" as the portion of the discharge from the reservoirs that can be decreased within the fulfillment of the minimum requirement for the downstream area of VJ ($50\ m^3/s$). It can also be explained as the water that is used for hydropower generation and not for downstream water users. In other words, it is water that has a technical possibility to be saved.

3.2.2. Identification of Savable Water

To make the situation clear, the Mae Klong river basin is divided into four blocks as shown in **Fig. 4** Area I consists of the catchment areas of SRN and KHL. Area ? is the part of catchment area from which water is drained upstream of VJ. It includes small irrigated areas as well. Area ? is made up of VJ and the Mae Klong irrigation projects. Area ? is the area downstream of the VJ dam.

When the release from VJ exceeds $50\ m^3/s$, the surplus water at VJ (*Svj*) is alculated as,

$$Svj = Rvj - 50, \tag{1}$$

where *Rvj* is release from VJ. If the surplus release at VJ and the release from the reservoirs occur simultaneously, *SW* must be the smaller one in *Svj* and *Rd*, thus can be calculated by the following formula (Shinzawa and Okamoto 1985):

$$SW = Min\ (Svj, Rd), \tag{2}$$

where *Rd* is the sum of the release from SRN and KHL. In this case, it is simply understood that *Rd – SW* means the necessary release from the reservoirs for water use sectors.

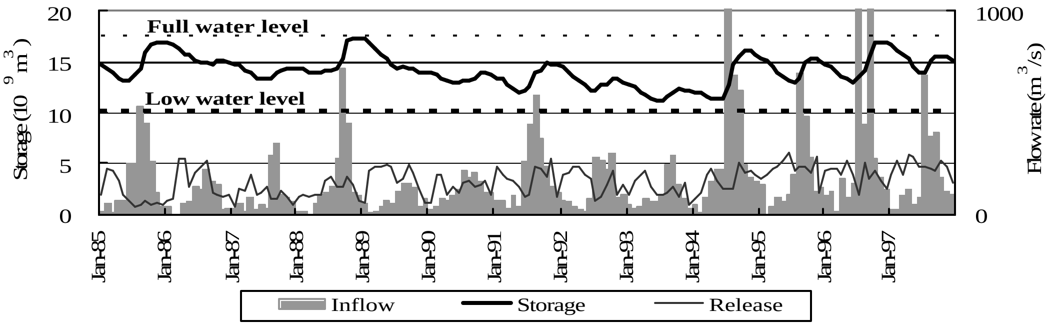

Fig. 1 Reservoir operation record (SRN)

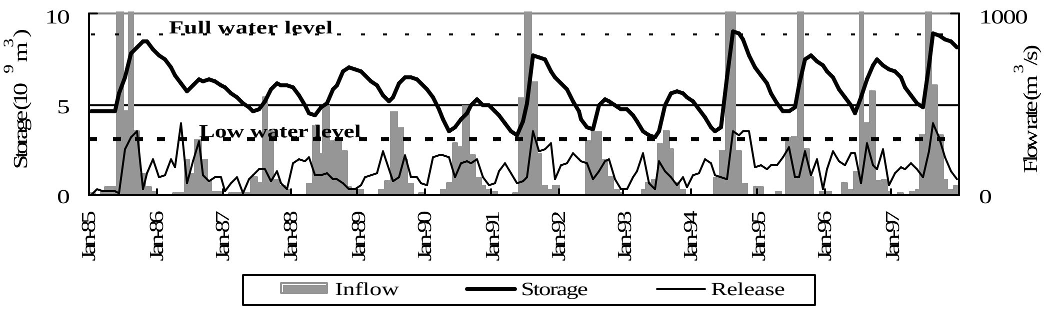

Fig. 2 Reservoir operation record (KHL)

