Study on validity of the hydroelectric dam operation adopted GSM and the information about typhoons

Hideyuki Takakura[1,a], Takayuki Matsubara[1,b], Eiichi Nakakita[2,c], Nozomu Takada[3,d]

[1]Electric Power Development Co.,Ltd, Tokyo, Japan
[2]Disaster Prevention Research Institute, Kyoto University, Kyoto, Japan
[3]Meteorological Engineering Center Co.,Ltd, Osaka, Japan

[a]hideyuki_takakura@jpower.co.jp
[b]takayuki_matsubara@jpower.co.jp
[c]nakakita@hmd.dpri.kyoto-u.ac.jp
[d]n.takada@meci.jp

ABSTRACT

In recent years, unusual rainfalls and floods have increased, and social demands are increasing that hydroelectric power dams, which have no function for flood-control originally, function as the flood-control dam.
The long-term rainfall forecast is needed for the hydroelectric power dam to have the flood-control function by lowering reservoir water level with power generation.
In this study, a new proposed weather and flood forecasting method, which combines the efficient formulation of GSM (Japan Meteorological Agency's Global Spectral Model) and the information about typhoons, was applied to Ikehara and Kazeya hydroelectric power dams at Kumano river basin and evaluated. The results showed that the new flood-control method had the applicability to the dam operations in terms of the reductions of the max discharge from the dams.

1. INTRODUCTION

In recent years, unusual rainfalls and floods, which appear to be caused by global warming, have increased and social demands are increasing that flood-control capacity of dams are reinforced as the valuable facilities for disaster prevention. For example, Tsuruda dam (a specified multipurpose dam) on Sendai river in Japan was reinforced its function for flood-control by dam reconstruction and changing a part of volume for water resources into for flood-control after the heavy rainfall disaster struck this basin in 2007. On the other hand, hydroelectric generation have revaluated as one of excellent renewable energy from a perspective of CO_2 reduction and anticipated that this method of power generation is utilized effectively.

Reservoir type hydroelectric power dams store a large amount of water in a high-water season and its power plant is operated stably and efficiently depending on electricity supply and demand on a whole year. Therefore, reservoir water level is appropriate for keeping high in terms of hydroelectric power plant operation; meanwhile, it is appropriate for keeping low from a perspective of flood-control dam operations. For this reason, it is necessary for hydroelectric power dams, which have no functions for flood-control originally, to lower its reservoir water level with power generation only when a hard rainfall is predicted, while reservoir water level is kept high for hydroelectric power operation usually. Moreover a reliable and long-term rainfall forecast is needed to make a judgement that reservoir water level is lowered before floods come, because discharge for hydroelectric power is smaller than that from spillway gates and it takes a long time to lower reservoir water level.

Till now, rainfall and inflow into reservoir have been forecasted statistically from typhoon information, observed rainfall and observed inflow. Recently, cases have increased in number that rainfall and inflow forecasts using a numerical analysis model are applied to actual dam operations with a progressive improvement in computer capability. Japan Meteorological Agency (JMA) makes GPV (Grid Point Value) public as shown in Table 1.

Table 1. GPV (Grid Point Value) released from JMA

Model	Short term rain forecast	MSM (Meso Scale Model)	GSM (Global Spectral Model)	
Lead time	6 hours	39 hours	84 hours	264 hours
Period	30 minutes	3 hours	6 hours	24 hours
Resolution	5 km	5 km	20 km	

Wada et al. (2006) and Mitsuishi et al. (2010, 2011) proposed how to use rainfall forecast information, whose predictive lead time is not more than two days, for setting a start time to discharge before floods come and flood-control operation. On the other hand, Matsubara et al. (2013) proposed how to use GSM, whose predictive lead time is longer but whose accuracy is lower than MSM, for lowering reservoir water level with power generation before floods come at hydroelectric power dams in Kumano river basin in Japan.

In this study, the results that the above method using GSM have been applied to actual dam operations was reviewed and the method was evaluated from perspective of applicability and improvement effects. In addition, a better method of hydroelectric power dam operations has been considered.

2. AN OUTLINE FOR THE NEW FLOOD-CONTROL METHOD OF DAMS WITH WEATHER AND FLOOD FORECAST

2.1 An outline for Kumano river in Shingu river system

Kumano river in Shingu river system is a first-class river, which has 183 km length and 2,360 km^2 catchment area, and located on the southern part of the Kii peninsula (Figure 1). Kumano river has no flood-control dam and all the dams are for water resources. Ikehara dam and Kazeya dam are owned by Electric Power Development Co., Ltd (J-power) and have larger reservoir than the others. Therefore, both of the dams have helped flood-control operation to reduce flood damage to the lower river basin with lowering reservoir water level to the aim water level, which is below the "preliminary release" water level, in flood season (Figure 2, 3). However, after heavy rain disaster from typhoon No.12 in 2011, J-power set up an investigative commission about dam operations during floods (the commission) which composed of public officials, river administrators and literates in order to discuss possibilities to enhance voluntary flood-control capacity of dams owned by J-power. A new flood-control method was proposed in the commission. In this method, additional flood-control volume is secured by lowering the reservoir water level with power generation in advance to floods in order to reduce the max discharge from the dams. The new flood-control method has been applied to Ikehara dam and Kazeya dam from 2012.

