Operation principles of multipurpose reservoirs for stable water supply in the Mae Klong river basin

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Abstract: *The purpose of this study is to propose a reservoir operation principle in the Mae Klong River Basin so that water users can have a more stable water supply giving no adverse influence on hydropower generation. The authors analyze the operation records of water resource systems for the last thirteen years. It clarifies that substantial amounts of water released from multipurpose dams for power generation was followed by water shortage problems. A new operation rule, which includes two seasonal storage lines (an upper and a lower storage line), is proposed. The upper storage line is to prevent water from spilling during the flood season, while the lower line is to keep water for downstream water uses. A simulation of the reservoir's operation shows the effectiveness of the proposed principles.*

Key words: reservoir operation, operation rule, stable water supply, hydropower generation

1 Introduction

The Mae Klong river has two main tributaries, the Khwai Yai and Khai Noi, in which the multipurpose reservoirs, Srinagarind (SRN) and Khao Laem (KHL) are constructed, respectively. Just downstream from the junction of the tributaries, there is the Vajiralongkorn (VJ) diversion dam, from which water is supplied to the "Greater Mae Klong River Irrigation Project". These three hydraulic facilities have joined to control water in the basin since 1985, resulting in more availability of the water resources. With its relatively abundant water resources, the basin has been transferring water to the Bangkok Metropolitan area since 1995, and it is expected to supply more water in the future. The storage in these reservoirs, however, decreased to almost nothing during the dry seasons of 1993 and 1994, when the water use sectors downstream experienced a severe water shortage. These upstream reservoirs are year-to-year carry over reservoirs whose storage is greatly effected by the reservoir operation in the previous years. To properly understand the state of the water

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resources in this basin, hydrological and water demand conditions for continuous years should be discussed. The objectives of this study are to clarify how the water released from reservoirs has effectively been used by water users based on the water management records, and to propose a new reservoir operation principle for more effective water use in the basin.

2 Requests to reservoir operation from different sectors

To set up the operation principle, we must first consider the requests from different sectors, the hydropower generation sector and the water use sector including irrigation, municipalities, navigation, environment, etc. For the power generation sector, in the long run, it is desirable to release as much water as possible without letting the water level decrease very much. The share of hydropower generation in the total electricity consumption in Thailand is as much as 9 % (EGAT), so generating a lot of hydropower may also lead to a reduction in the consumption of fossil fuels such as natural gas, bunker oil or lignite, so the total production of hydropower is important. Also in the short term, the release of storage water, in such cases of regulating the capacity of hydropower generation to meet the peak load for each day is needed. On the other hand, other water sectors including the irrigation sector request mainly stableness in the water resources management. This is a small request for the reservoir operation.

In Japan, this difference causes a conflicting relationship between the hydropower sector and the other sectors. Introducing the concept of seasonal storage requirements (SSR) generally solves this problem. In the operation of reservoirs adopting SSR, operation priority is placed on water use sectors when the water level is less than the SSR set for each reservoir.

This method can be applied to the reservoir operation in the Mae Klong river basin. The problem is the effect on the power generation. In fact, this method, when applied to Japan, puts a limitation on power generation. However, the flow regimes and the reservoir capacities are quite different in the two countries. It may be worth studying in the future.

3 Analysis of the release from the Vajiralongkorn dam

3.1 Outline of the basin water management

The record of reservoir operation at SRN and KHL up to December 1999 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). Fig. 3. shows the release from the VJ dam. From these figures, we know that;

a. There has been no spilled water at SRN, while only some at KHL. This means that most of the water is released from the storage dams through power generating turbines.

b. There is a large variance in the rainy season inflow from year to year. There have been especially big inflows from 1995- 1997, which are apparently different from the inflow pattern during previous years.

c. Although the floods at SRN and KHL occurred almost in the same years, they do not always occur simultaneously. This may be because of the different rainfall sources in the SRN and KHL basins (1998, Sugiyama et al).

d. The water storage in the reservoirs largely decreased when the rainy season inflow was low for two successive years.

e. The downstream release from VJ has usually been larger than 50 CMS, which is the minimum requirement to prevent seawater intrusion in the estuary of the river (AIT, 1994).

3.2 Method of Analysis

3.2.1 "Savable Water"

There are two sources of surplus release from VJ, where water is released more than 50 CMS. One is the release from SRN and KHL, and the other is the side flow occurring between the storage dams and the VJ diversion dam. Of these, the side flow is not controllable because it is a natural discharge from the downstream area of the storage dams. However, the surplus originating from the release of the storage dams has a possibility of being saved in the reservoirs.

The authors define "Savable Water" (SW) as the portion of the discharge from the storage dams that can be decreased within the fulfillment of the minimum requirement for the downstream area of VJ. SW defined in this way is not the water that can really be saved in the reservoirs, but the water that has a technical possibility of being saved. Saving water is possible only when there is enough room in the reservoirs. Here, release requirement for hydropower generation is included in SW.

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 Figure 4. Area I consist of the catchment areas of SRN and KHL. Area covers all the area from where drainage water goes to the Mae Klong river upstream of VJ, including the irrigated areas. Area is made up of VJ and the Mae Klong irrigation projects.

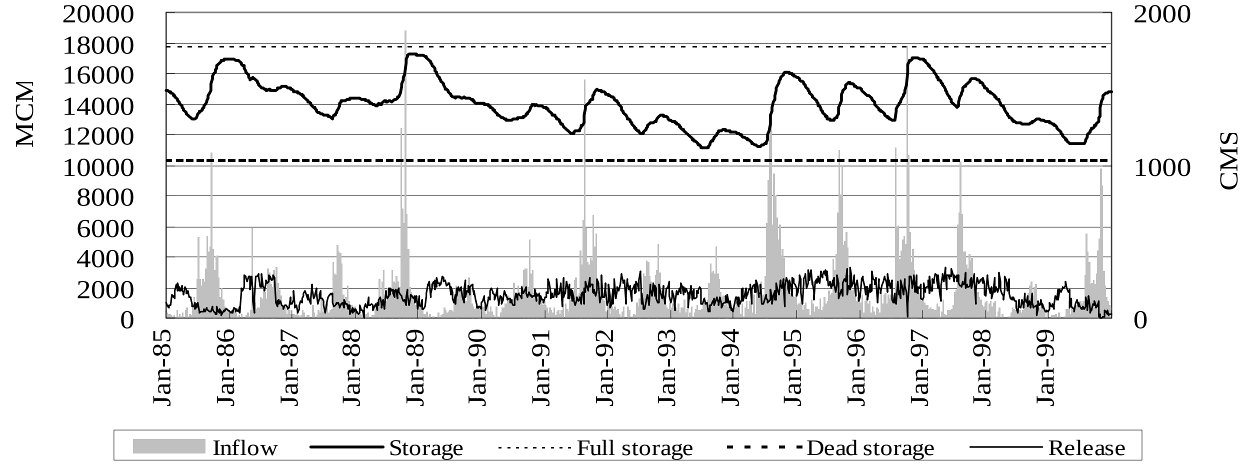


Fig. 1. Reservoir Operation Record (SRN)

