Effective Flood Control Methods for Dams Adapting to Climate Change

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ABSTRACT: Climate change caused by worldwide global warming has caused fear in Japan of the sea level rising, frequent concentrated rainfall, larger typhoons, and increasingly severe droughts and other disasters. As a result, the importance of flood control measures has increased as one way to respond to these changes of the climate. And providing new public infrastructure has become difficult for economic reasons in Japan, leading to discussions of how to improve the flood control effects of existing dams by using these dams more effectively.
This paper reports on studies to improve the flood control effectiveness of dams by performing flexible flood control operation different from that planned, for rainfall patterns which are changing in various ways under the effects of climate change

1 INTRODUCTION

In recent years, climate change accompanying global warming has become a serious public problem in Japan, increasing the importance of flood control measures as an adaptation measure. On the other hand, public works project funds are falling steadily, and the provision of new public infrastructure in Japan will become increasingly difficult in the future. Therefore, in Japan, flood control measures based on the more effective use of existing dams are now being discussed.

The flood control operating rules for dams in Japan are constructed in order that they are most effective during the magnitude and inflow wave form hypothesized at the planning stage.

Therefore, when rainfall differs from the flood hypothesized at the planning stage, a dam may not be sufficiently effective.

This paper considers challenges facing present flood control operating methods from the perspective of effective use of existing dams and reports on a study of a more effective dam flood control method which permits the reduction of floods on the rivers downstream from dams as one measure to deal with climate change.

2 GEOGRAPHICAL CONDITIONS

Japan, located on the eastern end of the Asian Monsoon zone, features extremely severe climatic conditions including average annual rainfall of approximately 1,690mm , which is about twice the world's average rainfall of about 810mm, and particularly heavy rain during the seasonal rain front period from June to July, and downpours during the typhoon season which is centered on September.

Japan's topography and geology increase its vulnerability to disasters. Located on the Circum-Pacific Orogenic Belt, Japan's mountains are precipitous, its steeply graded and short rivers rapidly discharge rainwater into the ocean, and faults and landslide zones are found in all parts of the country.

With 70% of Japan covered with mountains and hills, its large population and vast assets are concentrated on a few narrow plains. About 50% of Japan's population and approximately 75% of its assets are concentrated on about 10% of its land, which lies below the water level of rivers in flood. Japan's core functions are also concentrated, with more than 5 million people living and working on about 577km^2 of land which is zero meters above sea level in the three huge metropolitan regions of Tokyo, Nagoya, and Osaka (Tokyo Bay, Ise Bay, and Osaka Bay).

Japan is, as these facts show, highly vulnerable to floods and sediment disasters.

3 STATE OF THE IMPACT OF CLIMATE CHANGE ON JAPAN

In recent years in Japan, the impacts of climate change accompanying global warming have become conspicuous in the form of increasing rainfall intensity, and frequent flood disasters.

3.1 *Increasing intensity of rainfall*

In recent years, frequent concentrated downpours have caused severe damage every year throughout Japan. In particular, rainfall intensity has increased, as the number of rainfalls with hourly rainfall of 50mm or more, which was an average of about 200 per year from 1977 to 1986, rising to an annual average of 313 between 1996 and 2006. And the number of rainfalls with hourly rainfall of 100mm or more, which was an average of 2.2 times per year from 1977 to 1986, more than doubled to an annual average of 5.1 times from 1996 to 2006 (Table 1).

Table1. Average annual frequency of short downpours.

	Average annual frequency from 1977to1986	Average annual frequency from 1987to1996	Average annual frequency from 1997to2006
Hourly rainfall of 50mm or more	200	234	313
Hourly rainfall of 100mm or more	2.2	2.4	5.1

3.2 *Frequency of floods*

In Japan, the number of years when typhoons, concentrated rainfall or guerilla rainfall cause frequent disasters are increasing, and these phenomena are assumed to be abnormal weather caused by the impact of climate change.

(1) Frequency of typhoons and concentrated downpours in 2004.

In 2004, typhoons and concentrated downpours caused frequent damage throughout Japan. A record number of 10 typhoons made landfall in Japan that year.

[Niigata – Fukushima Downpours]

On July 12 and 13, the activation of the seasonal rain front, which had stopped moving in a belt from the Japan Sea to the southern Tohoku Region, caused downpours in Niigata Prefecture and Fukushima Prefecture, breaching levees on the Ikarashi River, the Kariyata River, and other rivers on the Shinano River System, triggering disastrous flooding in Sanjo City and other regions of Niigata Prefecture.