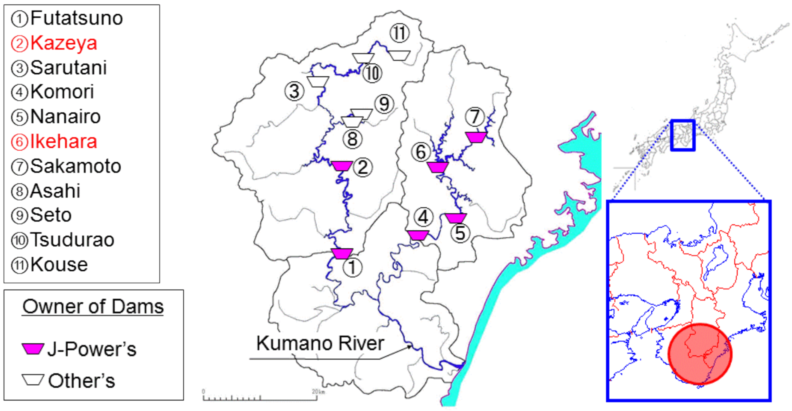

Figure 1. The location of dams in Kumano river basin

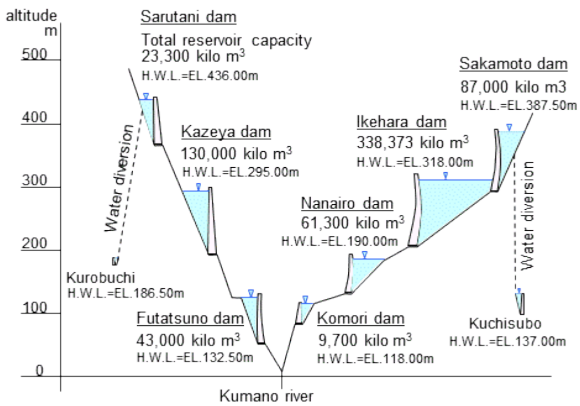

Figure 2. The location of dams and total reservoir capacity in Kumano river basin

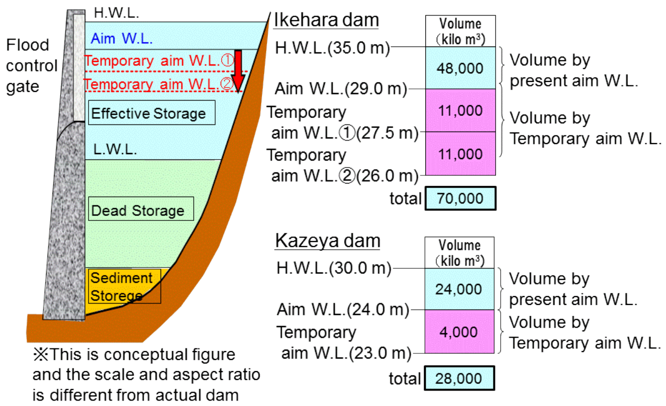

Figure 3. The image of available capacity for flood-control secured by aim water level in Ikehara dam and Kazeya dam

2.2 An outline for the new flood-control method

2.2.1 Criteria for drawdown operation before floods

Table 2 and Figure 4 show the criteria for drawdown operation before floods, applied to Ikehara dam and Kazeya dam. When all the conditions listed in Table 2, i.e. (i) typhoon location, (ii) forecast of a typhoon course and (iii) average 84 hours rainfall in Kumano river basin, are met, dam operators can conclude that there is a strong probability to come floods to each dam location, then would start to lower the reservoir water level up to the temporary aim water level as shown in Figure 3 with full-power generation. The temporary aim water level of Ikehara dam has been set two phases. The reservoir water level is lowered to phase 1 (W.L.=27.5 m) when a predicted value of rainfall is between 200 mm and 500 mm, and the level is lowered to phase 2 (W.L.=26.0 m) when the value is over 500 mm. Because the capacity for hydro-power discharge of Kazeya dam is small, reservoir water level is kept the temporary aim water level with ordinary power generating operation. In case the criteria for drawdown operation are applied to Ikehara dam and Kazeya dam, available capacity (about 98 Mio m^3) for flood-control is secured. In this paper, a detailed basis how to set the standard is omitted. Please refer to the paper of Matsubara et al. (2013) and the report of Electric Power Development Co.,Ltd (2012).