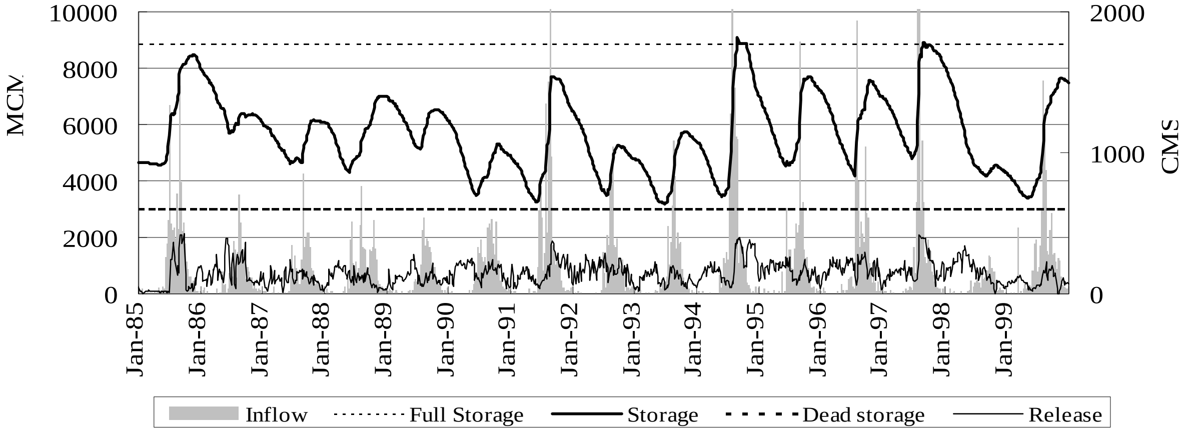


Fig. 2. Reservoir Operation Record (KHL)

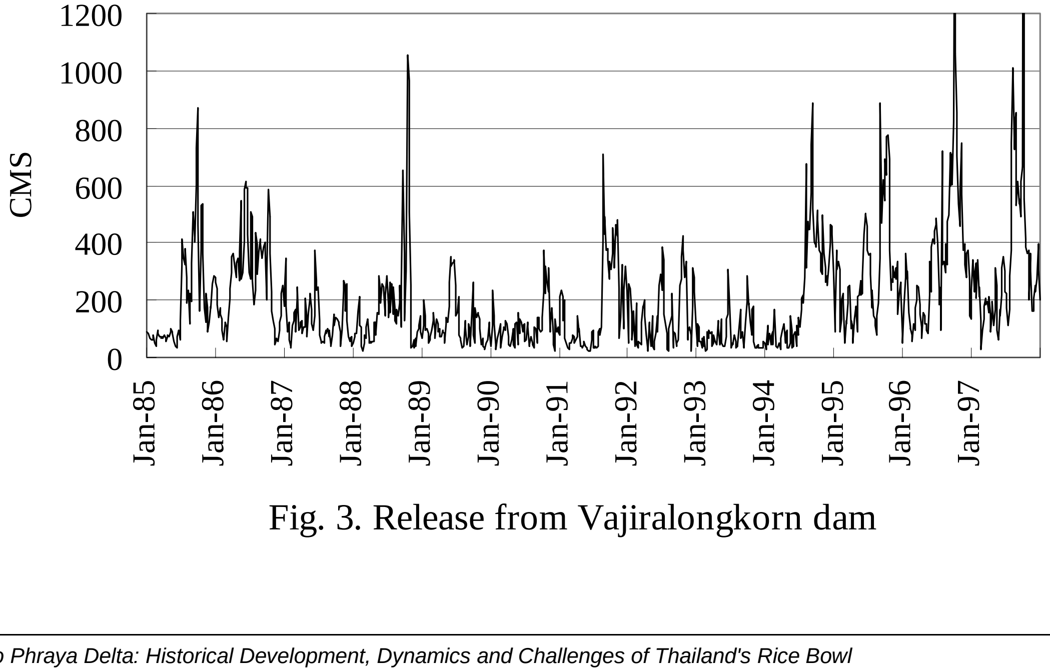


Fig. 3. Release from Vajiralongkorn dam

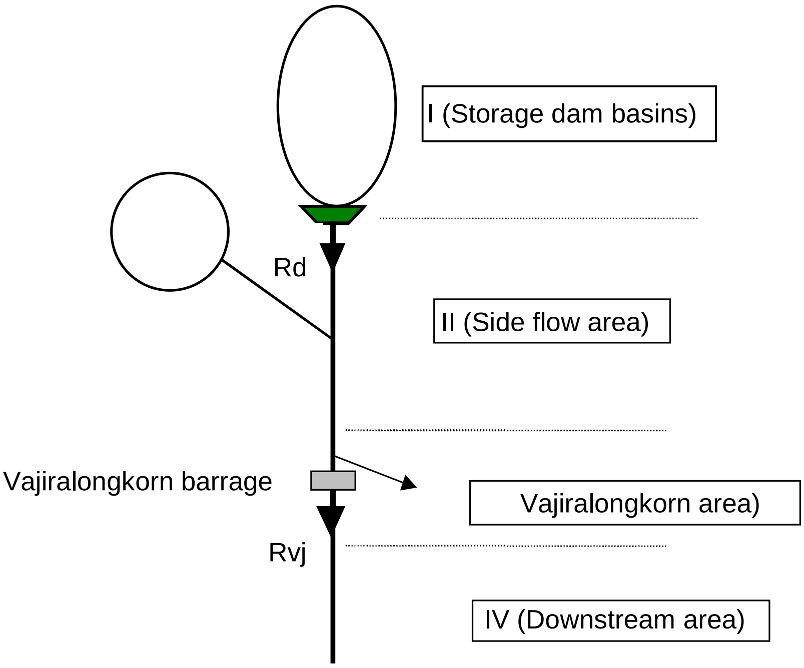


Fig. 4. Modeling of the Mae Klong River Basin

When the release from VJ exceeds 50 CMS, the surplus water at VJ is calculated as,

$Svj = Rvj - 50$,

where Rvj is released from VJ. If the surplus release at VJ and the release from the storage dams occur simultaneously, SW can be calculated by the following formula;

$SW = Min\ (Svj, Rd)$,

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 (NR) for water use sectors from the reservoirs.