These downpours claimed 6 lives and flooded 2,149 houses above their first floor level and another 6,208 houses below their first floor level.

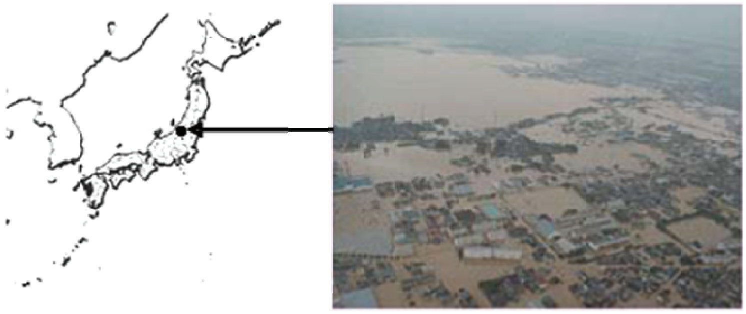

Photo. View of flooding triggered by the breaching of the levee on the Ikarashi river (Sanjo city in Niigata prefecture) (Ministry of land, infrastructure, transport and tourism white paper 2006).

[Typhoon 23th]

Typhoon 23th made landfall in Kochi Prefecture and crossed Japan on October 20. Its total rainfall was 500mm in Shikoku, and more than 300mm in northern Kinki, Tokai, and Koshin Regions. This rainfall breached levees on the Maruyama River and Izushi River in the Maruyama River System, triggering disastrous flooding in Tomioka City and elsewhere in Hyogo Prefecture.

This typhoon left 98 people dead and missing and flooded 14,330 houses above the first floor level and another 41,228 houses below the first floor level.

Photo. View of flooding caused by a breached levee on the Maruyama river (Toyooka city, Hyogo prefecture) (Ministry of land, infrastructure, transport and tourism white paper 2006).

(2) Frequent occurrence of local downpours in 2008

In 2008, many concentrated downpours and local downpours occurred throughout Japan. On July 28, hourly rainfall of 114mm fell in Kanazawa City in Ishikawa Prefecture, flooding more than 500 houses above first floor level. On the same day, localized downpours occurred in Kobe City in Hyogo Prefecture, raising the water level on the Toga River flowing through the city by 1.34m in only 10 minutes, causing an accident which took the lives of 5 people including 3 children.

And on August 29, torrential rainfall with hourly rainfall of 146.5mm recorded in Okazaki City in Aichi Prefecture (heaviest rainfall ever recorded at that location) caused disastrous flooding.

Photo. View of abrupt rise of the water on the Toga river (Kobe city in Hyogo prefecture) (Construction bureau of Kobe city)

4 MEASURES USING EXISTING DAMS TO COUNTER CLIMATE CHANGE

It is predicted that the impact of more frequent concentrated rainfall and larger typhoons accompanying global warming seen in recent years will steadily increase flood risk, and with financial resources now restricted, it will become increasingly difficult to build new public infrastructure.

Under such circumstances, a method of using existing dams more effectively is needed as one way to adapt to climate change.

4.1 *Present flood control operating methods at dams*

Present dam flood control operating methods are intended to ensure that every dam will be most effective in protecting the downstream river at the flood scale and inflow wave forms hypothesized at the time each dam was planned. They are based on the calculation of the discharge flow rate according to the fluctuation of inflow rate and of the reservoir water level. This rule is a flood control operating method characterized by high degrees of dam operation reliability and reproducibility.

Specifically, there are several methods accounting for the flow capacity of the river downstream from the dam (Fig. 1).

(1) Constant discharge operation

When the inflow to the dam is equal to or higher than the set flow rate, discharging a constant quantity. About 29% of dams in Japan apply this method.

(2) Constant percentage – constant control operation

When the inflow to the dam is equal to or higher than the set flow rate, discharging a constant percentage of inflow until the peak inflow to the dam, then discharging a constant quantity after the peak inflow to the dam. About 42% of dams in Japan apply this method.

(3) Natural control operation

Applied where there is no gate for artificial operation, or even if there is a gate, it is left at a fixed aperture and not artificially operated during a flood period. This method is effective in the case of a small drainage basin where the flood arrival time is short and there is not enough time for dam operation. But because it is a natural discharge method, the water level in the downstream river rises more easily than when applying the other methods. About 28% of dams in Japan apply this method.