Table 2. The criteria for drawdown operation before floods

Criteria by the position and course of Typhoon, and the rainfall	
Center of Typhoon	North of Lat.15° N and Long,120~145° E
Course of Typhoon	Prediction course within a 300 km radius from the dam
Rainfall (GSM) *	1st : 200 mm 2nd : 500 mm

* : The average 84 hours rainfall in Kumano river basin

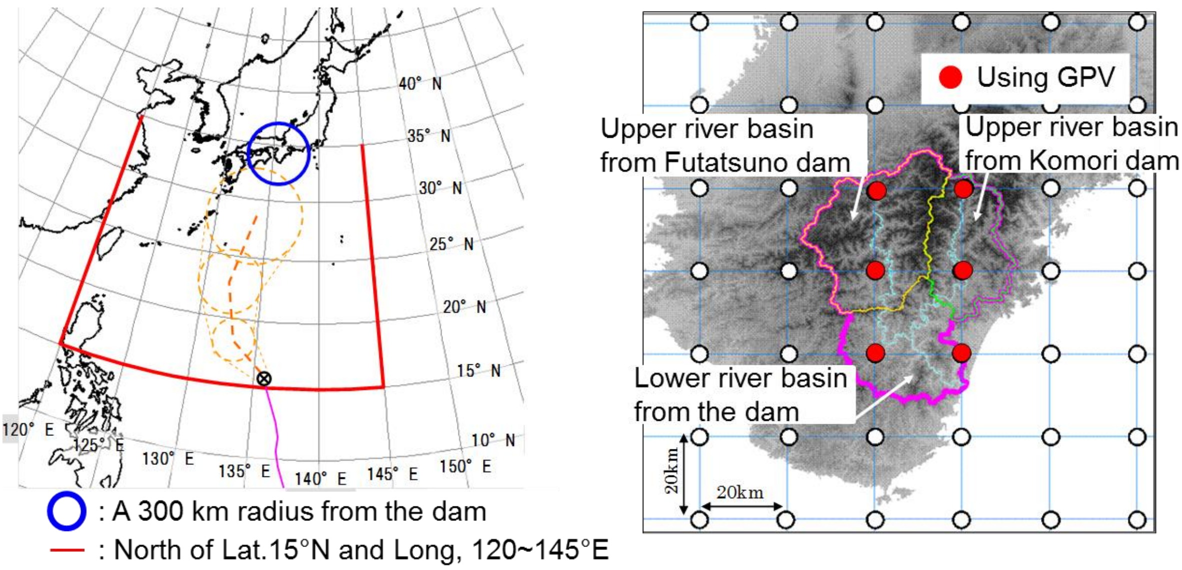

Figure 4. The criteria for Drawdown Operation before floods

2.2.2 Extension of time lag for delayed operation

A delayed operation rule is applied as the dam operation regulation of the Ikehara dam and Kazeya dam because generally flood propagation is facilitated after dam completion compared to the one when the dam did not exist. Under the delayed operation rule, dam operators are required to keep the certain amount of discharge from the dams for the fixed time (delayed period) after the inflow to the reservoir a flood quantity. In the case of Ikehara dam and Kazeya dam, the fixed time is 30 minutes and the flood quantity is 1,500 m^3/s. Only after that, the same amount of inflow is allowed to be discharged from the dams.

In the new flood-control method, the delayed period of Ikehara dam was extended to three hours from 30 minutes temporarily (Figure 5, green dotted line). It is difficult to control discharge before the peak of inflow with the present rainfall forecast accuracy, then the new flood-control method was based on delayed operation. The delayed period is extended by setting the temporary aim water level, and the max discharge can be reduced more than the one under the standard operation rule. The delayed period (three hours) is the limit of extension in case delayed operation is applied to the flood from typhoon No.12 in 2011. On the other hand, because of limited capacity for flood-control of Kazeya dam, so the delayed period can't be extended and the discharge from the spillway gates is reduced by using free-flow effect. Specifically, when reservoir water level is lowered into temporary aim water level, this low water level makes the capacity for discharge lower. When the spillway gates are opened corresponding to increasing inflow, however, such operation could not increase discharge rate, and when the spillway gates are fully opened, the flow conditions are shifted to free-flow. During free-flow condition, the discharge is smaller than the inflow with dam storage effect.