1.3 Results of Analysis

The savable water identification is performed using historical data for the unit time of 5 days. The result for a part of the studied period is shown in Fig. 5, where the contribution of the side flow to the surplus release from VJ is presented for 1991- 1997. The contribution of the savable water and the side flow is summarized in Table 1, showing that 86 percent of the surplus is the result of the release from the reservoirs.

The main part of the surplus originated from the side flow during the flood season of the rainy years. The surplus release from the side flow was small during the dry years such as in 1992 to 1994. Its occurrence, of course, is dependent on the water requirement upstream of VJ as well as on the rainfall in the region. Fig. 5 indicates that the water requirement is high enough to utilize all the discharge from the side flow area during the dry seasons.

This savable water was not efficient for water use sectors and was used only for hydropower generation. The important point here is that this water existed before the dry seasons in 1993 and 1994, which caused a severe water shortage. There must be surplus water that is equivalent to the total amount of the SW because the total discharge is larger than the total water requirement in the basin. 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 surplus water 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.

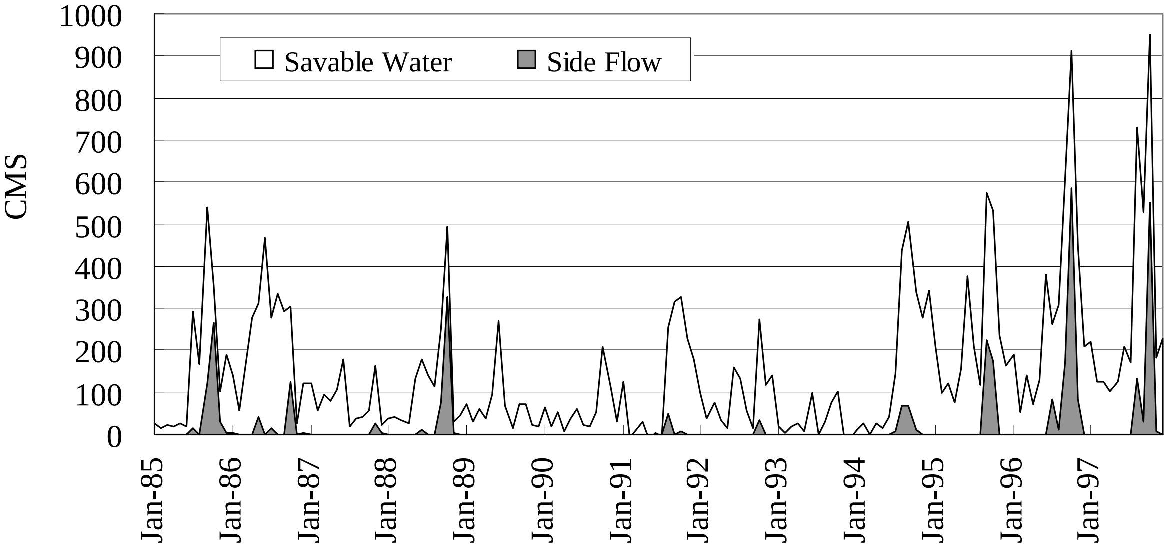


Fig. 5. Contribution of Side Flow in Surplus Release from VJ

Table 1. Origin of Surplus Release from VJ. (MCM)

Side Flow	8859	(14)
Reservoir Release	54414	(86)
Total	63273	(100)

Total volume during 1985-1997

4 New principle for reservoir operation

4.1 Proposal of Operation Principles

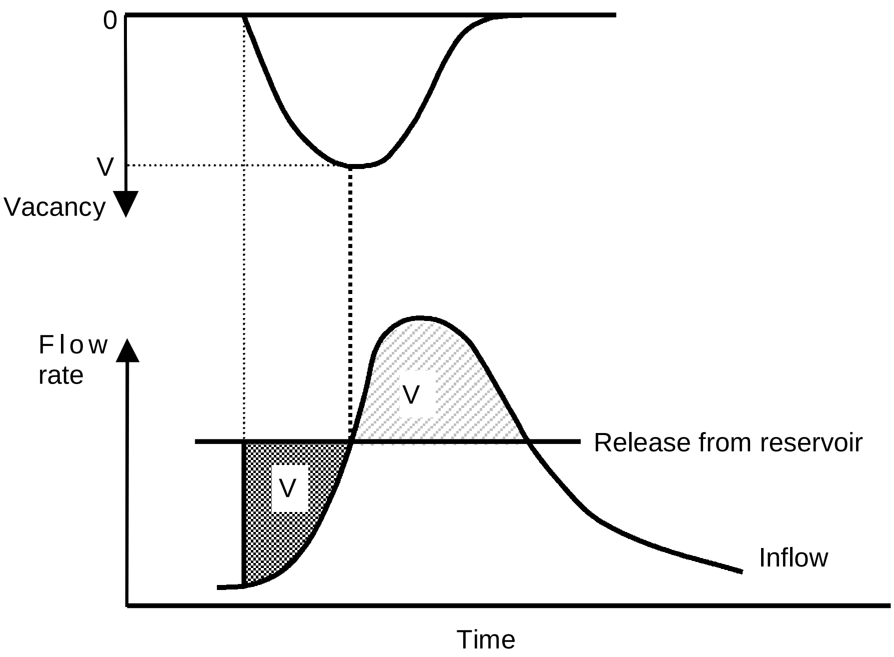
The fact that the water released from the dams includes a large amount of savable water suggests that there may be technical possibilities to improve the use of water in the reservoirs. The problem is how the surplus water should be released from the reservoirs under the condition that the water demand downstream is satisfied as well.

To discuss this possibility, the authors propose two kinds of rule curves or seasonal storage lines in the active storage. One is the “upper storage line” and the other is the “lower storage line”. The “upper storage line” is to avoid the spilling of water during flood season: It is designed so that no water spillage occurs as long as the operator follows the line. The “lower storage line” is 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 these two lines can be drawn apart in the reservoirs, the operator can release surplus water freely as long as the water level is between the two lines. If these lines cross each other, however, one of the sectors should be chosen as the sector that benefits prior to the other sector.

4.2 Calculation of Rule Curves

4.2.1 Upper limit/ Vacancy Requirement

A schematic explanation on the vacancy requirement to store a flood in a reservoir is shown in Fig. 6., where the vacancy requirement is *V* at the beginning of the flood time. The vacancy must be prepared through the previous release operation in advance. To gain a seasonal vacancy requirement line to store any type of flood in the past without spilling water, we should overlay the vacancy requirement lines on each day of the year, thus drawing an envelope line. This line will be developed independently for SRN and KHL.



