Sustainable and Safe Dams Around the World – Tournier, Bennett & Bibeau (Eds)

The method for increasing the waterpower generation by using the storage volume for flood control in the multipurpose dams

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ABSTRACT: In Japan, in recent years, it has become increasingly important to make the maximum effective use of dams now in operation. At multipurpose dams managed by the Ministry of Land, Infrastructure, Transport, and Tourism (MLIT) of Japan, the capacity for water use is clearly discriminated between the capacity for flood control and for water use such as power generation etc., but storing part of reservoir capacity for flood control and using it for hydropower generation etc. is considered as a method of more effective use of reservoir capacity. In this case, it is necessary to perform preliminary discharge quickly when flooding is predicted to ensure capacity for flood control, and when performing preliminary discharge, it is necessary to avoid abrupt raise of the water level in the river downstream from the dam. Considering such restrictive conditions, possible capacity for power generation in the capacity for flood control was calculated at two multipurpose dams on T River System, M dam and K dam. And the capacity which can be stored newly in two dams is 27% and between 4 and 6% of capacity for flood control respectively. And the results of a simulation have shown that when the new capacity for power generation has been used up, it is difficult to recover it because of the small inflow into the reservoirs. And the increase of power generation obtained from the capacity newly stored at two dams was small at only about 0.89%. But, in the future it will be necessary to expand such studies to cover all dams in Japan in order to consider the feasibility of increasing generated power.

RÉSUMÉ: Au Japon, il devient important de reconstruire le corps des barrages ou de réorganiser le volume des réservoirs de barrages à usages multiples pour en obtenir un usage plus efficient. Cet article présente l'étude de faisabilité de la méthode pour augmenter la production hydroélectrique en utilisant le volume de stockage pour le contrôle des inondations des barrages à usages multiples. L'étude a été réalisée pour deux barrages existants au Japon. Afin de conserver le volume de stockage d'eau pour le contrôle des inondations, il est nécessaire d'abaisser le niveau de l'eau avant que la crue ne pénètre dans le réservoir. Il est donc important de prévoir les précipitations et de contrôler le débit sortant du réservoir. Le résultat de la simulation a montré qu'il était possible de partager l'eau jusqu'à un volume de 58~84% pour le contrôle des inondations. Mais en raison du faible débit de la rivière, il devient difficile de récupérer le niveau d'eau, de sorte que l'augmentation de la production hydroélectrique ne représente que 0,89% de la production totale. Il est nécessaire de poursuivre les études de faisabilité pour d'autres barrages à usages multiples au Japon.

1 INTRODUCTION

In Japan, MLIT and the Japan Water Agency now directly manage 150 multipurpose dams, prefectural governments manage about 400, and there is now a demand to use these multipurpose dams more effectively than before.(MLIT, 2017)

Methods of using existing dams more effectively than in the past which are now considered include raising the dam height, excavating reservoirs to increase capacity, more efficiently operating reservoirs by increasing discharge capacity, or revising reservoir capacity distributions.

At multipurpose dams in Japan, the distribution of capacities is always strictly regulated, with sedimentation capacity set at the bottommost part the reservoir. And the capacity for water use needed to generate power and supply water for urban and irrigation use set above this, and capacity for flood control set at the top. (JDEC, 2003)

The elevations and capacities permitting the use of each purpose are decided, and floods are controlled, power generated, and water supplied to urban water suppliers within this predetermined capacity. But the capacity for flood control is stored only during flood control, but is normally not stored.

Therefore, storing the capacity for water use within the capacity for flood control, and when it is predicted that a flood will occur, discharging the capacity for water use, ensuring the specified capacity for flood control is considered to be the simplest method capable of using a dam more efficiently without reconstructing its dam body.

On the other hand, in Japan, urban water supply demand will not increase because of the decrease of population, the change of the structure of industry from heavy industry to the IT industry and the increase of the industrial use water recovery rate, and irrigation water supply facilities have already been fully provided, so it is power generation that will be the main water demand in the future.

To generate hydroelectric power, in the 1950s and 1960s, in addition to hydroelectric power dams constructed by electric power utility companies, many multipurpose dams were constructed with the participation of these electric power utilities, and if capacity for generation is ensured within capacity for flood control of a multipurpose dam, it is possible to increase the power generated not only by the power plant constructed at that dam but to increase the river flow rate to also increase the power generated by downstream power plants.

This paper reports on a preliminary study conducted to determine to what degree it is possible to increase the generation of power when the capacity of water use for power generation is ensured with the capacity for flood control at two multipurpose dams on T River System in Japan.

2 OUTLINE OF THE DAMS AND POWER PLANTS ON T RIVER SYSTEM

T River is a river located in central Japan, its length is 213 km and its drainage basin occupies 5,090 km^2 and 30,000 people live in this area. T River starts at S Lake with water surface area of 12.8 km^2, flows from north to south then flows into the Pacific Ocean. Mountain ranges with elevation of about 3,000 m extend north-south on the east and west sides of the river course.

There are two multipurpose Dams, M dam and K dam, on T River System. M dam, which is a multipurpose dam completed in 1958 on a left bank tributary of T River, is a concrete gravity dam with dam height of 69.1 m, and reservoir capacity of 29,952,000 m^3. K dam which is located in the south of M dam, completed in 1969, also on a left-bank tributary of T River, is a concrete arch dam with dam height of 105.0 m and reservoir capacity of 58,000,000m^3. The specifications of M dam and K dam are shown in Table 1. During the flood season, the water level is reduced to ensure capacity for flood control at both M dam and K dam, but at K dam, the flood season is divided into the rainy season and typhoon season. The capacity for flood control in rainy season is larger than in typhoon season. Outside the flood season, at M dam, the water level rises to the maximum water level, but at K dam, the capacity for flood control is ensured even outside the flood season. And in a case where flood is predicted at both M dam and K dam, the preliminary discharge method that lowers the water level is used. Reservoir capacity