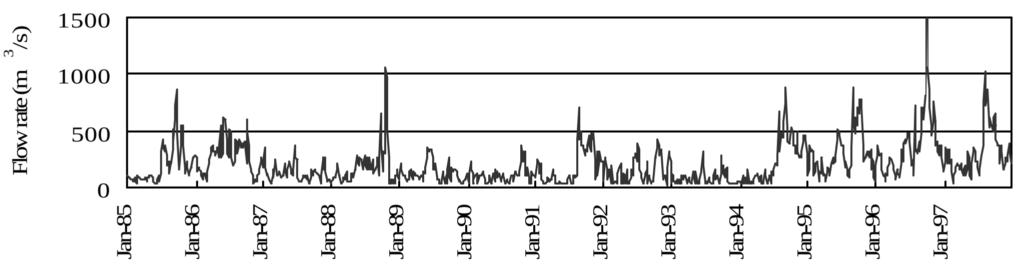

Fig. 3 Release from VJ

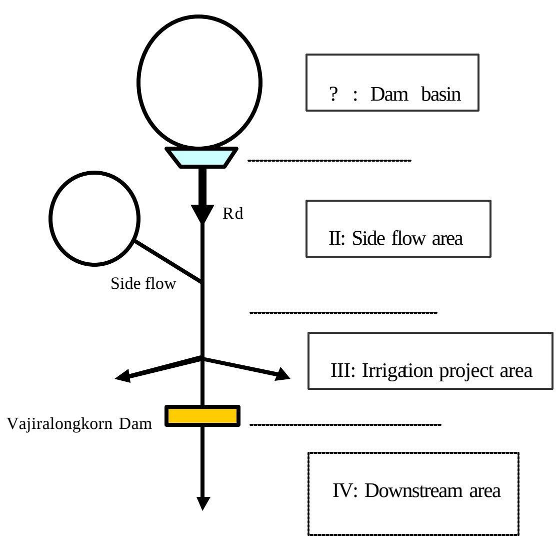

Fig. 4 Modeling of the Mae Klong River Basin
(Rd: Total release from SRN and KHL reservoirs)

SW in the Mae Klong River from 1985 to 1997 is calculated using the time unit of 5 days, which is longer than 2 days of traveling time for released water from reservoirs to VJ.

3.3 Result of Analysis

The result is shown in **Fig. 5**, where the contribution of the side flow to the surplus release from VJ is presented for 1985-1997. The contribution of the *SW* and the side flow is summarized in Table 2, showing that 86 percent of the surplus has been released from the reservoirs.

Figure 5 shows that almost all the surplus originating from the side flow has occurred during the rainy season. This means that the water requirement during the dry season is always higher than the side flow discharge.

The important point here is that *SW* existed before the dry seasons in 1993 and 1994, and this operation eventually resulted in a water shortage.

There must be surplus water in the basin, because the total discharge is larger than the total water requirement. There is a possibility of avoiding water shortage by properly distributing the surplus water over the year or successive years. The question is how to distribute the excess water in the basin under the condition that there should not be a water shortage for water use sectors or spilling water that is not used for power generation.

Table 2 Origins of savable water (10^9 m^3)

Origin	Volume (10^9 m^3)	%
Side Flow	8.9	14
Reservoir Release	54.4	86
Total	63.3	100

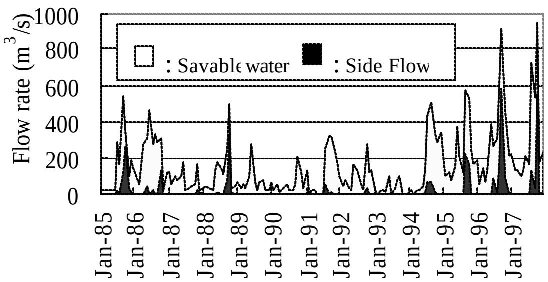

Fig. 5 Savable water and side flow in surplus release from VJ

4. ESTABLISHING NEW RESERVOIR OPERATION RULES

4.1 Proposal of Operation rule

The fact that the water released from the reservoirs includes a large amount of *SW* suggests that there exists a technical possibility to improve the reservoir operation. The problem is how the surplus water should be released from the reservoirs under the condition that the water demand downstream is satisfied as well.