The maximum release from each dam is decided at the maximum release for power generation, which is 255 CMS and 461 CMS for SRN and KHL, respectively, according to the record. In the determination of the flow rate at SRN, the pumping back from the Tha Thung Na reservoir is considered.

The results of the calculation for SRN and KHL are shown in Figures 7, 8 respectively.

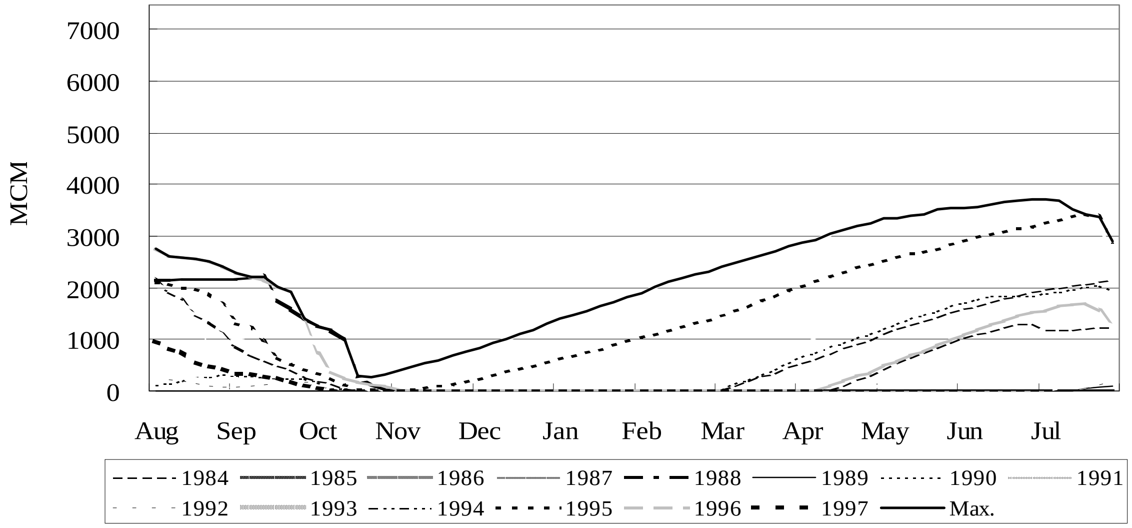


Fig. 7. Seasonal Vacancy Requirement (SRN)

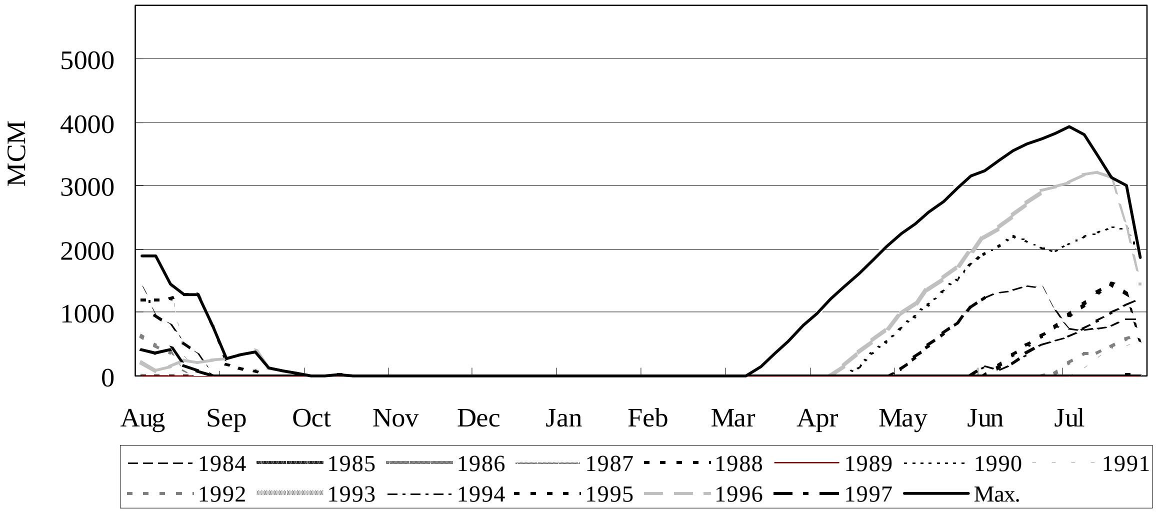


Fig. 8. Seasonal Vacancy Requirement (KHL)

4.2.2 Minimum Storage Requirement

A schematic explanation of the minimum storage requirement for a series of low flows is shown in Fig. 9, where the storage requirement for low flow regulation is W at the beginning of the low flow period. This volume of W is the minimum volume for the regulation when the release operation is subject to the water use sector. However, the water W should be stored through the storing operation in advance. The storage requirement lines determined in this way should be overlaid to draw an envelope line for the seasonal minimum vacancy line. This line assures a full water supply of any type and any magnitude of low flow that has occurred in the past.

The result of calculation for SRN and KHL is shown in Fig. 10, in which the upper limit line presenting the sum of vacancy requirements for SRN and KHL is also included.

4.2.3 Discussion on the Calculation Results

From these figures, we can say that;

1) The upper line is located above the lower line all through the year. This means that there is room for the operators to manage the storage so that both the hydropower sector and wateruse sector can be satisfied simultaneously.
2) The upper line is a guideline used to avoid spilling water in the case of a flood. Therefore, it depends on the operator as to whether he adopts the line strictly or not. However, the higher the water level he keeps, the more likely he will suffer from spilled water.
3) The lower line is a guide line to prevent water shortage for the past cases of low flow. Then, it depends on the operator as to whether he adopts the line strictly or not. However, the lower the water level he keeps, the more likely he will suffer a water shortage. It is also desirable for the hydropower sector to keep the water level above the lower line in order to get stable power generation.
4) These two lines should be adjusted or recalculated when new floods and droughts are experienced in the future.
5) An increase in the future water demands of the river system would also raise the minimum storage line.