Table 1. Specifications of M dam and K dam

	M dam	K dam
Year of completion	1958	1969
Height of dam(m)	69.1	105.0
Crest length(m)	367.5	293.5
Volume of dam body(m^3)	285,700	268,625
Total reservoir capacity(m^3)	29,952,000	58,000,000
Dam type	PG	VA
Drainage area(km^2)	311.1	288.0
Purpose of reservoir	C·I·H	C·I·H

PG: Gravity Dam, VA: Concrete Arch Gravity Dam, H:Power generation
C:Flood control, I:Irrigation, H:Hydroelectric

plan of M dam is shown Figure 2. Reservoir capacity plan of M dam was changed in 2018 to increase the capacity for flood control by decreasing the capacity for generation. And Figure3 shows reservoir capacity plan of K dam

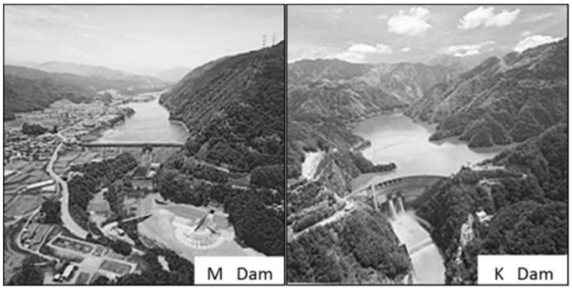

Figure 1. M dam and K dam

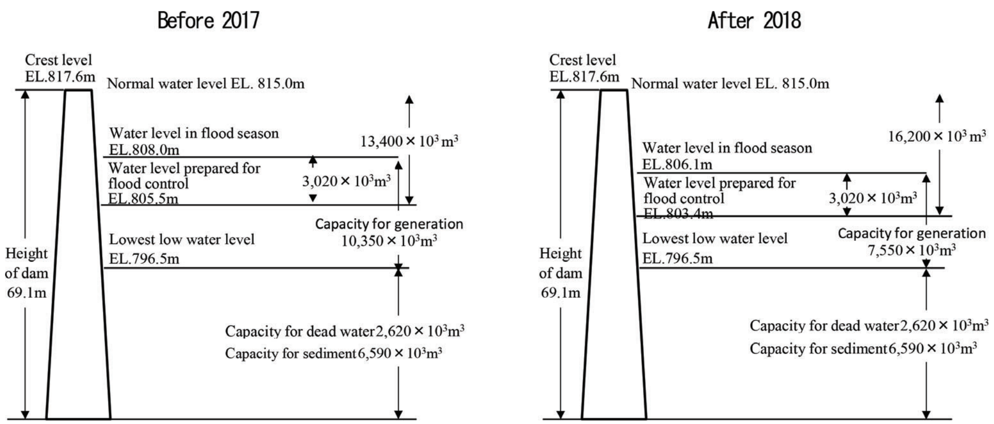

Figure 2. Reservoir capacity plan of M dam

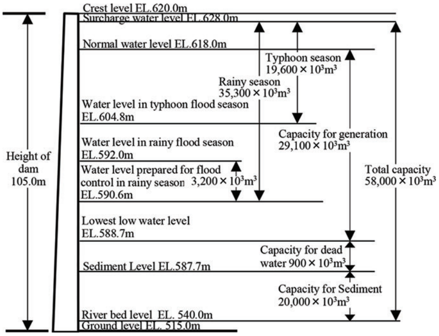

Figure 3. Reservoir capacity plan of K dam

There are three power plants with M dam —dam type M power plant, dam type TA power plant that intakes water from TA Dam just downstream from M dam, and dam and channel type H power plant which directly discharges into the main river course. O power plant and MK power plant are located on the main river course downstream from H power plant. And there are three power plants with K dam—dam type K1 and K3 power plant and dam and channel type K2 power plant—and K2 power plant discharges directly into the main river course. And on the main river course downstream from K2 power plant, dam type Y power plant and HI power plant are operated. Figure 4 is a diagram which schematically shows the locations of the power plants and dams in the basin of T River System where M dam and K dam are located. Discharge from M dam can be intaken by M,TA,,H,O,MK,Y &HI power plant and discharge from K dam can be intaken by K1,K2,K3,Y & HI power plant.

Table 2. Details of power plants in T river

Plant Name		M Plant	H Plant	TA Plant	K1 Plant	K2 Plant	K3 Plant
Date of commencement of operations		Feb-1958	Jul-1958	Apr-2017	Mar-1969	Mar-1969	Apr-2000
Type of plant		Dam type power plant	Dam and channel type power plant	Dam type power plant	Dam type power plant	Dam and channel type power plant	Dam type power plant
Drainage basin(km^2)		311.1	452.6	452.6	288.0	288.0	288.0
Intake(m^3/s)	(maximum)	25.6	19.0	1.10	8.0	8.0	0.88
Generated output (kw)	(maximum)	12,200	23,600	199	3,000	6,500	550
Net head(m)	(maximum)	58.85	151.8	23.00	46.1	99.9	83.41
Number of generators		6,500kW×2	12,700kW×2	210kW×1	3,194Kw×1	6,930kW×1	590kW×1
Dam Name		M Dam	TA Dam	TA Dam	K Dam	K Dam	K Dam
Water level (EL.)	(maximum)	815.0	754.5	754.5	613.0	613.0	613.0
	flood season	808.0 (6/1〜9/30)	—	—	in rainy season 592.0 (6/10~7/20) in typhoon season 604.8 (7/21〜10/5)	in rainy season 592.0 (6/10〜7/20) in typhoon season 604.8 (7/21〜10/5)	in rainy season 592.0 (6/10〜7/20) in typhoon season 604.8 (7/21〜10/5)

