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FLOOD CONTROL FOR TYPHOON 18 AT THE YODO RIVER SYSTEM IN 2013 - AVOIDANCE OF CATASTROPHE THROUGH COORDINATED OPERATION OF 7 DAMS (*)

Masayuki KANMURII
Vice-director, division of river management, department of river, Kinki regional development bureau ministry of land, infrastructure and transport

Hiroshi MORITA
General Manager, Yodo river integrated dam management office

Hideshi TAKEZAWA
Vice-director, Division of water resource facility maintenance and management, Kansai regional head office, Japan water agency

Tahiro AOYAMA
General Manager, Kizu integrated dam control and management office

Hirohisa MIURA
Technical staff, Kizu integrated dam control and management office

JAPAN

1. INTRODUCTION

On September 16, 2013, the heavy rains of typhoon 18 caused an overflow in a section of at the most 400 m on the right embankment of Katsura river downstream area close to confluence point of Katsura river, Uji river, and the Kizu river in Yodo river system.

(*) Régulation des crues sur le réseau hydrographique de la rivière Yodo-Gawa lors du passage du typhon Man-Yi sur le Japon en 2013– Évitement d'une catastrophe majeure grâce à la gestion coordonnée de 7 barrages.

At this time, the Hiyoshi dam upstream was utilizing its dam capacity to the fullest and was storing floodwater to implement flood control (disaster prevention operations). additionally, if the water level is high were the 3 rivers, the Katsura river, Uji river, and Kizu river merge at the overflow location, it will be affected in making flow difficult, and even at the uji river, the seta river barrage was completely closed and the Amagase dam was undertaking flood control and additionally, the dam group upstream of Kizu river (Takayama dam, Murou dam, Shorenji dam, Nunome dam and Hinachi dam) were also coordinating to lower the water level at this confluence point of the 3 rivers. (Fig. 1, Fig. 2)

Because it was possible to utilize all the facilities in Yodo river system to full capacity for flood control, the overflow downstream of the Katsura river was held to a level where stacked sandbags were able to avoid the worst case of collapse of embankment. (Fig. 3)

For the flood this time, because the kinki regional development bureau understood that the Katsura river might overflow, they gave instructions to consider dam operations and the Yodogawa dam integrated management office and water agency receiving these instructions, considered the best possible operational methods to lower the water level of where the 3 rivers merged as much as possible and undertook those operations.

This flood response, through the high level of technical skills, the large volume of information and the results of the analysis were diligently communicated and adjusted and in a short time, the flood control facilities distributed over the entire water system were coordinated and made to cooperate and an operation without precedence was undertaken, and demonstrating the very significant effect of the dams, and the operation of the dams can be thought to have prevented a mayor disaster.

Fig. 1
Hiyoshi dam utilizing its full capacity
Utilisation optimale de la capacité de rétention du barrage d'Hiyoshi

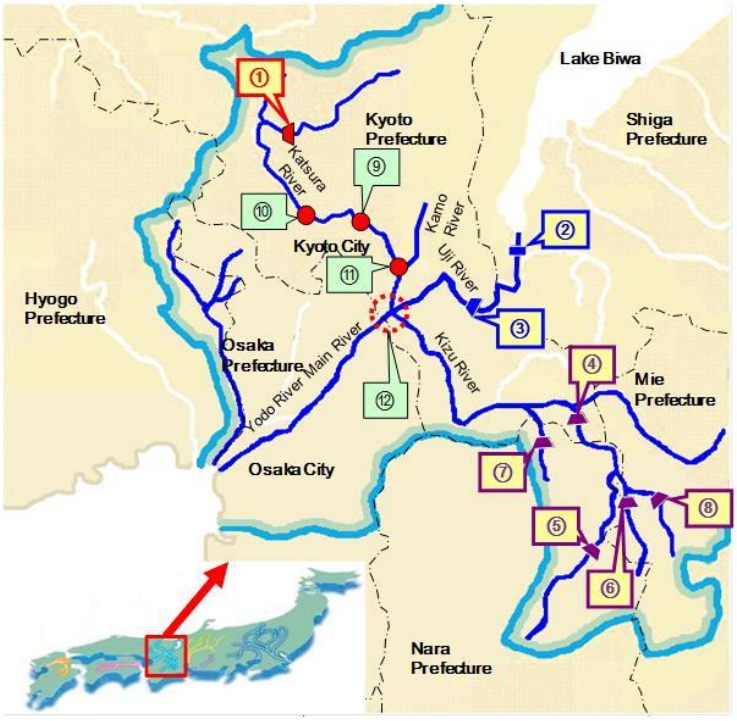

Fig. 2
Facilities location diagram of 7 dams in Yodo river system
Carte localisant les installations et les 7 barrages du réseau hydrographique de la Yodo-Gawa