Other methods include the total flood discharge storage method and the variable method, which are applied at only about 1% of dams in Japan.

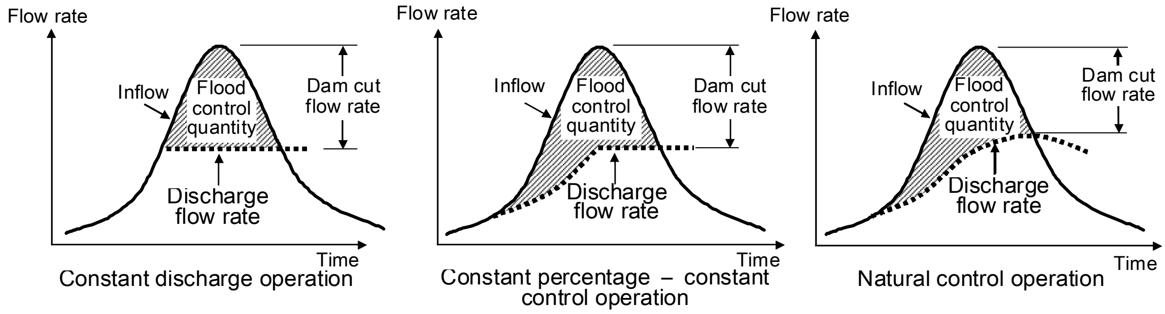

Figure 1. Dam flood control operation methods.

4.2 *Problems with present flood control operation methods*

The conventional dam flood control operation method basically sets the discharge flow rate based only on variation of the dam inflow and reservoir water level at the present time, without utilizing predicted values for future floods etc.

But in many cases, the flood control capacity is not entirely used under floods below the planned scale, so there are cases where the effectiveness of the operation is limited because it does not effectively reduce the water level in the river downstream from the dam.

4.3 *Examples of flood control problems performed at dams*

As examples of flood control problems at dams, operations performed at two dams to deal with major recent floods are organized based on the relationship between the dam's flood control capacity usage rate and a reference point water level in the downstream river and shown in Table 2.

Table 2. Relationship of a dam's flood control capacity usage rate with the water level at a reference point in the downstream river during flood discharge.

River system	River	Flood discharge date	River downstream from dam			Dam		
			Reference points	Max. water level (m)	Danger level	Dam	Total rainfall (mm)	Flood control capacity usage rate (%)
G River	G River	Sept. 16, 2006	Y Reference point	7.81	Inundation danger level	H Dam	192.3	27.9
K River	K River	July. 11, 2002	M Reference point	2.26	Inundation caution level	S Dam	145.4	35.5
	S River					G Dam	161.1	23.2
	K River	Sept. 17, 2007		2.53	Inundation caution level	S Dam	181	40.5
	S River					G Dam	295.5	87.7

(1) H Dam on G River

During a flood in G River System on September 16, 2006, at Y point, which is a reference point on the river downstream from the dam, the water level rose to a maximum of 7.81m which exceeded the "inundation danger level (water level which may cause an inundation resulting in considerable damage including flooding of houses etc.) of 7.59m".

At that time, the operators of H Dam located upstream discharged 180m^3/s of the maximum inflow of 760m^3/s to perform a maximum of 580m^3/s of flood control in compliance with its flood control operation rules.

At that time the flood control capacity usage rate at H Dam was about 28%, with the result that the flood control operation ended with considerable capacity remaining unused.

At the time of this flood, 63.5ha of land was flooded in M City located downstream from the dam, inundating 495 houses. It was necessary to implement a flood control operation method involving over-cutting the discharge from the dam (impounding more of the flow rate by narrowing the discharged quantity using the normal flood control operation method) to mitigate the damage in the downstream region.

(2) S Dam and G Dam on K River

A comparison of the flood discharges in the K River System on July 11, 2002 and on September 17, 2007 shows that on July 11, 2002, the total rainfall in the S Dam drainage basin and G Dam drainage basin were almost identical, but on September 17, 2007, the total rainfall in S dam drainage basin was 181mm, but it was 1.6 times as large, at 295mm in the G dam drainage basin. As this shows, there are cases where the rainfall distribution inside a drainage basin differs.

[Flood of July 11, 2002]

During the flood of July 11, 2002, the flood control capacity usage rates at S Dam and at G dam were 35.5% and 23.2% respectively, so that at both dams, flood control operation ended with considerable capacity remaining unused.