Plant Name		O Plant	MK Plant	Y Plant	HI Plant
Date of commencement of operations		Apr-1927	Apr-1929	Jan-1936	Jan-1952
Generation type		channel type power plant	channel type power plant	Dam and channel type power plant	Dam and channel type power plant
Drainage basin(km^2)		1571.4	1,793.0	2,980.0	3,650.0
Intake(m^3/s)	(maximum)	33.38	41.5※1	200.0※2	256.00
Generated output (kw)	(maximum)	1500	28,800※1	54,500※2	101,000
Net head(m)		5.7	79.35	36.86	45.65
Number of generators		1,746kW×1	2(total 14,400kW)	16,000kW×4	26,800kW×3
Dam Name		O Dam	MK Dam	Y Dam	HI Dam
Water level (EL.)	Intake	587.58	550.00	355.00	308.00
	Discharge	581.52	464.74	316.51	259.60

※1 37.7m^3/s、26,700kw before July.2017
※2 175.0m^3/s、54,500kw before Dec.2017

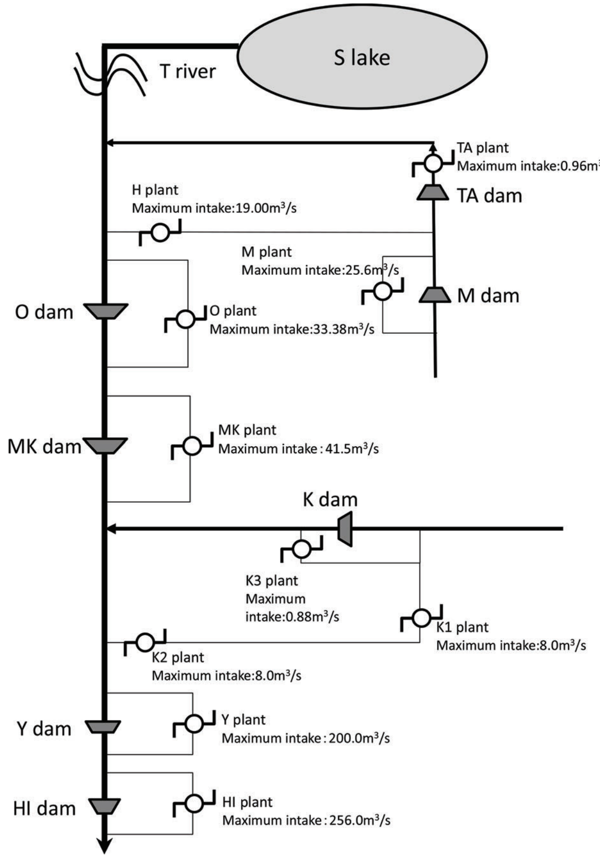

Figure 4. Power plants and dams in T river

3 STATE OF INTAKE OF EACH POWER PLANT

Figure 5 shows the water level and inflow at M dam from May to October 2015, and the intake of H power plant. At M dam, when the capacity for power generation is low at 10,533,000m^3 and the inflow to the reservoir is small at between 10 and 20 m^3/s during the flood season, power is generated only during the daytime when electric power demand is high. (lowest graph in Figure 5.) At K dam, similarly, during the flood season, K1 and K2 power plants only generate power during the daytime when electric power demand is high.

At O power plant and MK power plant located on the main river course, the maximum intake is small at 33.38 m^3/s and 41.5 m^3/s (37.7 m^3/s before July 2017) respectively, and in the case where the flow rate of the inflow is higher than the intake capacity, the water must be discharged downstream ineffectively without passing through the generators, so volume discharged from H power plant is restricted under centralized control in order to be able to generate electric power most efficiently throughout T River System. At Y power plant and at HI power plant, the maximum intakes are high at 200 m^3/s and 265 m^3/s respectively, and there is little need to restrict the volume discharged from the upstream power plants in order to prevent ineffective discharge.