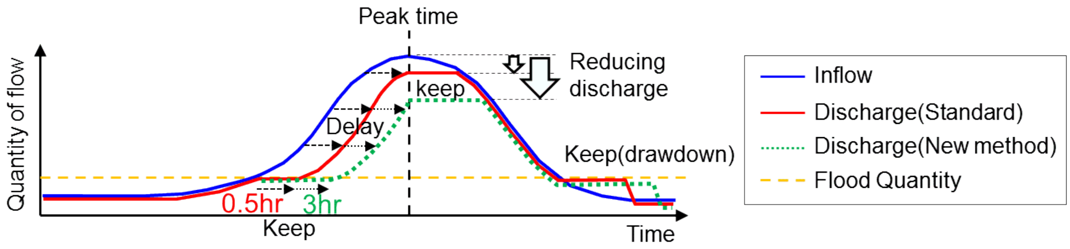

Figure 5. The image of reducing discharge by extending delayed period

2.2.3 Result of the advance estimation

Table 3 shows the number of typhoons, which met the criteria for drawdown operation and actually reached the flood quantity at Ikehara dam between 2001 and 2011 (250 typhoons). The hitting ratio is 95.6% (=(A+D)/N), the capture ratio is 91.6% (=A/(A+C)) and the concordance ratio is 52.3% (=A/(A+B)) when the criteria are applied to Ikehara dam. Therefore, the criteria for drawdown operation are judged realistic and practicable ones. Figure 6, 7 show the reducing effect of discharge from Ikehara dam and Kazeya dam in case the criteria are applied to each dam. The max discharge is calculated the same way the following simulation (3.2.4). It is possible to reduce the max discharge by applying the new flood-control method and the method is judged an effective method.

Table 3. The actual results of floods, which met the criteria, between 2001 and 2011

Criteria	Flood *	No-Flood
Hit	11 cases (A)	10 cases (B)
Not hit	1 case (C)	228 cases (D)

N = A+B+C+D = 250 typhoons (2001～2011)   * : the flood quantity is 1,500 m^3/s

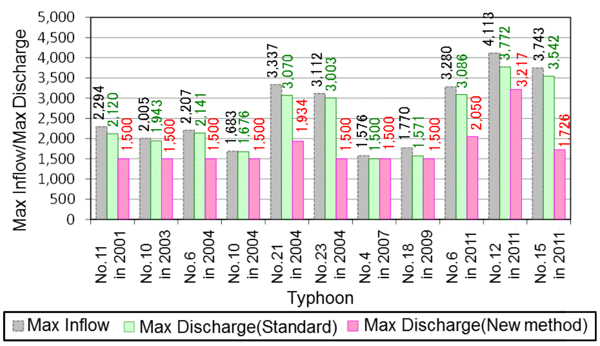

Figure 6. Ikehara dam simulation for evaluation of discharge reduction

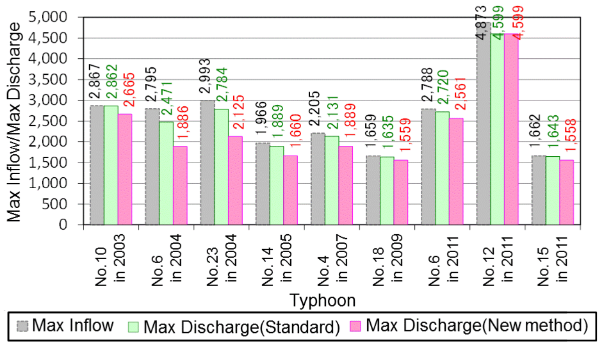

Figure 7. Kazeya dam simulation for evaluation of discharge reduction

3. RESEARCH METHOD

3.1 Research procedure

Figure 8 shows the research procedure. The actual results of typhoons, which met the criteria for drawdown operation and actually reached the flood quantity at Ikehara dam between 2012 and 2014, were organized and the validity of the criteria was evaluated. Then the effect of discharge reduction was evaluated by drawing a comparison between inflow and discharge in case the flood-control operation was applied. Finally, the validity of the new flood-control method was evaluated synthetically.

1) Evaluation of Criteria for Drawdown operation

↓

2) Evaluation of Reduction of Discharge

↓

3) Total Evaluation

Figure 8. The research procedure

3.2 Research method

3.2.1 Objective floods

In this consideration, 79 typhoons, which occurred between 2012 and 2014 after applying the new flood-control method to Ikehara dam and Kazeya dam, were set as the targets. Table 4 shows flood data on the typhoons, which met the criteria in objective typhoons.

3.2.2 The validity evaluation of the criteria

In this validity evaluation, the criteria's reliability as a flood prediction system and whether the criteria have enough time to lower reservoir water level to the temporary aim water level or not were evaluated. The criteria's reliability as a flood prediction system was evaluated in the same way Table 3. The lead time for lowering water level was simulated at Ikehara dam, whose reservoir water level is lowered with power generation in advance to floods. 5 flood cases, which met the criteria and the flood quantity (1,500 m^3/s) actually (Table 4), were taken as the objects of simulation.

Table 4. The actual results of floods, which met the criteria

year	Typhoon No.	criteria	Max inflow (m^3/s) a		Max discharge* (m^3/s) b		Ratio (%) (a-b)/a*100	
			Ikehara dam	Kazeya dam	Ikehara dam	Kazeya dam	Ikehara dam	Kazeya dam
2012	4	Hit	2,068	1,378	325	569	84	59
	17	Hit	2,708	1,211	1,442	637	47	47
2013	4	Hit	319	160	0	0	100	100
	18	Hit	2,273	3,589	0	2,499	100	30
	26	Hit	329	369	0	29	100	92
	27	Hit	328	381	0	152	100	60
2014	11	Hit	2,080	3,392	743	2,643	64	22
	18	Hit	1,657	390	0	70	100	82
	19	Hit	749	279	0	143	100	49

* : discharge at time when inflow reached max

3.2.3 Evaluation of the effect of discharge reduction

The effect of discharge reduction was evaluated by comparing actual inflow, calculated discharge and actual discharge from the dam.