1	Hiyoshi dam	*1*	*Barrage d'Hiyoshi*
2	Seta river barrage	*2*	*Barrage de la rivière Seta*
3	Amagase dam	*3*	*Barrage d'Amagase*
4	Takayama dam	*4*	*Barrage de Takayama*
5	Murou dam	*5*	*Barrage de Murou*
6	Shorenji dam	*6*	*Barrage de Shorenji*
7	Nunome dam	*7*	*Barrage de Nunome*
8	Hinachi dam	*8*	*Barrage d'Hinachi*
9	Arashiyama point	*9*	*Point d'Arashiyama*
10	Kameoka HOZU bridge point	*10*	*Point du pont de Kameoka Hozu*
11	overflowed locations of Katsura river downstream area	*11*	*Zones d'inondation de la rivière Katsura*
12	3 rivers merging point of Yoda river	*12*	*Confluent des trois rivières avec la Yoda*

Fig. 3
Flood control activities by flood fighting corps
Actions de lutte contre les inondations par les brigades de lutte

2 . OUTLINE OF JAPANESE DAM OPERATIONS

Japan is within the asian monsoon region and floods are concentrated during the rainy season of june and the typhoon season in October and the rivers flow from steep mountains through a small watershed and because the gradient of river bed is steep, the flow from rainfall can become intense in a short time. Moreover, as metropolises develop, and population and property concentrates on downstream plains, heavy damages may be caused when embankments collapse.

Therefore, when floods occur, judgment on detailed dam operations are required and the administrator of the dam shall acquire and analyze weather forecasts, weather information from weather radars, downstream river information, dam reservoir information, etc., in real time and shall undertake flood controls operations and minimize the flood damage at downstream of the dam.

Additionally, even when the flooding is greater than the planned scale, and it is predicted that if prescribed flood control operations are continued, the water would surpass the surcharge water level (s.w.l.) which is the maximum water level during flood designed as the full capacity of the dam, an emergency gate operations (ego) would be carried out.

Flood control operations for emergency gate operations to store more water in the dam than decided upon, are determined in advance because decisions must be made and implemented in a very short time.

3 . ADVANCED DAM OPERATIONS

When flood damage may occur downstream depending on the progress of river improvement and the situation of rainfall even though prescribed flood controls operations have been done, if there is allowance in the flood control reservoir capacity of the dam, operations to hold water more than prescribed flood control operations can be done to lessen the water level downstream.

If multiple dam facilities are within the river system, coordinated operations between the dams are undertaken and the water level downstream can be lowered.

However for this type of operation, it is necessary to consider on a consistent basis to return to prescribed flood control operations because the actual rainfall may be heavier than predictions.

For the response to flooding during typhoon 18 in 2013, flood control to store water by the dams exceeding normal operations were performed in order to reduce the water level downstream of the dams as much as possible. Additionally, unprecedented advanced operations were collaborated in order to lower the water level at where the 3 rivers merged as much as possible.

The following will describe the flood control on the Yodo river during typhoon 18 in 2013.

4 . OUTLINE OF TYPHOON 18 IN 2013

Typhoon 18 was generated at sea near the Ogasawara islands on September 13th, at 3:00 pm, and as shown in Fig. 4, gained strength while travelling north on the southern seas of japan, and on the 14th at 9:00 am it developed into a large typhoon with the radius of an area with strong wind area radius of over 500 km.

In the Kiniki region, in accordance with the approach and passage of the typhoon, from the effect of the moist air flowing in from the surrounding area with the front and the typhoon, and the rain clouds of the typhoon itself, the area of rain remained and led to strong rains for a long period of time (Fig. 5). For this reason,

the meteorological agency for the first time since its operation, announced on the 16th at 5:05 am, ”emergency weather warning “ for heavy rainfall for Kyoto, Shiga, and Fukui prefectures.

This special alarm requires the highest level of vigilance for weather information and is issued when heavy rains that are predicted to happen only once in a few decades occur.

Additionally, evacuation instructions were issued to approximately 340,000 residents of state administrated river basin in the Yodo river system and 180,000 people received evacuation advisories.