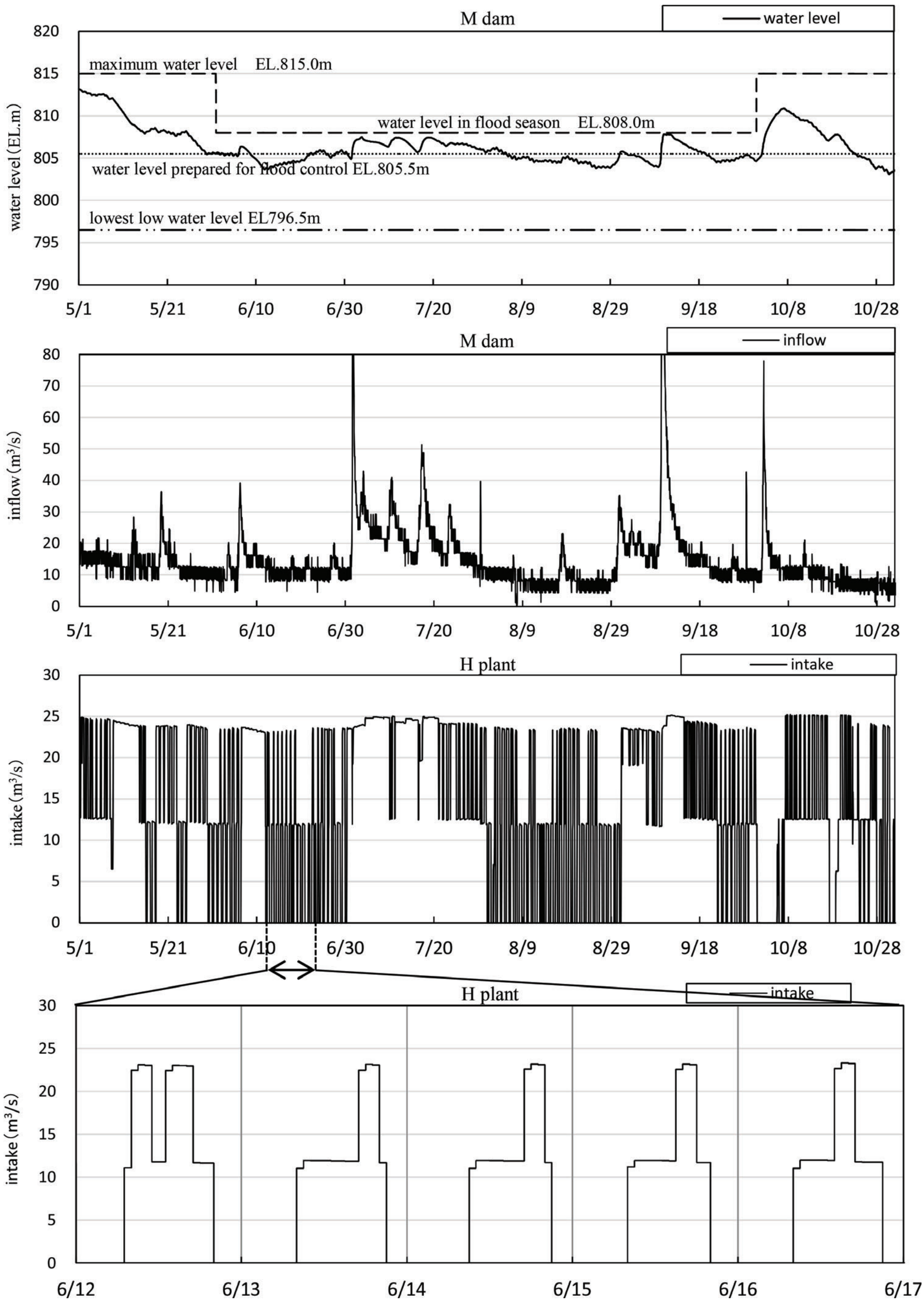

Figure 5. Water level and inflow of M dam and intake of H plant (2015)

4 METHOD OF USING CAPACITY FOR WATER USE WITHIN CAPACITY FOR FLOOD CONTROL

An operation method which increases generated power by ensuring new capacity for water use to generate power within the capacity for flood control at M dam and K dam was studied. As rules to ensure new capacity, the following rules were applied based on the intake situation analyzed in chapter 3. Both M dam and K dam were operated to ensure capacity for flood

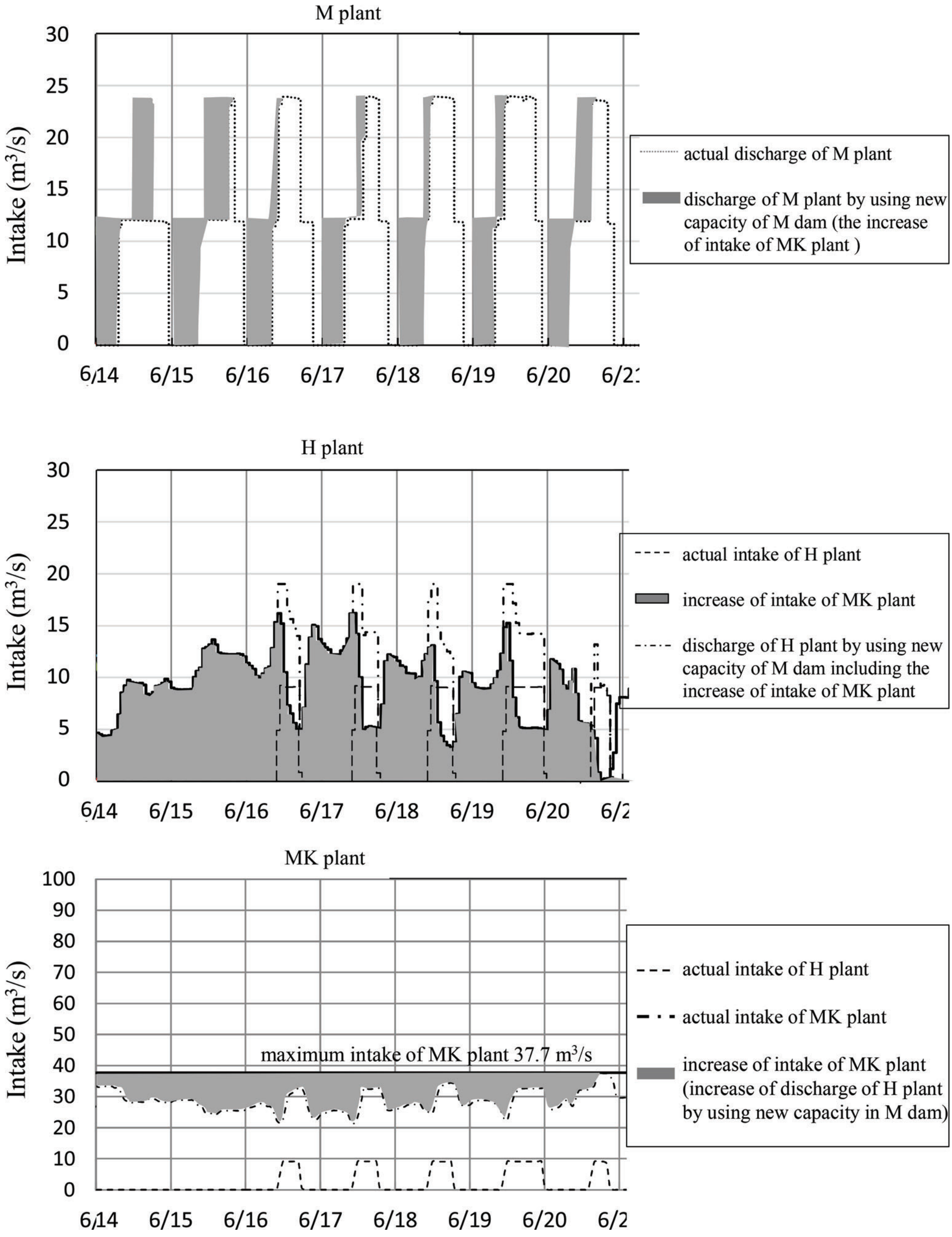

Figure 6. Use of new capacity for generation of M,H,MK plant and M dam

control by lowering the water level only during the flood season, and the new capacity for water use was obtained within the capacity for flood control only during the flood season in the summer.