During this flood, at both dams, flexible operation, such as overcutting the discharge should have been done to use more of the flood control capacity, in order to further mitigate the flooding along the rivers downstream from the dams.

[Flood of September 17, 2007]

During the flood of September 17, 2007, the flood control capacity usage rates were 87.7% at G Dam and 40.5% at S Dam, so their flood control operations ended with almost all the capacity used at G Dam but with considerable capacity remaining unused at S Dam.

During this flood the operation of the two dams should have been coordinated so they complemented each other to further mitigate the flooding on the river downstream from the dams.

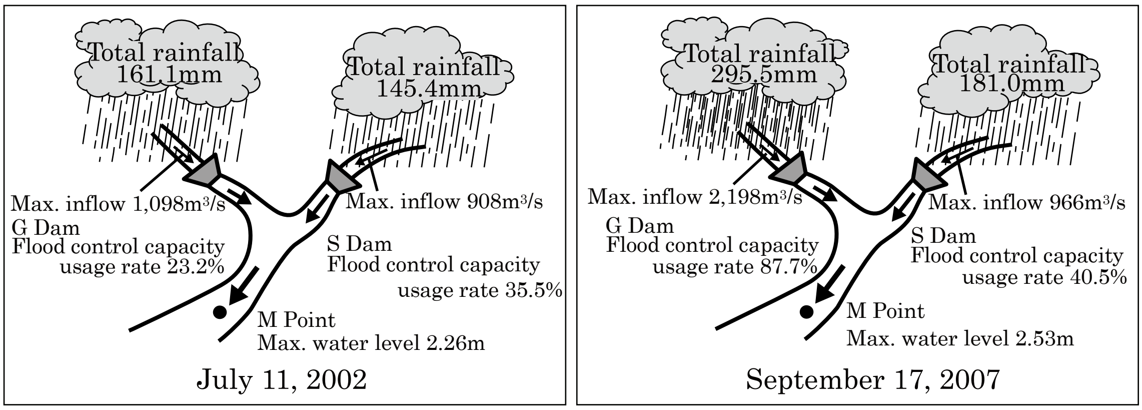

Figure 2. Flooding on the K river system.

Climate change occurring in recent years is predicted to cause frequent downpours and more powerful typhoons, but there are many uncertainties regarding the degree to which these will increase flood risk. So in order to be able to deal with conditions marked by such a high degree of uncertainty, it is essential to establish flood control operation rules which will reduce flood risk in downstream rivers by more effectively using the flood control capacity of dams in order to effectively respond to climatic conditions and downstream river conditions. And in order to enhance the reliability and reproducibility of operations, rules should be established in advance.

5 INITIATIVES TO ESTABLISH MORE EFFECTIVE FLOOD CONTROL OPERATION METHODS FOCUSED ON THE DOWNSTREAM RIVERS.

Below, two examples of flood control operation methods which are now the object of research in response to the above problems are introduced.

5.1 *Flood control operation rules using predicted values*

To mitigate flooding along rivers downstream from dams, criteria for judgments to lower dam discharge rates based on the state of flooding on downstream rivers and on future predicted rainfall and present free flood control capacity have been established. The criteria have been investigated at some dams since 2007 (Fig. 3).

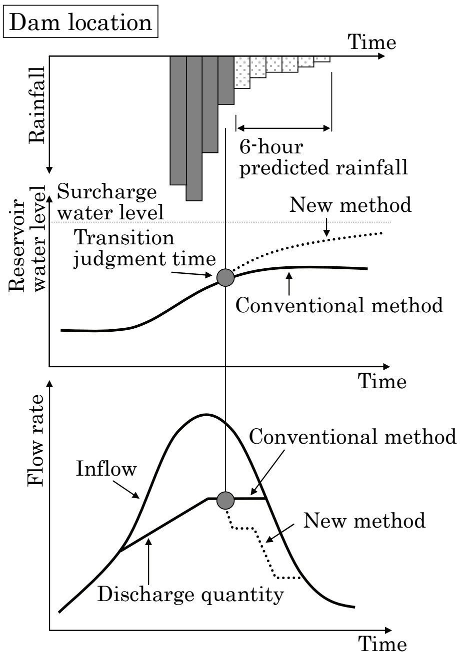

Figure 3. Conceptual diagram of flood control rules using rainfall prediction.

5.1.1 *Outline of the method*

This method is, as criteria for judging the water level in the downstream river, intended to make a transition decision when a flood is predicted. This method is a way to lower the discharge quantity based on operating rules in a case where the present free flood control capacity is larger than the predicted inflow to the dam.