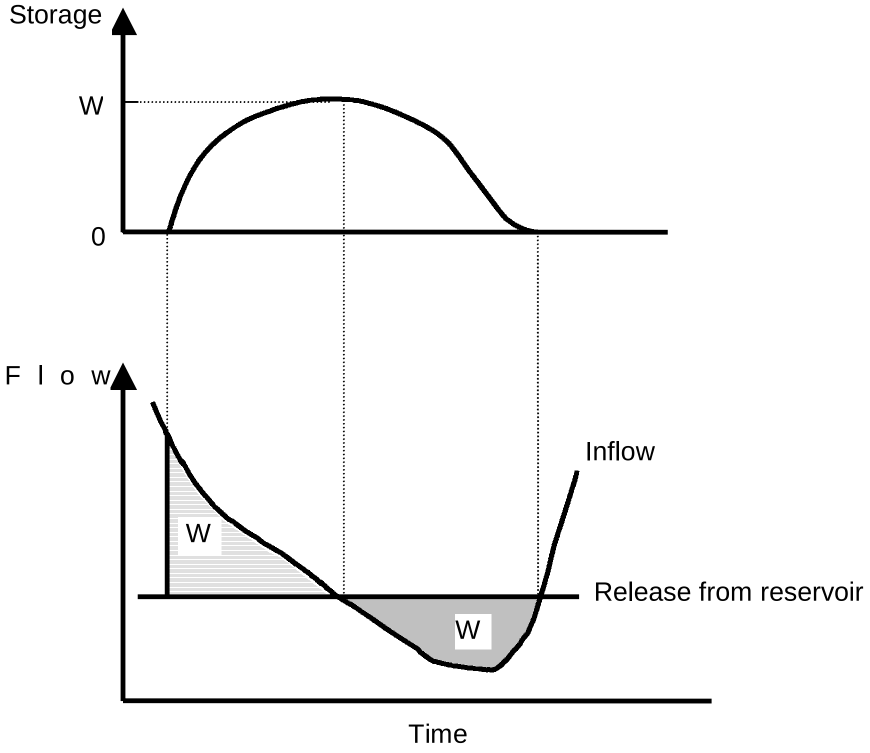


Fig. 9. Storage Requirement for Low Flow Augmentation
Storing water in advance is needed to get enough storage at the beginning of a low flow period.

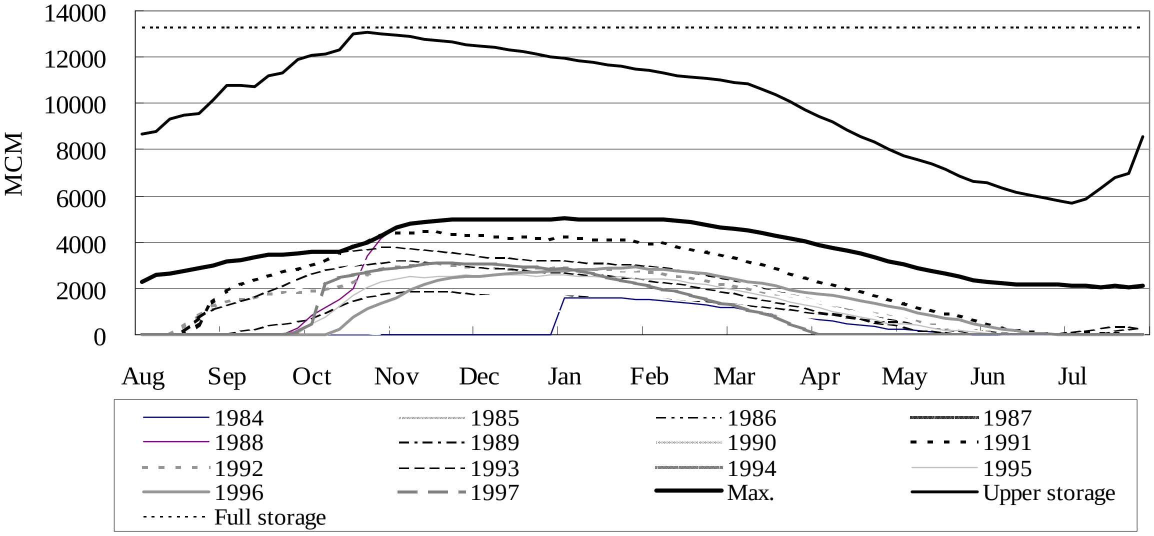


Fig.10. Seasonal Storage Requirement and the Upper line for the two reservoirs

4.3 Proposal of a new operation rule

The upper and the lower lines can be settled separately, which means that it is possible to operate the reservoir without fatal competition between the water use and hydropower sectors. For this purpose, the maximum flow rate of water should be released when the water level in each reservoir is above the upper line, so that there will not be any spilled water. On the contrary, 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 operator may release water, as he wants, when the water level is between the two lines.

With regard to this operation, when the water level is between the upper and lower lines, the operator is requested to have a principle for operation. There are two alternatives. One is to keep the reservoir water level relatively low to avoid a compelled release at the maximum flow rate when the water level comes up to the upper line. However, this operation principle is accompanied with the frequent restriction of release when the water level decreases under the lower line. The other is to keep the water level higher to avoid the low flow restriction. This may also serve more for electricity yields because of a high water head. However, the operator might frequently experience water at a higher level than the upper line in this case.

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

1) The standard release of water from each reservoir should be decided according to the rate of stored water to the storage capacity at the upper line.
2) The maximum rate of water should be released from each reservoir when the water level is higher than the upper line.
3) The release from the reservoirs should be restricted to the necessary release when the stored water is less than the storage at the lower line.

5 Simulation of reservoir operation

5.1 Decision of the release from reservoirs

To discuss a reasonable rule for the standard release of water from each reservoir, we have examined the following formula for deciding the release; from the reservoir Q,

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

where Q_{max} is the maximum release from the reservoir, S is the present 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 study, we have adopted these cases of a equaling; 1.0, 2.0, and 3.0. Fig. 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. It will realize a relatively low water level in the reservoir. On the contrary, when $a = 3.0$, the release Q is kept lower, thus resulting in a higher water level as a whole. We should note that Sup is the storage at the upper line and it changes seasonally.

In the actual decision of the releases, two cases arise when the Q calculated by formula (1) should be adjusted;

1) When the sum of the calculated Qs is less than the necessary release (NR), the release must be increased up to the NR: each Q is increased by the same ratio of the NR to the sum of Qs.

2) When the sum of the stored water in the two 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 of Qs.

The simulation was performed for the period of January 1985 to December 1997. The initial storage conditions for the reservoirs were the same 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 calculated as

(Water level – Low water level) x (Released water volume) x 9.8 / 3600 (kWh)

Although we don’t know the actual turbine efficiency at the different water levels, we can roughly compare the power generation abilities in the historical and simulated operations.

5.2 Results of simulation

Fig. 12 shows the results of the simulation for the total storage in the two reservoirs, in which the equations are changed for $a = 1.0$, 2.0, and 3.0. Figs. 13 and 14 show the simulated release from each reservoir compared to the recorded ones. The major results of the simulation are summarized in Table 2.