Rules such as the following were considered for M dam

The point of this rule is that MK power plant should be operated at the maximum intake because the maximum power generation of MK plant is the biggest among the upper group of plants of T River. (Figure 4.)

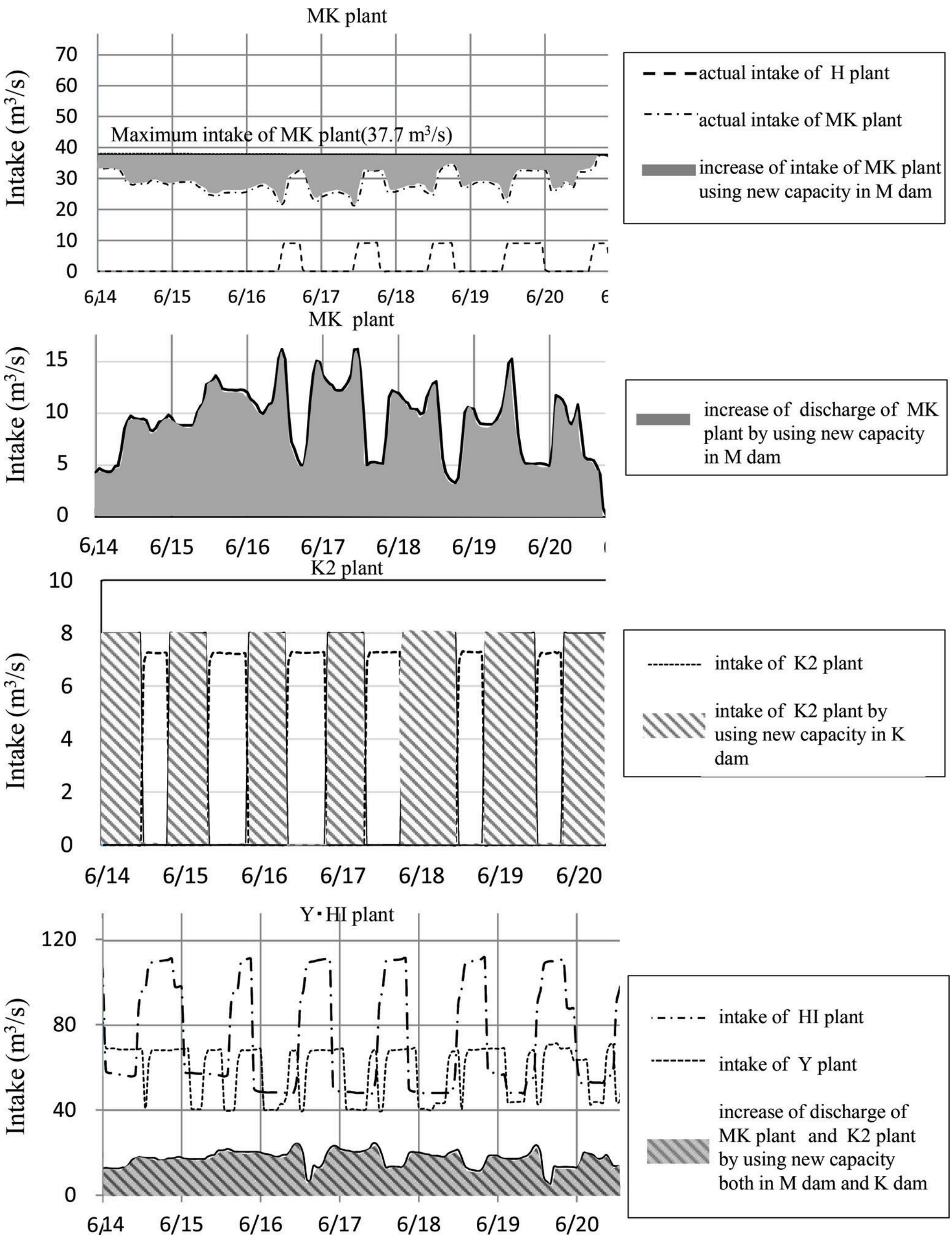

Figure 7. Use of new capacity for generation of K1,K2,Y,HI plant and K dam

When MK power plant intakes water below the maximum intake during the flood season, the difference between the actual intake and maximum intake of MK power plant is supplemented by the discharge of H power plant.(Figure 6. H plant and MK plant)

To ensure power generation intake at H power plant, power generation intake is done at M power plant using the capacity for water use newly stored by M dam. (Figure 6. M plant)

In the case where MK power plant generates power using the maximum intake, H power plant and M power plant intake more water than actual intake using the new capacity of M dam and when the new capacity of M dam is fully used, supplement of intake of MK power plant is stopped at that time.

Intake of O power plant is increased only by an amount equal to the amount of increase of discharge from H power plant when O power plant generates power below the maximum intake.

In Figure 6 the grey zone shows the necessary supplemental intake of MK plant.

The following rules are considered for K dam.

The point of this rule is that K1 and K2 power plant should be operated at continuous intake. K1 and K2 plant generate mainly during daytime now.

When K dam ensures new capacity for water use during the flood season, K1 and K2 power plant use its capacity to generate electric power continuously by the maximum intake. (Figure 7. K2 plant)

Y power plant and HI power plant located downstream increase generated energy by an amount only equal to the discharg which used the new capacity of M dam and K dam.

In Figure 7 grey zone in the second graph of MK plant shows the increase of discharge from M dam and zone by diagonal line in the third graph is the increase of discharge from K dam. And grey zone with diagonal line in Figure 7 Y・ HI plant shows the total increase of discharge from M dam and K dam.