To discuss this possibility, the authors introduce two kinds of rule curves, which are presented by seasonal storage lines for the active storage. One is the "upper line" and the other is the "lower line". The "upper line" is to show how to avoid the overflow during flood season. It is designed so that no overflow occurs as long as the operator follows the line. The "lower line" is to show how to keep enough water in the reservoir for downstream water users: It is designed so that no water shortage occurs as long as the stored water under this line is exclusively used for water users. If the upper line is above the lower line all through the year, the operator can release surplus water freely as long as the water level is between the two lines.

4.2 Determination of Rule Curves

4.2.1 Upper line/Vacancy Requirement

A schematic explanation of the vacancy requirement for a flood is shown in **Fig. 6**, where all the floodwater that exceeds the release capacity for hydropower generation is stored in the reservoir. The vacancy requirement for this operation is V at the beginning of the flood or when inflow exceeds the release capacity for power generation. However, this vacancy must be prepared through the antecedent operation. Every vacancy requirement seasonally determined for each of the thirteen years should be overlaid to develop an envelope line, which is the upper line. This line should be determined independently for SNR and KHL.

The maximum releases from SRN and KHL are decided according to the operation record, as 255 m^3/s and 461 m^3/s, respectively.

4.2.2 Lower line/ Seasonal Storage Requirement

A schematic explanation of the minimum storage requirement for a series of low flows is shown in **Fig. 7**, where the storage requirement for low flow regulation is *W* at the beginning of the low flow or the time when inflow become less than the release requirement. *W* is the minimum volume of water for regulation when the release operation is subject to water use sectors. However, the storage of water at volume *W* must be realized through the precedent operation. The storage requirements determined for a year should be overlaid to draw an envelope line to determine the seasonal storage requirement for the reservoir. This line assures a full water supply for any type or magnitude of low flow that has occurred in the past.

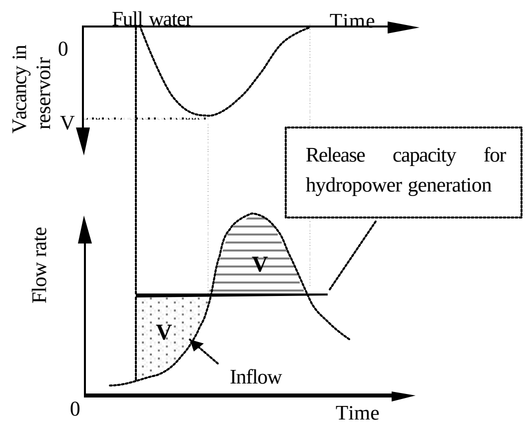

Fig. 6 Vacancy requirement for storing excess inflow

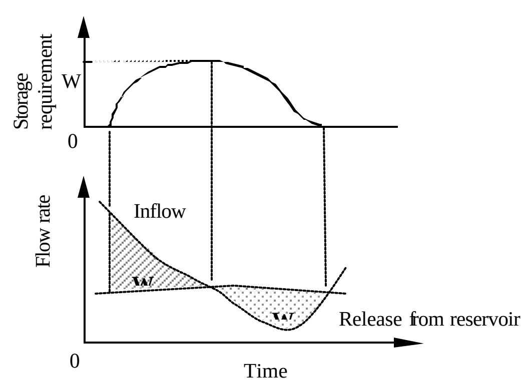

Fig. 7 Storage requirement for low flow augmentation

4.2.3 Results and Discussion

The results of the calculation of the vacancy requirement of SRN for each year are shown in **Fig. 8**, where the thick line presents the maximum value for each time point. The result for KHL is presented in **Fig. 9** in the same way. **Figure 10** shows the results of storage requirement calculation for the river system, which includes the two reservoirs. The thick line indicates the maximum value for each time point, and thus becomes the lower line. The sum of the vacancy requirements in SRN and KHL is also drawn downward from full water level in **Fig. 10**.

It should be noted that the upper line is located above the lower line throughout the year. This means that there is room for the reservoir operator to manage the storage so that both the hydropower generation and the water use sectors can be satisfied simultaneously.