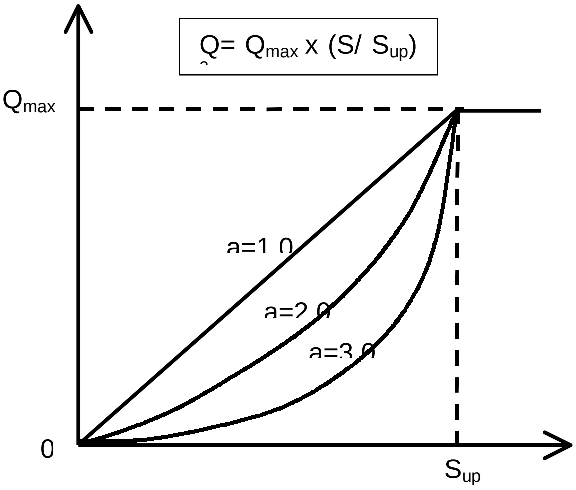


Fig. 11. The Proposed Relation between the Release and the Storage in Each Reservoir

5.3 Discussion

Storage management for water supplies

a= 1.0

Storage was relatively low throughout the period. Even during the last 4 years, when the inflow was successively high, the storage was almost always far less than the S_{up}. It decreased down to almost zero in the dry season of 1990, when the area suffered from 2 successive dry years. It should be stressed that the storage was frequently under the lower line for long periods, thus strongly limiting the use of water for power generation.

a= 2.0

Storage was relatively high throughout the period. However, the storage in the dry seasons of 1990 and 1991 went down below the lower line for 10 months in total.

a= 3.0

Storage was kept at a relatively higher level throughout the period, and only in the dry season of 1990, storage was less than the lower line for several months. The storage was almost always more than the recorded storage after 1991.

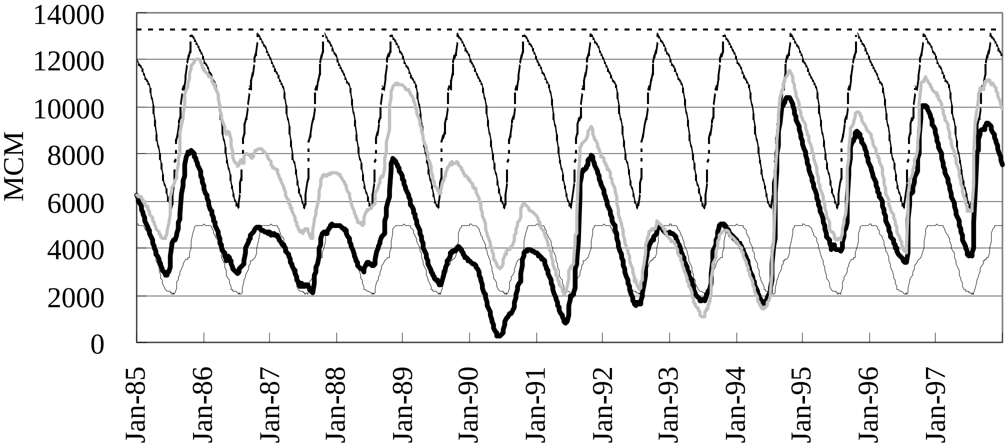
(2) Potential energy for power generation

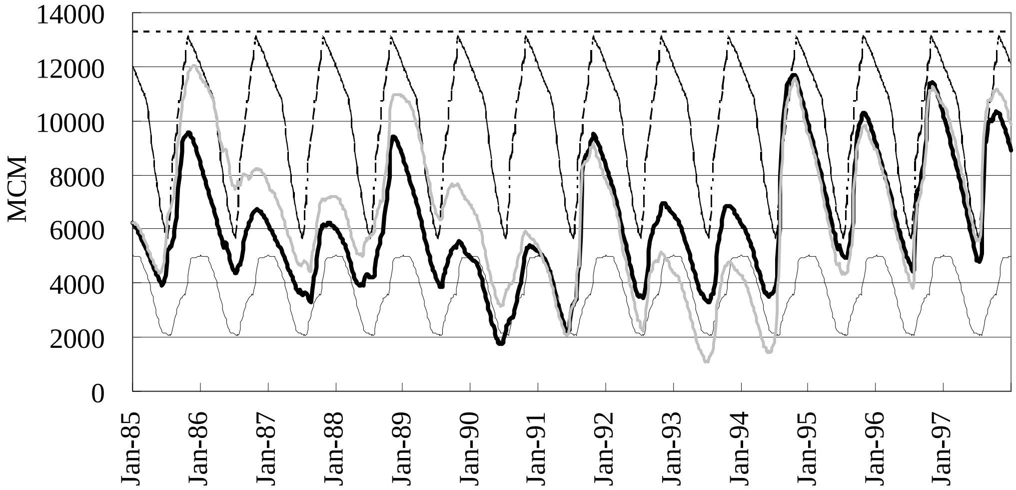
Potential energy for power generation was highest when *a= 3.0* in the equation, in which the gained power was increased by 0.6 % compared to the historical cases. On the contrary, in other cases of *a*, the potential energy was less.

(3) Release from each reservoir

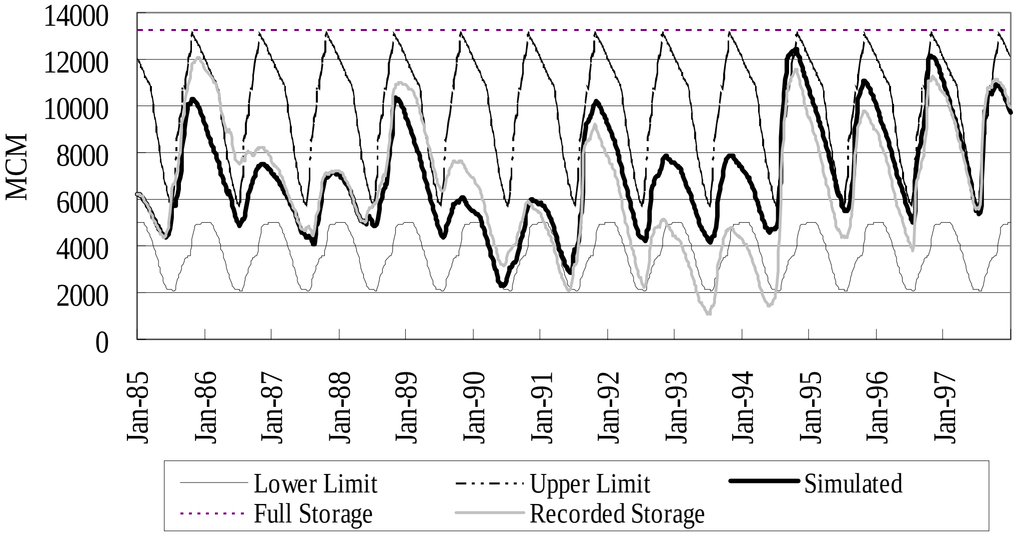
In the case of *a= 1.0*, the release is theoretically stable. However, it actually fluctuated very much by being restricted when storage frequently became less than the lower line.