5 SETTING THE NEW CAPACITY FOR WATER USE

When it is predicted that a flood will occur in the case of setting new capacity for water use within the capacity for flood control, it is necessary to promptly discharge capacity for water use within the capacity for flood control considering the safety of the downstream river to ensure the specified capacity for flood control. Therefore, the new capacity for water use which can be stored within the capacity for flood control has, as its upper limit, the capacity which can be discharged from the time when the occurrence of the flood was predicted until the flood flow rate is achieved.

This concept is shown in Figure 8.

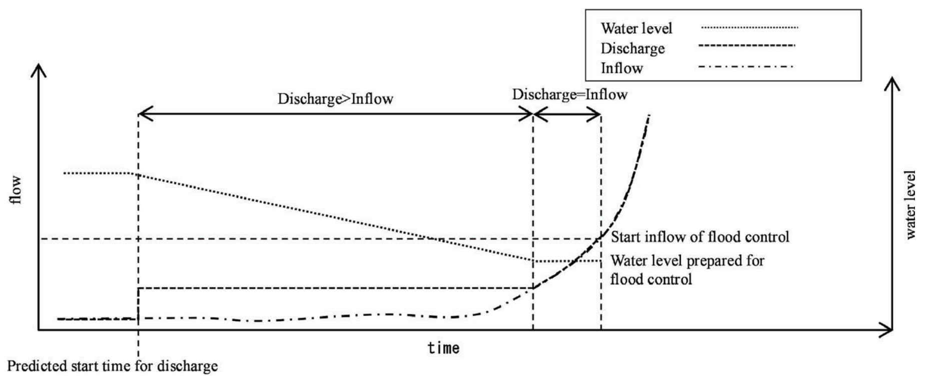

Figure 8. Concept of maximum water level of capacity for water use in capacity for flood control

In Japan, rainfall is predicted by the Meteorological Agency using a Messo Scale Model (MSM) to announce rainfall predictions for the next 39 hours every 3 hours. First, the flood which reached the flood flow rate stipulated for dams in the past and the measured rainfall at that time are abstracted. And the maximum value of the total value of MSM predicted rainfall over a period of 39 hours from the time when the flood arrived when these floods occurred (mm/39 hours) was abstracted and the smallest of these values was set as the rainfall at which discharge of the new capacity for water use must begin. This value is as shown below. However, predictions 39 hours in advance started in 2017, while prior to this prediction were made only 33 hours in advance, so for this value, predictions for the next 33 hours were used. (MLIT, 2003, 2016)

M dam 33mm/33hr

K dam 75.5mm/33hr

The capacity for water use stored within capacity for flood control must be discharged when the total value of rainfall predicted by MSM exceeds this rainfall. And to what degree it can be stored depends upon the volume discharged, and the larger the volume discharged, the more can be stored. A study was done to find out to what extent it would have been possible to store water which actually occurred between 2007 when predictions using MSM started until 2016 according to the size of volume discharged tracing back from the time the flood flow rate was reached. As the volume discharged, quantities which can be stored were calculated hypothesizing volumes discharged in four steps:25.6 m^3/s (max. power generation intake), 50 m^3/s, 100 m^3/s, and 200 m^3/s at M dam, and 8.88 m^3/s (max. power generation intake), 50 m^3/s, 100 m^3/s, and 200 m^3/s at K dam.

The results are shown in Table 3 to Table 5.

In Table 3 to Table 5, italicized numbers represent cases where even if water was stored from the water level to which the level should be reduced by discharge in advance when the occurrence of a flood was predicted (water level prepared for flood control), the water level does not rise to the water level in flood season, and shows that if the volume discharged is small, it is impossible to store a sufficient quantity. For all seven floods which occurred from 2007 to 2016, the minimum level of storable capacity for water use is EL. 808.1 m at volume discharged of 100 m^3/s and EL.813.8m at volume discharged of 200 m^3/s at M dam. In the case of K dam, it is EL. 595.5 at volume discharged 100 m^3/s and EL. 599.9 m at 200 m^3/s during the rainy season, and EL. 606.0m at 50 m^3/s, EL. 608.8 m at 100 m^3/s and EL. 618.0m at 200 m^3/s during the typhoon season.

But when discharge was done before the flood occurred at flow rate of 100 to 200 m^3/s, it is impossible to effectively use the new capacity for water use to generate electric power. And on tributaries of T River, the flow rate which flows constantly is lower than 100 m^3/s, and flow

Table 3. Maximum water level for generation in the capacity for flood control (M dam) (Discharge:25.6 (Maximum intake for generation),50,100,200m^3/s)

No.	Date of flood	Max inflow (m^3/s)	Total rainfall before measurement of inflow (mm)	Maximam predicted rainfall by MSM before flood inflow (mm/33hr)	Maximum storage water level in capacity for flood control				Necessary time for drawdown (hr)
					Discharge (25.6m^3/s)	Discharge (50m^3/s)	Discharge (100m^3/s)	Discharge (200m^3/s)	
1	2007/9/7	254.2	220.2	346.1	*804.8*	806.1	809.0	814.8	25
2	2009/10/8	221.4	95.7	121.1	*806.0*	809.7	815.0	815.0	73
3	2010/7/14	229.3	145	68.3	*803.8*	*804.7*	811.8	815.0	79
4	2011/5/11	293.2	134.3	113.3	*804.3*	*805.3*	808.7	815.0	49
5	2011/9/3	218.3	102.5	116.9	*803.9*	*805.2*	**808.1**	**813.8**	24
6	2011/9/21	317.4	150.1	160.1	*804.0*	*805.5*	808.8	815.0	28
7	2013/9/16	235.8	122.5	171.9	*805.0*	806.6	809.8	815.0	29

Italic letters : under water level in flood season
Bold letter : maximum water level of capacity for generation in flood control capacity

Table 4. Maximum water level for generation in the capacity for flood control(K dam in rainy season) (Discharge:8.88(Maximum intake for generation),50,100,200m^3/s)