3.2.4 Simulation conditions

In this research, the simulation conditions were set as follow.

- Objective floods : the floods, which met the criteria and made the discharge from Ikehara dam increase to the flood quantity (5 cases).
- Starting reservoir water level : the aim water level (W.L.=29.0 m) kept with ordinary dam operation.
- Inflow : actual inflow into the reservoir.
- Discharge for power generation : 342 m^3/s (the maximum discharge for power generation)
- All discharge from the dam : the dam discharge a same amount as inflow before inflow reach the flood quantity (1,500 m^3/s). After inflow is over the flood quantity, delayed operation (three hours delay) is started.
- Change of reservoir water level : reservoir water level was calculated by using reservoir capacity curve.

3.2.5 Total evaluation

The validity of the criteria and the effect of discharge reduction by applying the new flood-control method were evaluated comprehensively. In addition, tasks were distilled from the research results above and actual dam operations, then a further improvement method of hydroelectric power dam operations was considered.

4. RESEARCH RESULTS

4.1 Validity of the criteria for drawdown operation before floods

Table 5 shows the number of typhoons, which met the criteria for drawdown operation and actually reached the flood quantity at Ikehara dam between 2012 and 2014. The hitting ratio was 94.9% (=(A+D)/N), the capture ratio was 100% (=A/(A+C)) and the concordance ratio was 55.6% (=A/(A+B)). Figure 9, 10, 11, 12, 13 show the results of discharge simulation in case of 5 objective floods.

Table 5. The actual results of floods, which met the criteria, between 2012 and 2014

Criteria	Flood *	No-Flood
Hit	5 cases (A)	4 cases (B)
Not hit	0 case (C)	70 cases (D)