The quantity stored by the dam is completely replaced by the equivalent rainfall (mm) to compare their size.

(1) Total inflow (mm)
Conversion of future inflow rate into the dam to equivalent rainfall
= lag-time rainfall + 6 hours cumulative predicted rainfall
or = equivalent rainfall when present inflow rate has continued for 6 hours
Lag-time rainfall: rainfall equivalent to the time until rainwater flows into the dam
6 hours cumulative predicted rainfall: short-term predicted rainfall by the Japan Meteorological Agency etc.

(2) Total discharge (mm)
Conversion of discharge quantity during 6 hours to equivalent rainfall
Rainfall equivalent to the total discharge = total discharge/drainage basin area

(3) Total quantity stored (mm)
= (1) total inflow – (2) total discharge

(4) Present free capacity (mm)
Conversion of present free capacity of the flood control capacity to equivalent rainfall
Rainfall equivalent to free capacity = free capacity/drainage basin area

(5) Decision to implement flood control by the new method
(3) Total quantity stored < (4) present free capacity → can be implemented
(3) Total quantity stored > (4) present free capacity → cannot be implemented

5.1.2 *Problems on this method*

This method uses short-term predicted rainfall values announced by the Japan Meteorological Agency, and the rainfall trend is approximately predicted, but the divergence with measured values is often wide. So it is assumed under the condition that the discharge rate is 100% considering the safety of the dam (all the rain which has fallen flows instantly into the dam). As a result, conditions for using the flood control capacity more effectively are not necessarily set and it is difficult to begin operations to reduce the discharge quantity. In the future, it will presumably be necessary to perform research to improve rainfall prediction precision and to set discharge rates in order to enhance effectiveness.

5.2 *Flood control operation rules which do not use predicted values*

To mitigate flooding in a river downstream of a dam, flood control rules which lower the discharge from a dam based on the relationship of the water level in the downstream river with the flood control capacity usage rate are being studied (Fig. 4).

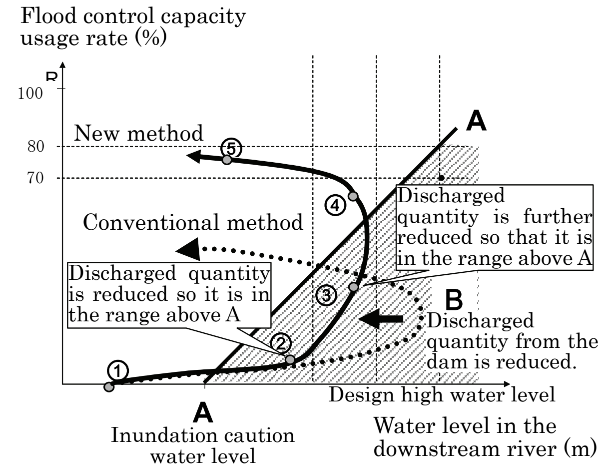

Figure 4. Conceptual diagram of flood control rules not using rainfall prediction.

5.2.1 *Outline of the method*

(1) A downstream river water level – flood control capacity usage rate relationship diagram is prepared for each dam.

(2) A-A lines are set for each dam. The setting of an A-A line varies between dams and the optimum line is set based on past flood discharges etc.

(3) In a case where the relationship of the water level in a downstream river with the flood control capacity usage rate is to the right of the A-A line, or in other words in the B range, it is judged that there is leeway in the capacity and the discharge from the dam is reduced so that it is in the range above the A-A line.

The goal is for the flood control capacity to reach approximately 80% when the water level in the downstream river reaches the planned water level.

A schematic relational diagram representing the downstream river water level – flood control relationship is shown (Fig. 5).