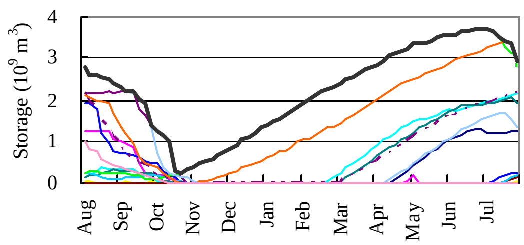

Fig. 8 Vacancy requirement (SRN)

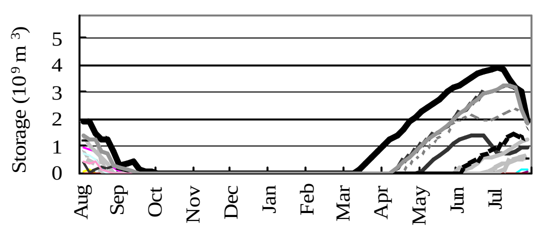

Fig. 9 Vacancy requirement (KHL)

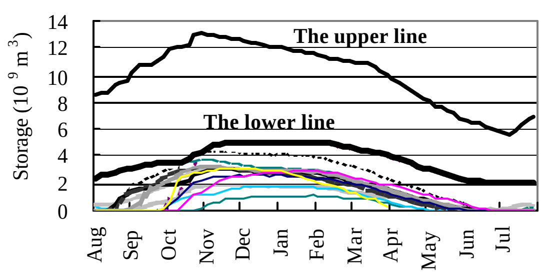

Fig. 10 Storage requirement (lower line) and upper line for the Mae Klong River system

4.3 Proposal of release decision rule

In order to satisfy both of the hydropower generation and water use sectors under these two lines, the following operation is required: The maximum water flow rate should be released when the water level in each reservoir is above the upper line, so that there will not be any overflow: No more than the necessary amount of water should be released when the water level is under the lower line in order to avoid a possible water shortage in the future. The operators may release water, as they want, when the water level is between the two lines.

The authors propose an operation rule for the reservoirs as follows:

1) Water should be released from each reservoir at its capacity for hydropower generation when the water level is higher than the upper line.
2) The release from the reservoirs should be restricted to the "necessary release", which means the minimum requirements for water use sectors, in case the actual water level is below the lower line.
3) The standard release of water during the time when the actual water level is between the lower and the upper lines should be decided according to the volume of water stored above the lower line.

5. SIMULATION OF RESERVOIR OPERATION

5.1 Decision of the release from the reservoirs

In order to establish a reasonable rule for the standard release, the authors have examined the following formula:

$$Q = Q_{max} \, (S / S_{up})^{a}, \qquad (3)$$

where Q is the standard release, Q_{max} is the maximum release from the reservoir, S is the current storage, S_{up} is the storage at the upper line, and a is a constant. By changing a, different release patterns can be expressed.
In this paper, we show three cases of a equaling *1.0*, *3.0*, and *5.0*, which will have significant results in reservoir operation. **Figure 11** shows the relationship between S and Q. When $a = 1.0$, the relation is linear, and Q is larger than those in other cases at the same storage level. This will realize a relatively low water level in the reservoir. In contrast, when $a = 5.0$, the release Q is kept lower, thus resulting in a higher water level as a whole. We should note that S_{up} is the storage on the upper line and that it changes by time, and that Q is calculated for each of the reservoirs.

In the actual stage of the releases, two cases to adjust the Q calculated by equation (3) arise:

1) When the sum of Qs is less than the necessary release (NR), the release must be NR. This increase from Qs to NR should be allocated to the two reservoirs proportionally.
2) When the sum of the stored water in the reservoirs is less than the minimum storage, the sum of Qs must be reduced down to the NR: In this study, each Q was decreased by the same ratio of the NR to the sum.