N = A+B+C+D = 79 typhoons (2012～2014)　　* : the flood quantity is 1,500 m^3/s

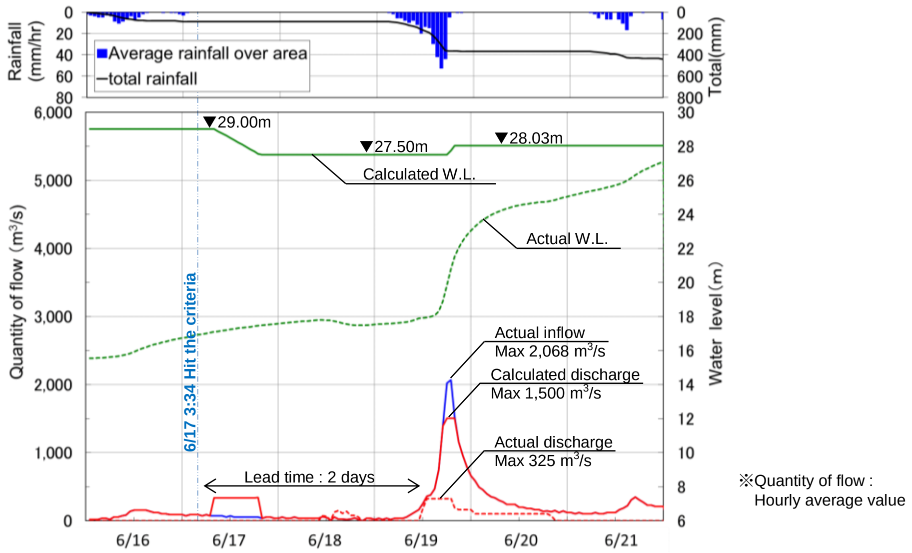

Figure 9. The result of simulation for typhoon No.4 in 2012

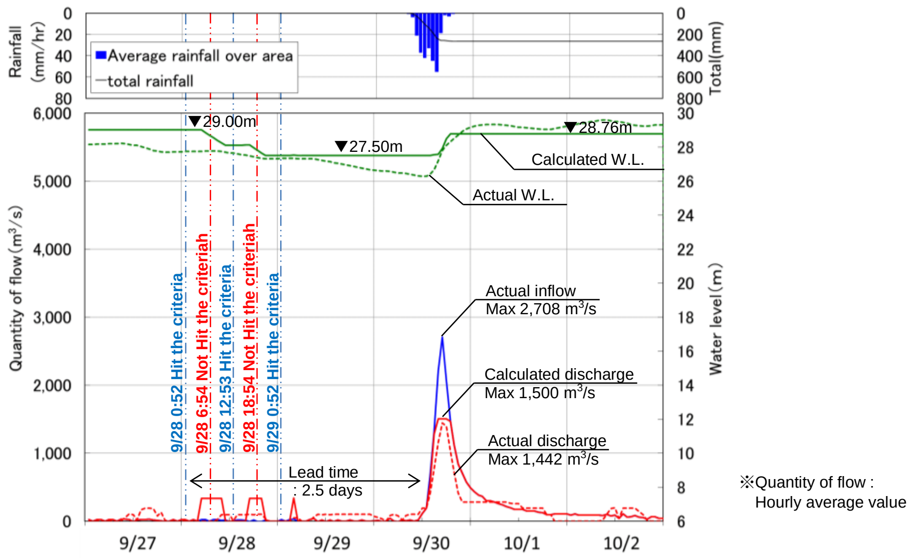

Figure 10. The result of simulation for typhoon No.17 in 2012

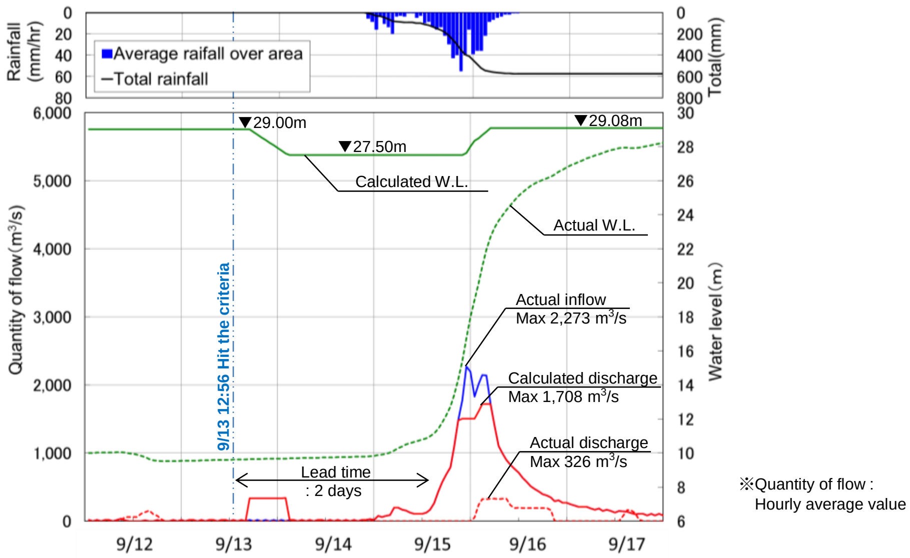

Figure 11. The result of simulation for typhoon No.18 in 2013

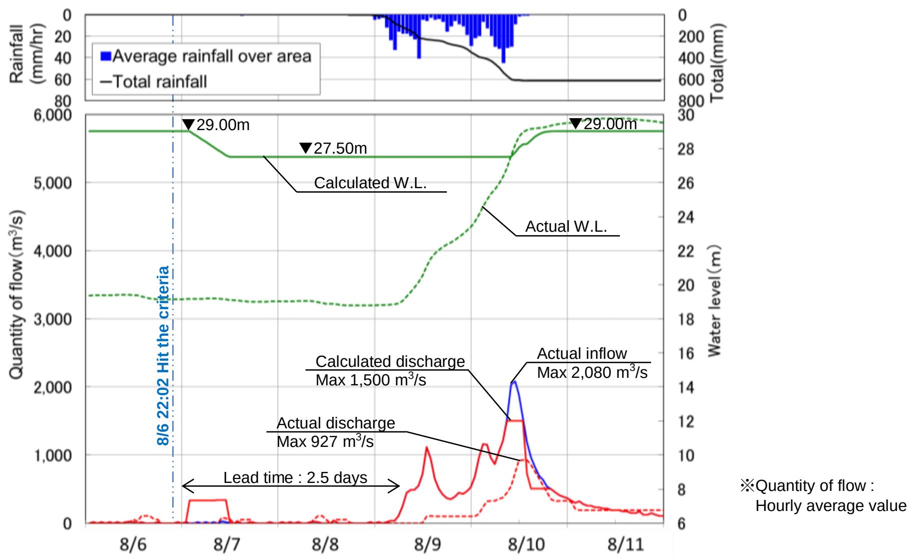

Figure 12. The result of simulation for typhoon No.11 in 2014

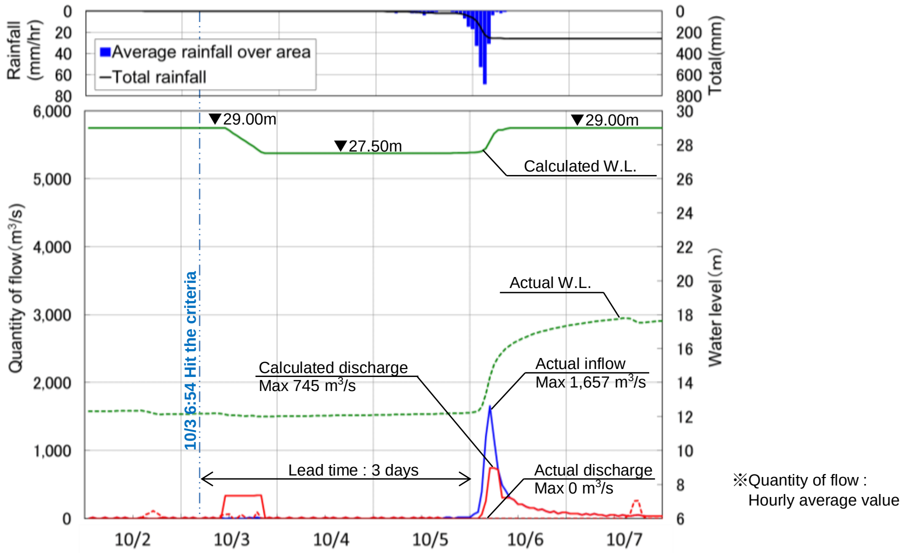

Figure 13. The result of simulation for typhoon No.18 in 2014

There were two days for lowering the reservoir water level after all the conditions of typhoon and rainfall prediction met the criteria, and it was enough time to lower reservoir water level from starting level to the temporary aim water level. As described above, the criteria don't have any problem at present and it was evaluated as relevant ones. It is necessary to store and check flood data continually for improving the criteria in the future.

4.2 Verification of the effect of discharge reduction

The max discharge from Ikehara dam had a range from 1,657 m^3/s to 2,708 m^3/s. Except for typhoon No.18 in 2013 (Figure 11), the inflow reached each peak during the keeping discharge operation had three hours as delayed period. Therefore, the max discharge was 1,500 m^3/s and the reduced discharge was between about 150 m^3/s and 1,200 m^3/s. In case of typhoon No.18 in 2013 (Figure 11), the flood duration time was over 3 hours and had increased to second peak after the inflow reached the flood quantity. Therefore, the max discharge was 1,708 m^3/s by delayed operation. Actually, because the reservoir water level was lower than the temporary aim water level, the reduced discharge was between about 50% and 100% at the time peak inflow came (Table 4). As described above, the simulation showed that it is possible to reduce the discharge with delayed operation. In addition, the actual discharge was able to be reduced more than the calculated discharge because the reservoir water level was lower than the temporary aim water level. However, the objective floods in this paper was smaller than typhoon No.12 in 2011, then the calculated the reservoir water level was from 28.0 m to 29.0 m and Ikehara dam had some capacity for capturing inflow when the floods finished. Therefore, it is necessary to make a study on the method of using this amount of space for further reducing the discharge in case a flood is smaller scale than typhoon No.12 in 2011.

4.3 Total evaluation