In the case of *a= 3.0*, the release was limited to a small value when the water level was low, as we can see in Figure 11. It brought high fluctuation to the release, while less fluctuation was seen in the case of *a= 2.0*.



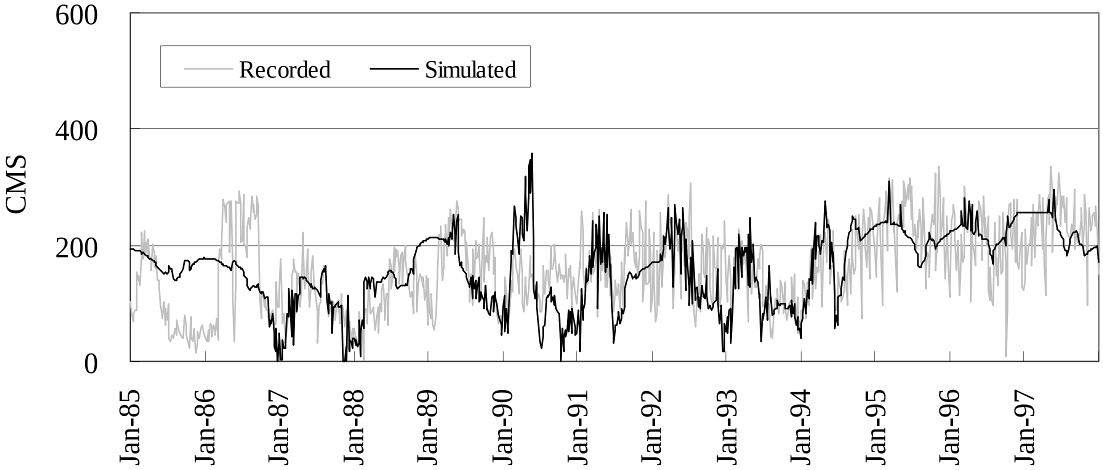


a=2.0



a=3.0

FIG. 12 SIMULATION RESULTS OF TOTAL WATER STORAGE IN THE TWO RESERVOIRS at Different *a* Values in the Proposed Rule