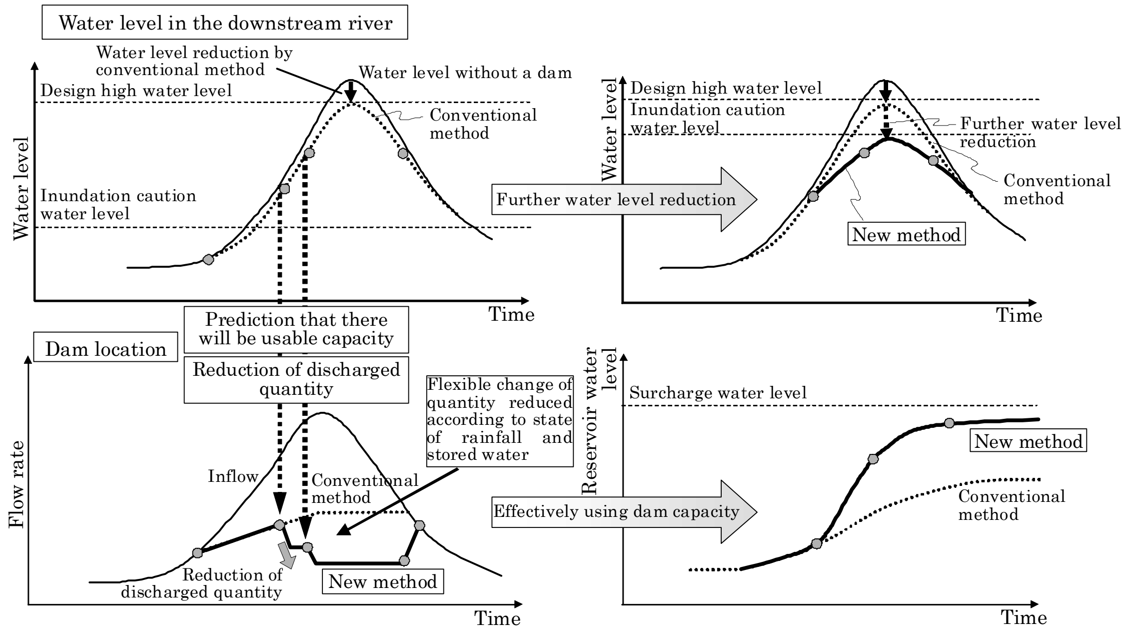

Figure 5. Schematic relational diagram of water level in a river downstream from a dam with flood control.

5.2.2 *Simulation results*

To confirm the results obtained by the new method, a verification based on a simulation was performed taking G Dam on K River System as an example (Fig. 6).

The results confirmed that applying the conventional flood control operation rules, the water level at M location on the downstream river increased to 4.41m, which exceeds the design high water level, but applying the new method held the water level down to 3.90m, which is below the design high water level.

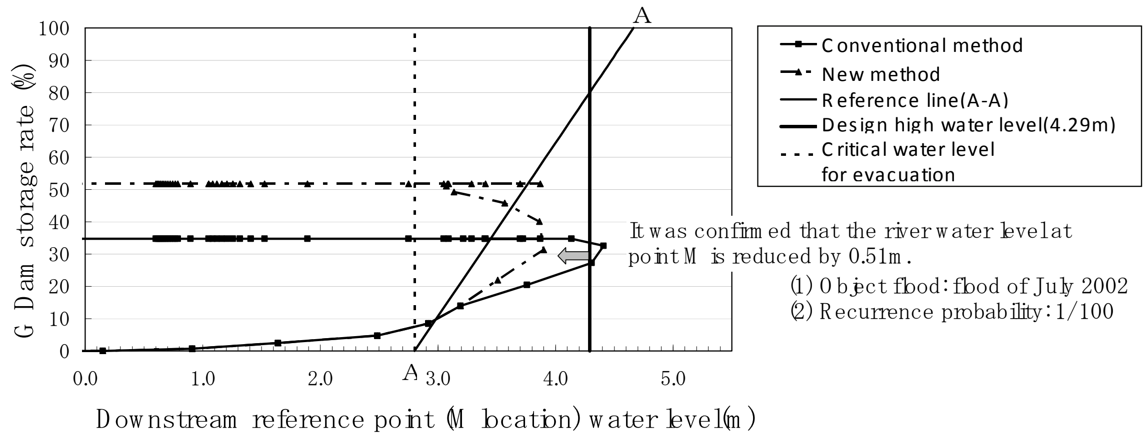

Figure 6. Results of the simulation of G dam on K river system.

6 CONCLUSIONS

This paper has introduced an example of the state of the study of flood control operation methods intended to more effectively utilize existing dams which is considered one measure to counter climate change now considered. In addition to the studies introduced, a number of problems related to flood control operations using water supply capacity, operation during excess flood discharge, and linked operation of a group of dams, remain to be resolved. It will be necessary to resolve these while also considering uncertainty concerning the characteristics of each dam and drainage basin, and climate change.

We plan to conduct further research in order to bring these methods as nearly as possible to the practical application stage while resolving these problems.