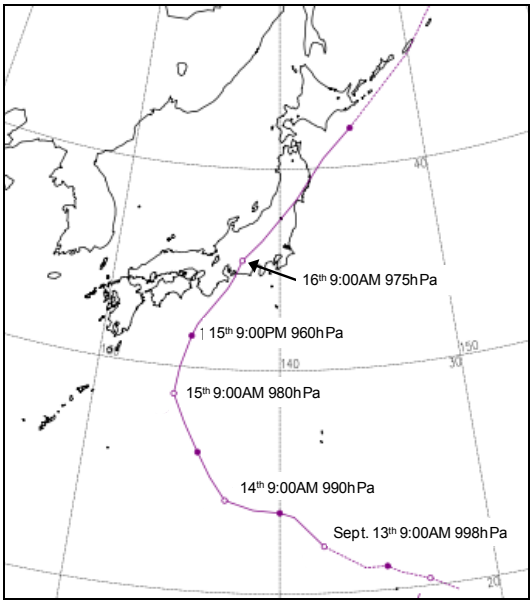

Fig. 4
Typhoon 18 path diagram
(Material provided by the japan meteorological agency (partially edited))
Trajectoire du typhon Man-Yi
Document fourni par l'Agence météorologique japonaise (partiellement révisé)

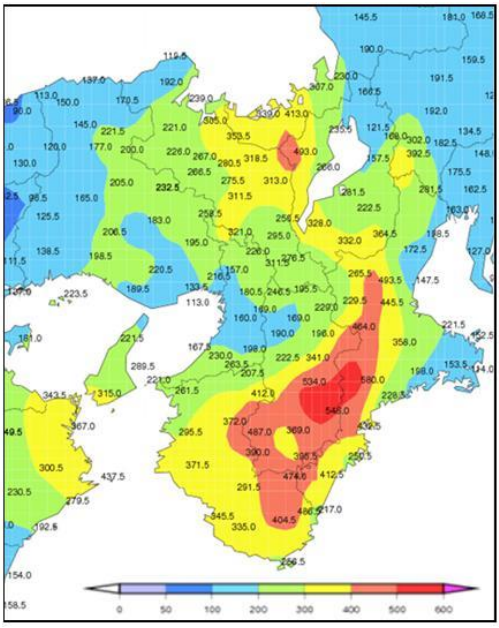

Fig. 5
Cumulative rainfall volume
(36 hours from 3:00 am, sept. 15, to 15:00 pm, Sept. 16)
Carte des hauteurs de pluie cumulées
(pendant 36 heures entre le 15 septembre 3 h et le 16 septembre 15 h)

5 . FACILITIES OF 7 DAMS IN YODO RIVER WATER SYSTEM

The source of the Yodo river originates from small and large tributaries coming from the mountainous region of Shiga prefecture and is collected in lake Biwa and from Otsu city, changes its name to the seta river and the Uji river, then near the border between Kyoto and Osaka prefectures, the uji river, the Katsura river and Kizu river are confluent together flowing southwest on the Osaka plains as the Yodo river, and finally flows into Osaka bay.

The main river flow extends 75 km, and the flow area is about 8,240 km^2 and flows through 6 prefectures, Osaka, Hyogo, Kyoto, Shiga, Nara, and Mie. The basin supports the base of society, economy, and the culture of the Kinki district and approximately 12 million people live there.

The lake Biwa has extremely effect of flood control for the Yodo river system because the lake Biwa basin area occupies half of the Yodo river basin and outflow river from the lake Biwa is only the seta river. On the seta river, ministry of land, infrastructure, transport and tourism (Mlit) manages the seta river barrage to control outflow, and there exists the Amagase dam in the downstream area of the Uji river also managed by mlit.

On the Katsura river is the Hiyoshi dam managed by the Jwa, on the Kizu river is the Takayama dam, Murou dam, Shorenji dam, Nunome dam, and Hinachi dam also managed by the Jwa.

6 . OUTLINE OF FELOOD MEASURES OF THE YODO RIVER SYSTEM DAMS

The rainfall from typhoon 18 caused large-scale flooding on the Yodo river system. Especially at Hiyoshi dam, the flood surpassed the designed maximum inflow volume and the largest flood control operations since management started was undertaken, additionally the Nunome dam recorded the maximum inflow volume since its management started.

The 7 dams managed by Mlit and the Jwa carried out flood control and the seta river barrage had done fully closed all gates operations for first time in 41 years for the mitigation of flood damage.

Especially at Amagase dam and Hiyoshi dam, the start of ego was delayed specially to reduce river discharge at downstream reducing the volume of flow downstream, and at the Kizu river upstream dam group, 5 dams coordinated operations to lower the water levels of the Nabari river and where the 3 rivers merged.

The flood control situations of each dam are shown in Table 1.