No.	Date of flood	Max inflow (m^3/s)	Total rainfall before measurement of inflow (mm)	maximum predicted rainfall by MSM before flood inflow (mm/33hr)	Maximum storage water level in capacity for flood control				Necessary time for drawdown (hr)
					Dischrage (8.88m^3/s)	Dischrage (50m^3/s)	Dischrage (100m^3/s)	Dischrage (200m^3/s)	
1	2007/7/15	223.6	134.0	122.5	*590.6*	592.9	597.5	606.8	36
2	2010/7/15	346.2	232.0	81.6	*590.6*	*591.4*	600.1	618.0	70
3	2011/5/11	263.9	153.0	118.6	*590.8*	594.0	599.3	610.1	41
4	2015/7/1	216.6	81.1	75.5	*590.9*	593.1	**595.5**	**599.9**	21
5	2016/5/11	243.9	120.8	77.0	592.7	601.9	610.5	618.0	66

Italic letters : under water level in flood season
Bold letters : maximum water level of capacity for generation in flood control capacity

Table 5. Maximum water level for generation in the capacity for flood control(K dam in typhoon season) (Discharge:8.88 (Maximum intake for generation),50,100,200m^3/s)

No.	Date of flood	Max inflow (m^3/s)	Total rainfall before measurement of inflow (mm)	maximum predicted rainfall by MSM before flood inflow (mm/33hr)	Maximum storage water level in capacity for flood control				Necessary time for drawdown (hr)
					Dischrage (8.88m^3/s)	Dischrage (50m^3/s)	Dischrage (100m^3/s)	Dischrage (200m^3/s)	
1	2007/9/6	230.2	102.0	189.3	605.2	607.4	610.5	**618.0**	26
2	2011/9/21	247.6	147.0	143.5	*604.8*	**606.0**	**608.8**	**618.0**	26
3	2013/9/16	304.1	126.0	138.8	605.2	607.7	610.8	**618.0**	26

Italic letters : under water level in flood season
Bold letters : maximum water level of capacity for generation in flood control capacity

rate of 100 to 200 m^3/s is considered dangerous for residents who use the river for fishing etc. Thus, if the discharge from the new capacity for water use stored within the capacity for flood control is considered to be "inflow + power generation discharge (max. intake)", it is considered possible to avoid an abrupt increase of the river flow rate and is thought to be a method which is more desirable as a method of lowering the water level during floods. If this method is used, even though the capacity for water use which can be newly stored decreases, it is possible for the water level to fall even if the inflow increases, and it is also possible to lower the water level while generating electric power.

The following was established regarding the rainfall which triggers the start of discharge by this discharge method. First, it is assumed that the predicted rainfall in the drainage basin (prediction for the next 39 hours) all flows into the reservoir. Next, the total capacity that consists of the capacity for flood control and the capacity which can be discharged in 39 hours by power generation discharge is compared with the quantity of water stored in the reservoir according to the cumulative value of predicted rainfall. If the former is smaller than the latter, preliminary discharge is done assuming it is necessary to lower the water level.

Inversely, if the former is larger than the latter, preliminary discharge is not done assuming that it is not necessary to lower the water level.

Case where preliminary discharge is done

(capacity for flood control + capacity which can be discharged in advance by power generation discharge)/river basin area ≦ (cumulative value of rainfall predicted by MSM)

Case where preliminary discharge is not done

Table 6. Maximum storage in capacity for flood control (discharge: inflow+maximum intake for generation)

Dam name		Maximum storage in capacity for flood control		The percentage of storage for generation in capacity for flood control(%)
		water level(m)	storage ($\times 10^3 m^3$)	
M dam		806.4	3,594	26.8
K dam	Rainy season	592.5	1,247	3.5
	Typhoon season	605.7	1,247	6.4

(capacity for flood control + capacity which can be discharged in advance by power generation discharge)/river basin area > (cumulative value of rainfall predicted by MSM)

If the rainfall which triggers the performance of preliminary discharge is calculated based on such concepts, the following is found. This value is larger than the value which was obtained from the prediction by MSM.

M dam		52mm/39hr
K dam	Rainy season	115mm/39hr
	Typhoon season	66mm/39hr

Table 6 shows the results of calculating the capacity for water use which can be stored within the capacity for flood control at this rainfall.

At M dam, it was $3{,}594\times10^3 m^3$, and at K dam it was $1{,}247\times10^3 m^3$, which are 26.8%, 3.5% (rainy season), and 6.4% (typhoon season) respectively of the capacity for flood control.

6 INCREASE OF POWER GENERATION

Flow rate data for 2015 which was a dry year was used to perform a trial calculation of the degree that generated power was increased by the new capacity for water use shown in Table 7. And the reservoir operating diagrams during the flood season for M dam and K dam at this time are shown in Figure 9 and Figure 10 respectively.

Because of the operation of M dam based on a new reservoir operating plan beginning in 2018, whose water level in flood season is lower than the prior water level by 1.9m, the water level is lower than the value even if the new capacity for water use is set within the capacity for flood control. And regarding K dam, the new capacity for water use within the capacity for water use is low, but because the capacity for water use that can be stored after the start