The simulation was performed for the period of January 1985 to December 1997. The initial storage conditions of the reservoirs were set as the actual ones. In this simulation, "potential energy" was estimated. The potential energy here refers to the electricity that might be produced if the turbine efficiency is 100%, and is calculated as

$$\text{Water head (m)} \times \text{Released water volume (m}^3\text{)} \times 9.8 / 3.6 \times 10^{-6} \text{ (kWh)}.$$

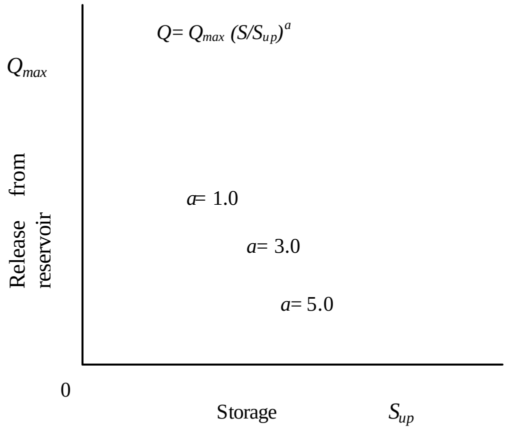

Fig. 11 The proposed relation between release and storage in the reservoir

5.2 Results of Simulation

Figures 12, **13**, and **14** show the results of the simulation for the total storage in the two reservoirs, in which the equations are changed for a=1.0, 3.0, and 5.0, respectively. The simulation results on the total potential energy are summarized in **Table 3**.

Table 3 Comparison of potential energy

	Recorded	Simulated		
		a=1.0	a=3.0	a=5.0
SRN	22.51	22.24	22.44	22.46
KHL	10.5	10.39	10.77	10.79
Total	33.01 (100.0)	32.63 (98.9)	33.21 (100.6)	33.25 (100.7)

Unit: 10^6 MWh,
Period: Jan. 1985 to Sep. 1997

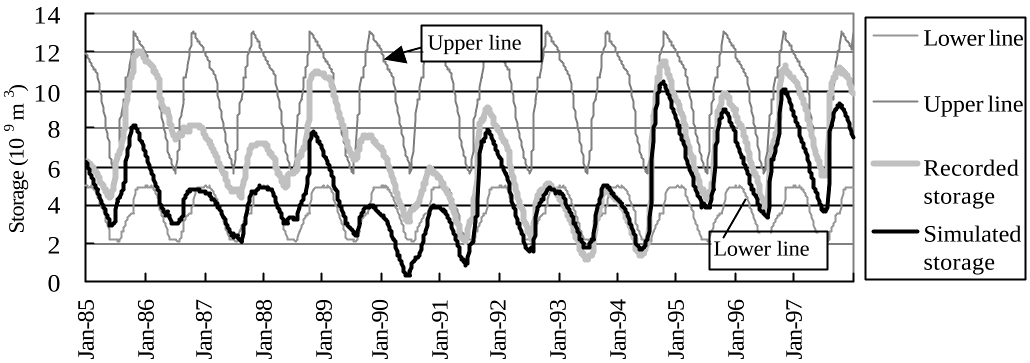

Fig. 12 Simulated storage in the two reservoirs (a=1.0)

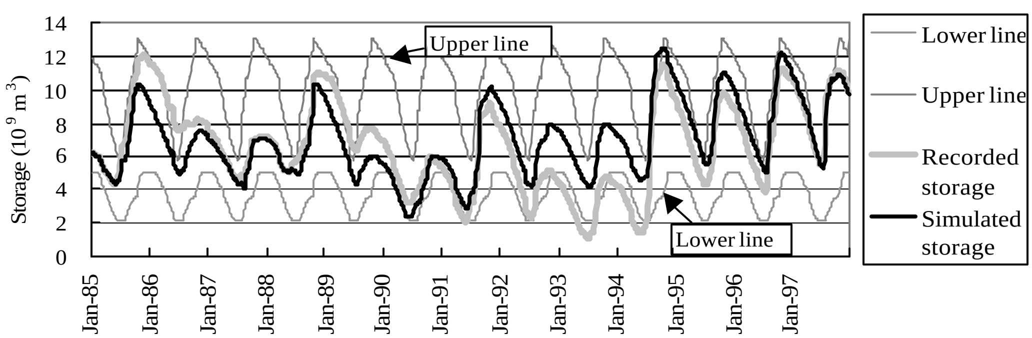

Fig. 13 Simulated storage in the two reservoirs (a=3.0)