As identified above, the criteria for drawdown operation in advance to floods have validity and a certain degree of effect of reducing discharge from dams. Therefore, the new flood-control method applied to Ikehara dam and Kazeya dam is effectual, though it is necessary that the method is reviewed continually. Additional consideration will be needed to yield any findings about the further reducing method of discharge by using some capacity for capturing inflow to the maximum according to scale of flood. In actual dam operations, dam operators foresee a change in inflow : peak inflow, time of peak inflow, a gross inflow and so on, and operate the spillway gates for reducing discharge.

In general, in order to reduce discharge to the maximum, the discharge is set to the minimum without that a volume, which calculated by subtracting a gross discharge from a gross predicted inflow, is over an amount of space for capturing inflow. However, the present prediction accuracy is not enough to set discharge directly and unambiguously from rainfall and inflow forecast, then dam operators control discharge after he check whether an actual inflow begin to decrease and whether rain radar shows rain area pass over a catchment area. Therefore, the reducing discharge operation has room for improvement depending on scale of typhoon if a gross inflow can be predicted accurately and early.

Figure 14 shows the correlation between actual total rainfall or average 84 hours predicted rainfall in Kumano river basin and actual 4 days gross inflow. Moreover, Figure 15 shows the correlation between average 84 hours predicted rainfall and actual total rainfall in Kumano river basin. JMA's GSM is applied to the predicted rainfall. The typhoons which was close to Kumano river basin between 2008 and 2014 is targeted on. Figure 14 shows actual total rainfall has a strong correlation with actual gross inflow, and it is possible to predict gross inflow if total rainfall is predicted accurately. On the other hand, 84 hours predicted rainfall has a weak correlation with actual gross inflow, and there are some cases that predicted rainfall is remarkably more or less than actual rainfall (Figure 15). Therefore, in order to sophisticate a hydroelectric power dam operations, it is necessary to improve an accuracy of rainfall forecast, predicted total rainfall at the beginning. In addition, it is assumed that improving an accuracy of rainfall forecast: peak hourly rainfall, peak time of rainfall, hyetograph and so on, sophisticate a hydroelectric power dam operations.

It seems that the method proposed by Yu et al. (2015) could be applied to an accuracy improvement of rainfall forecast, for example. This is a method correcting an predictive error of an ensemble rainfall forecast with rain radar and radar rainfall prediction, and the method improve an accuracy of rainfall prediction until 30 hours later substantially.