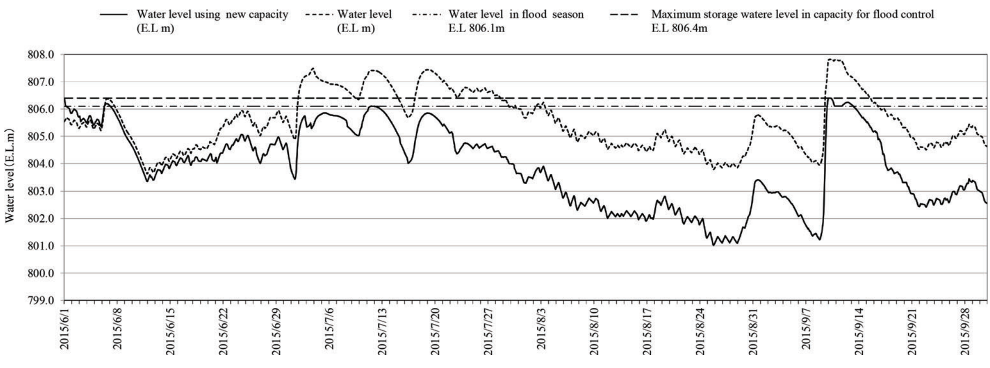

Figure 9. Water level using new capacity of M dam

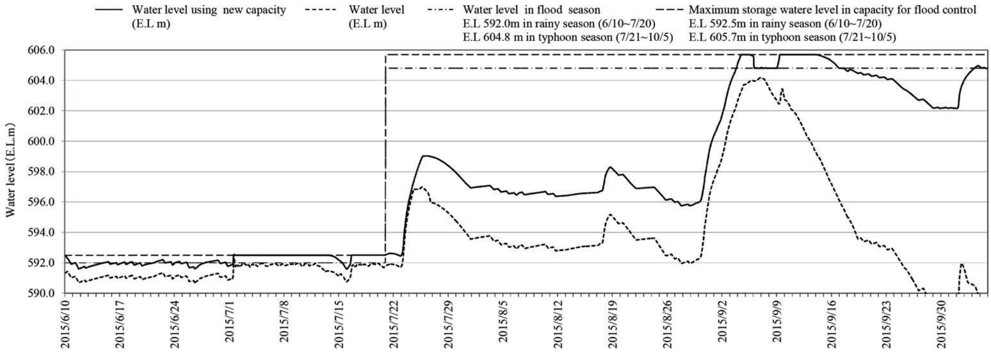

Figure 10. Water level using new capacity of K dam

of the typhoon season increases, K dam can be operated at a water level higher than the measured value. It is presumed that the new capacity for water use which was first obtained at M dam and at K dam falls because at both dams, the inflow is small and once preliminary discharge has been done, it is difficult to restore the water level.

The results of using the electric power generated per unit of water at each power station to compute the increase of generated power are shown in "Table 7 Increase of generated power and ratio to annual generated power at plants".

Table 7. Increase of generated power and ratio to annual generated power at plants

Plant name	Total generated power in flood season(×10³kwh)			The raito of annual generated power	
	Actual generated power	Generated power using new capacity	Increase of generated power	Annual generated power(×10³kwh)	Increase ratio to annual generated power(%)
M	21,411	21,085	-325	48,795	—
H	36,559	36,698	139	115,879	0.12
O	441	513	72	—	—
MK	66,588	67,834	1,247	—	—
TA	349	351	2	—	—
K1	3,513	4,207	694	8,804	7.89
K2	10,343	11,009	666	25,747	2.59
K3	1,085	1,161	76	3,149	2.42
Y	98,976	99,424	448	—	—
HI	181,098	181,835	737	—	—
Total	420,363	424,117	3756	—	—

Total generated power in flood season	
Actual generated power (×10³kwh)	420,362
Generated power using new capacity(×10³kwh)	424,117
Increase of generated power(×10³kwh)	3,755
Ratio(%)	0.89

Table 7 shows that the total increase of generated power in 2015 at each power plant is 3.755×10^3kwh per year, which was an increase of 0.89% over the total measured generated electric power.

And at the percentages of annual generated power of H and K1 to K3 power plant which were provided as measured values by electric power utility operators, K1 power plant which intakes water from K dam was the most efficient at 7.9%.

7 CONCLUSIONS

The simulation at M dam and K dam shows following results.

It is possible to store water in the capacity for flood control and to discharge it before flood by prediction of rainfall using MSM.

One of the desirable method to lower water level before flood at M dam and K dam is to discharge water at the rate of "inflow + maximum power generation discharge"

Maximum storage in the capacity for flood control is 26.8% in M dam and 3.5 ~ 6.4% in K dam.

The total increase of power generation at T River System by using water stored in the capacity for flood control in M dam and K dam is 0.89% over the total measured power generation.

The ability to store new capacity for water use within capacity for flood control to increase power generated by hydroelectric power plants to use existing dams more effectively will reduce emissions of global warming gases, preserving the global environment.

If the new capacity for water use within the capacity for flood control can be raised, generated power can be greatly increased, but the following are three challenges to storing new capacity for water use within capacity for flood control.

At multipurpose dams in Japan, water users who use the capacity for water use which has been stored bear its cost. The capacity for water use which has been newly stored within the capacity for flood control is a capacity discharged during floods and it cannot be guaranteed that it will always be easily restored to its specified water level, but setting rules governing the bearing of this cost is a challenge.

At K Dam and M Dam which were the object of the trial calculations, the power generation volume discharged was small so it was impossible to obtain sufficient capacity. There are dams where it is easy to obtain capacity and dams where this is not the case, so it is necessary to conduct similar studies at various dams.

It is presumed that there are some dams where, premised on being able to obtain new capacity for water use, it is possible to strengthen power generation systems. It is necessary for electric power utilities and managers of multipurpose dams to conduct discussions including such points.

REFERENCES

Japan Dam Engineering Center, June 2005, *Construction of multipurpose dams* (in Japanese)

Ministry of Land, Infrastructure, Transport and Tourism, River Bureau, River Environment Division April 2003. *Handbook on flexible management testing of dams* (in Japanese)

Ministry of Land, Infrastructure, Transport and Tourism, Water and Disaster Management Bureau, March 2016. *River sediment control technology standards, maintenance (Dams)* (in Japanese).

Ministry of Land, Infrastructure, Transport and Tourism, Water and Disaster Management Bureau, River Environment Division, July 2017. *Rules for inspections of dam operating regulations to prepare for the introduction of flood control methods which maximize the use of a dam's functions, Commentaries* (in Japanese)