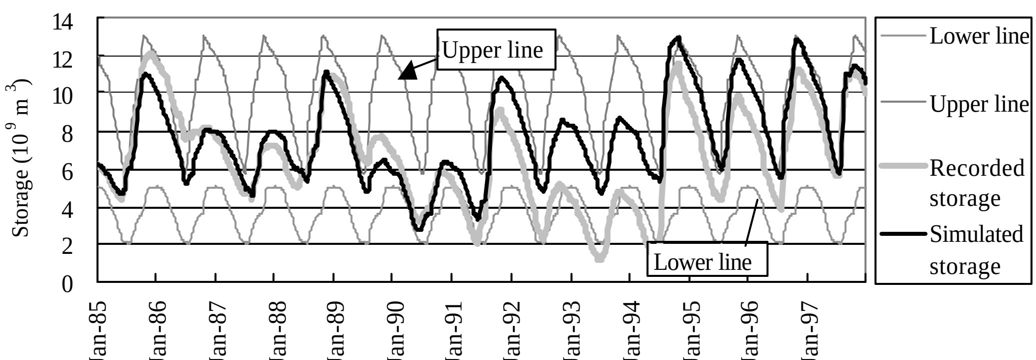

Fig. 14 Simulated storage in the two reservoirs (a=5.0)

5.3 Discussion on the Simulation Results

5.3.1 Storage management for water supplies

When a=1.0, storage is relatively low throughout the period. Even during the last 4 years, when the inflow is successively high, the storage is almost always far less than the S_{up}. It decreases down to almost zero in the dry season of 1990 after two successive drought years. It should be stressed that the storage is frequently under the lower line for long periods, thus strongly limiting the use of water for power generation. When a=3.0, storage is maintained at a relatively higher level throughout the period, and only in the dry season of 1990, storage is less than the lower line for several months. The simulated storage is almost always more than the recorded storage after 1991. When a=5.0, the storage is maintained at a high level throughout the period; however, it often reaches the upper line in the rainy seasons of last four years. It means that the operator is frequently obliged to release water at the maximum discharge to avoid water spilling in this case.

5.3.2 Potential energy for power generation

Potential energy for power generation is highest when a=5.0 in the equation (3), in which the gained power is increased by 0.7% compared to the recorded cases. In the case of a=3.0, it is also increased. In the case of a=1.0, the potential energy is less than the recorded one by 1.1%. It can be considered that keeping the storage level higher can raise hydropower generation. These calculation results are total amount of potential energy for power generation, in which the peak load generation is not considered. In order to apply these calculation results to the actual operation, the timing and necessary release for peak load generation has to be considered.

5.3.3 Overall evaluation

The proposed operation rule could achieve the successful regulation of low flow, with no special damage to the power generation sector, especially in the case of a=3.0, and 5.0. We can understand that the operator should manage only how the surplus water should be released in addition to the necessary releases, meeting the power demand. Under this condition, the power generation sector can select any kind of rule. However, the cases of a=3.0, and 5.0 seemed to be more acceptable.

6. CONCLUSIONS AND RECOMMENDATIONS

(1) The serious water shortages in 1993 and 1994 in the Mae Klong River Basin were brought about not by an absolute water deficiency in the basin but by the improper distribution of available water over the years.

(2) The upper and the lower lines, which were developed both in order to avoid spilling during the flood season and to prevent water shortage during the dry season, were drawn apart in the two reservoirs in the basin. This shows that it is possible to operate the reservoir without fatal competition between the water use and hydropower sectors.

(3) The proposed rule was proved by simulation to be effective in satisfying different requests from both the water use sector and the power generation sector.

(4) The upper and the lower lines should be adjusted for new types of floods and droughts in the future, as well as in response to changes in water demand.

(5) The operation rules discussed above could be effectively used as a guideline according to the daily water demand of the power generation sector if the rigid rules are inconvenient.

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