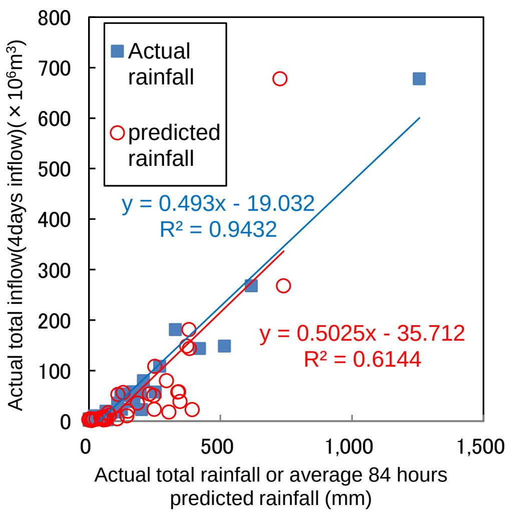

Figure 14. Correlation total rainfall with total inflow

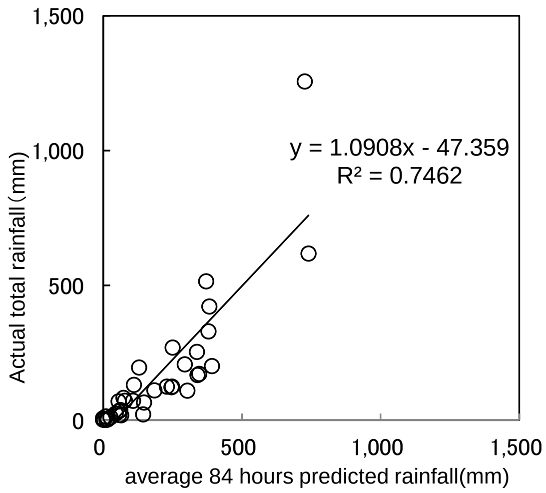

Figure 15. Correlation predicted rainfall with actual total rainfall

5. CONCLUSION

The result of applying the new flood-control method with JMA's GSM and the information about typhoons to the hydroelectric power dam operations in Kumano river basin is as below.

- The criteria for drawdown operation before floods have high reliability as a method of flood prediction and have enough time to lower the reservoir water level with power generation.
- The simulation of Ikehara dam operations showed that Ikehara dam was able to reduce the max discharge during floods from about 2,700 m^3/s to 1,500 m^3/s by applying updated delayed period of 3 hours (original period is 0.5 hour). In actual operation, the reduced discharge was about 1,300 m^3/s.
- It is found that the criteria for drawdown operation were effective and gave a certain degree of effect on reducing the max discharge from the dam during floods, then the new flood-control method applied to Kumano river basin is exhibited its availability. The new flood-control method has been applied to the actual dam operations from June 2012, then data on the spillway gates operation during floods with the new flood-control method was recorded and the method was reviewed properly and continually together with local community.
- It is important to improve an accuracy of rainfall forecast, especially predicted total rainfall, to sophisticate the current new flood-control method.

6. ACKNOWLEDGEMENTS

The authors would like to thank Professor Emeritus Ikebuchi, Professor Hori and Professor Tachikawa of Kyoto University for their guidance.

7. REFERENCES

Electric Power Development Co.,Ltd (2012) : The Improvement of Dam Operation and Communication of information in Shingu River Basin. http://www.jpower.co.jp/oshirase/2012/06/oshirase120604.html

Matsubara T, Kasahara S, Shimada Y, Nakakita E, Tsuchida K, & Takada N (2013). *Study on Applicability on Information of Typhoons and GSM (Global Spectral Model) for Dam Operation*. The journal of Japan Society of Civil Engineers, Ser. B1 (Hydraulic Engineering) Volume 69(4), pp I 367-372, 2013.

Mitsuishi S, Sumi T, & Ozeki T (2010). *Dam Operations using Precipitation Forecasts by Weather Research and Forecasting Model*. The Journal of Japan Society of Dam Engineers, Volume 20, No. 2, pp 94-104, 2010.

Mitsuishi S, Sumi T, Ozeki T, & Yagami T (2011). *Research on Risk Management of Dam Flood Control by Utilizing Rainfall Prediction*. The journal of Japan Society of Dam Engineers, Volume 21, No. 4, pp 242-250, 2011.

Wada K, Kawasaki M, & Tomizawa Y (2006). *The Study on Applicability of Precipitation Forecasting Information for River Flood Management Report*. The technical note of National Institute for Land Infrastructure Management, No. 329, March 2006.

Yu W, Nakakita E, Kim S, & Yamaguchi K (2015). *Improvement of rainfall and flood forecasts by blending ensemble NWP rainfall with radar prediction considering orographic rainfall*, The journal of Hydrology, Volume 531, Part 2, pp 494-507, 2015.