600
400
200
0
CMS
Recorded
Simulated
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Jan-86
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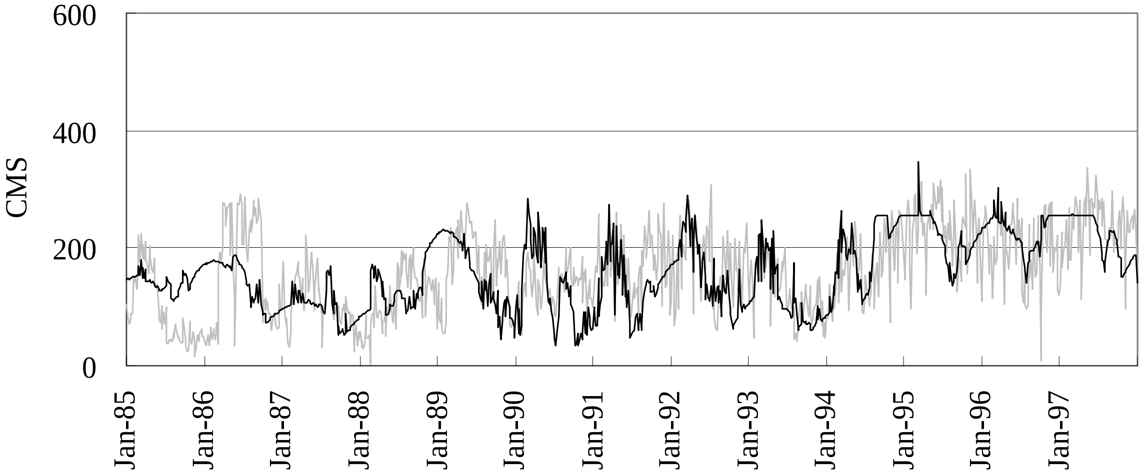
a=1.0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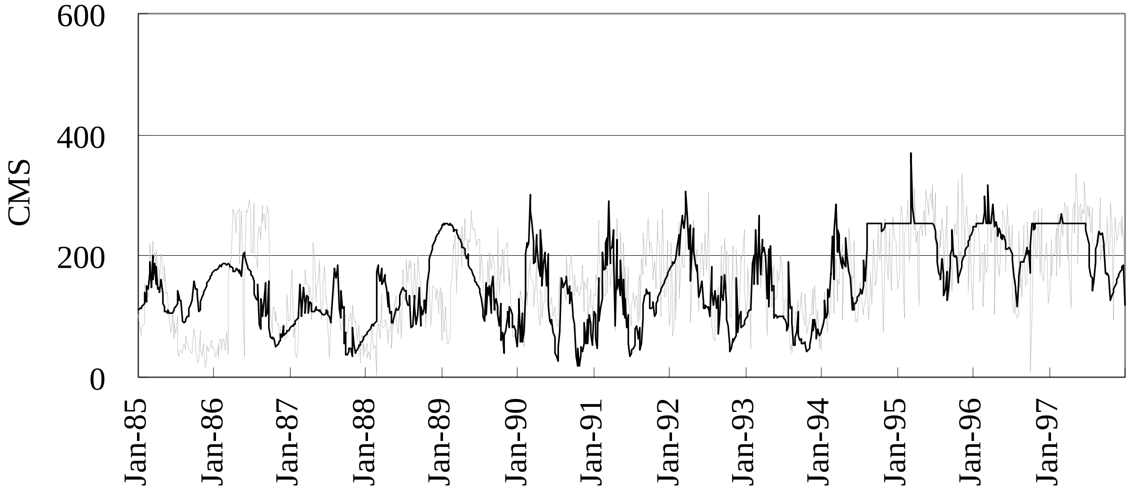
a=2.0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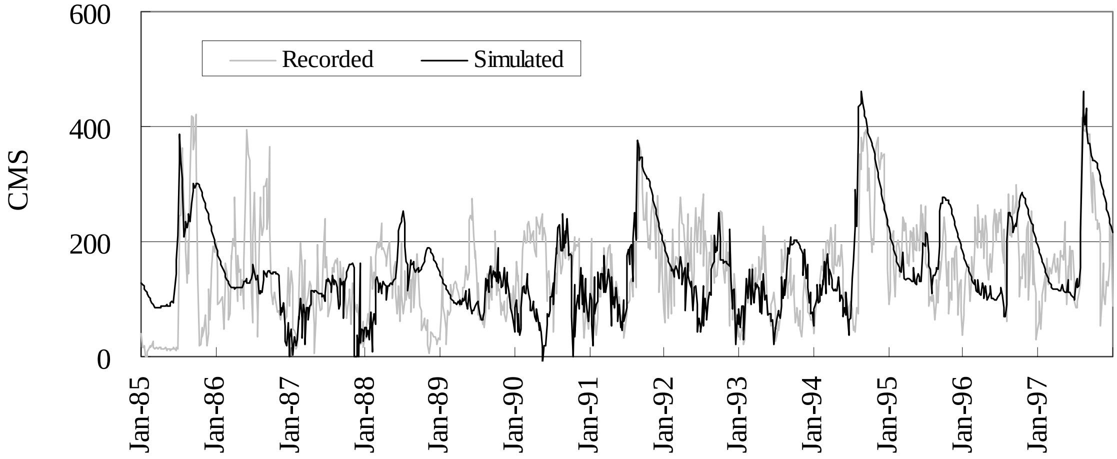
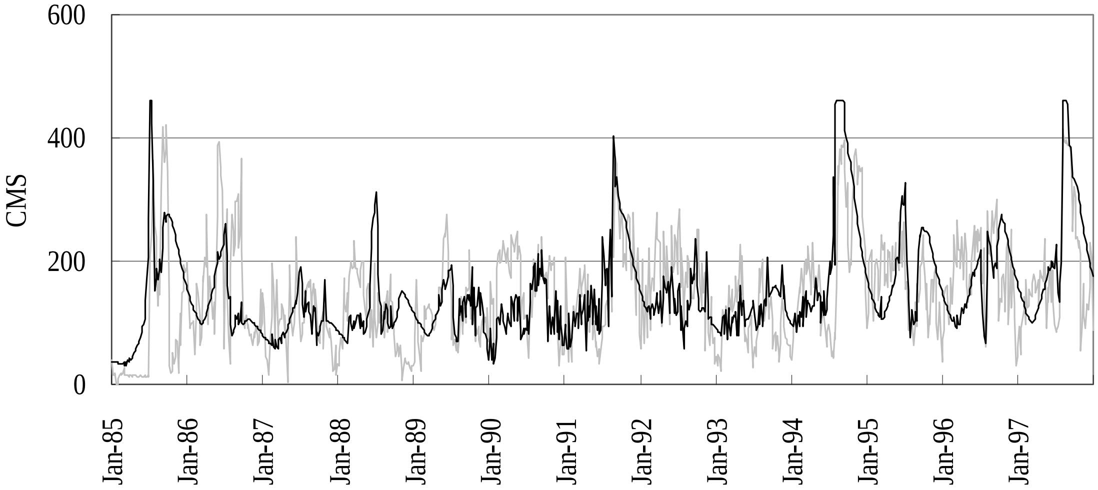
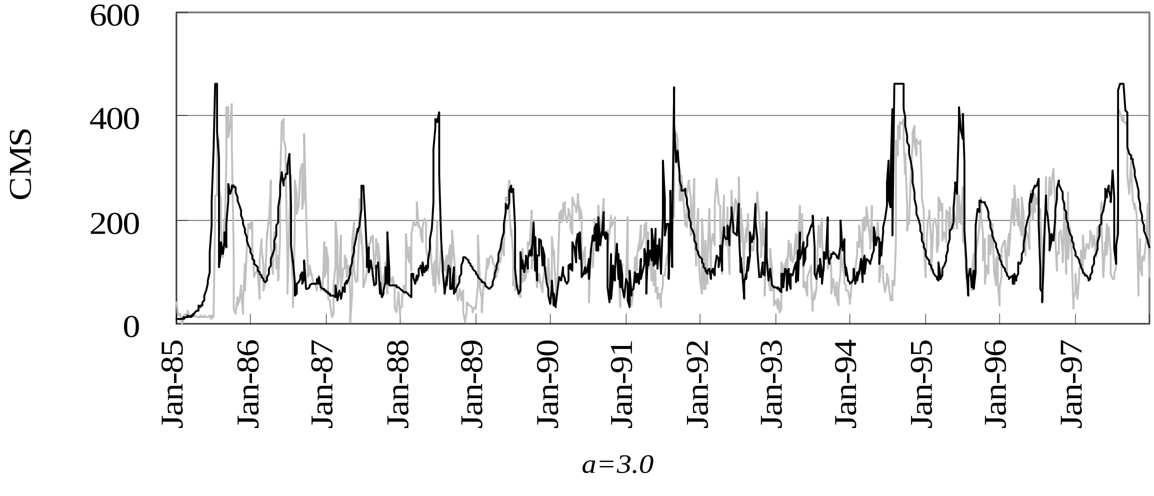
a=3.0



a=1.0



a=2.0



a=3.0

FIG. 14. SIMULATED RELEASE FROM KHL DAM AT DIFFERENT *A* VALUES.

(4) Overall evaluation

The proposed operation rule could realize the successful regulation of low flow, with no special damage to the power generation sector, especially in the case of *a= 2.0* and *3.0*.

We can understand that the operator can decide only how the surplus water should be released in addition to the necessary releases. Under this condition, the power generation sector can select any kind of rule. However, the cases of *a= 2.0* and *3.0* seemed to be most acceptable.

6 Conclusions

(1) 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 excessive water over the years.

(2) The upper and the lower storage lines, which are set in an active storage area to avoid spilling during the flood season and to prevent water shortage during the dry season, respectively, were drawn apart in the two reservoirs in the basin. This shows that the conflict between the water use sectors and the hydropower generation sector does not basically exist.

(3) The proposed rule was proved by simulation to be effective in fulfilling 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 to the changes in water demand. The water demand for the power generation sector should also be considered.

(5) The proposed rule for release is to provide guidelines for the operation of the reservoir. The decisions on the daily release may be made according to the daily water requirements for the power generation. In the daily operation, the traveling time to the point where the water is needed should be properly considered.

Table 3. Summary of Simulation

		Recorded	*a=1.0*	*a=2.0*	*a=3.0*
Spilled water 10^9 m^3	SRN	0	0	0	0
	KHL	0.515	0	0	17.4
Total power generation capacity * 10^{10} kWh	Total	3.301	3.263	3.308	3.321
		(1.0000)	(0.9885)	(1.0021)	(1.0061)

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