Table 1
Flood control situation of each dam

management	river name	facility name	basin area (km2)	basin average rainfall volume (mm)	inflow volume at maximum adjustment (m^3/s)	dam maximum adjustment volume (m^3/s)	discharge volume at maximum adjustment (m^3/s)	reservoir stored volume ($\times 10^3$ m^3)
mlit	uji river	amagase dam	352	300	1360	500	860	8700
jwa	kizu river	takayama dam	615	290	1580	1130	450	23700
	kizu river	shorenji dam	100	368	500	330	170	5000
	kizu river	murou dam	136	226	330	250	80	4000
	kizu river	nunome dam	75	252	200	150	50	2700
	kizu river	hinachi dam	76	440	320	250	70	5900
	katsura river	hiyoshi dam	290	345	1690	1540	150	44600

The reservoir stored volume indicates the volume retained from the volume retained at the time when the inflow volume reached the flood volume, to the maximum volume retained.

7 . FLOOD CONTROL OF YODO RIVER WATER SYSTEM DAM GROUP

7.1. COORDINATED OPERATIONS OF SETA RIVER BARRAGE AND AMAGASE DAM

The accumulated rainfall on the lake Biwa basin area was 280 mm from when it started raining, the maximum average rainfall for an hour over the Amagase dam basin area was 37 mm, the accumulated rainfall from when it started raining was observed to be 300 mm.

The lake Biwa basin area is 3,848 km^2, the maximum inflow to the lake Biwa is estimated approximately 6,000 m^3/s in the case of the heavy rain caused by typhoon 18.

Water level of the lake Biwa was raised 1.0 m because outflow from the lake Biwa is only the seta river and its flow capacity is 800 m^3/s as maximum. (Fig. 6)

At the Uji river in the downstream of the seta river, Amagase dam coordinated flood control operations with the seta river barrage that had done fully

closed gates operation for the first time in 41 years, because inflow to Amagase dam reservoir was exceeded regulated amount to start prescribed flood control operations. By doing this, Amagase dam reduced the discharge volume of 500 m^3/s to the downstream against the maximum inflow of 1,360 m^3/s into Amagase dam reservoir with the discharge to 860 m^3/s.

After this, the Amagase dam was to undertake emergency flood disaster prevention operations. However, because the water level of the river downstream of the dam was high, the start of the operations was delayed, and water was retained as much as possible. By the operations, the flow was reduced for a maximum of 50 m^3/s compared to that of predetermined emergency flood disaster prevention operations.

As a result, the Amagase dam retained approximately 8,700,000 m^3 during the flood and the reservoir water level reached 78.18m that is approximately 30 cm beneath the s.w.l. of 78.50 m, designed highest level but was able to lower the water level of the Uji river and the point where the 3 rivers merge. (Fig. 7, Fig. 8)

The seta barrage promptly shifted to the gate operations with the opening midway, then operations to fully opened gates to reduce the water level of the lake Biwa with monitoring the river water level of downstream after operations to fully close all gates.

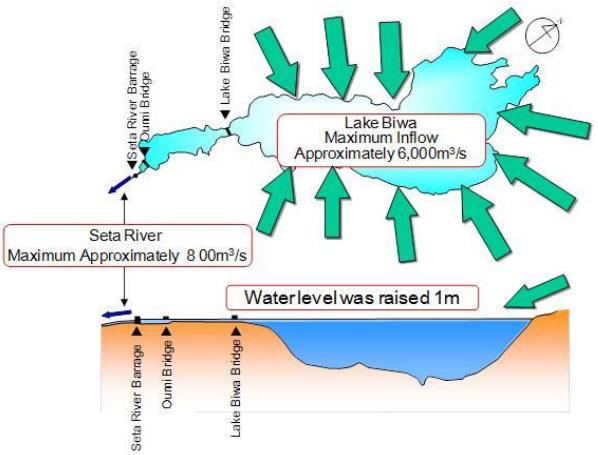

Fig. 6
Situation of Lake Biwa during flooding
État de la crue au niveau du lac Biwa

Fig. 7
Seta river barrage fully closed for the first time in 41 years
Première fermeture complète du déversoir de la Seta-Gawa en 41 ans

Fig. 8
Amagase dam retaining to its maximum
Remplissage total du barrage d'Amagase

7.2. HIYOSHI DAM RETAINING FLOOD WATER THAT EXCEEDED THE S.W.L

The maximum average rainfall for an hour over the Hiyoshi dam basin area was 34 mm, the accumulated rainfall from when it started raining was observed to be 345 mm. the designed maximum inflow of 1,510 m^3/s was exceeded at Hiyoshi dam and was approximately 1,690 m^3/s, the most since management began in 1998. For this reason, if prescribed flood control operations were continued, it was

predicted that the reservoir level would exceed the s.w.l. and so emergency flood disaster prevention operations had to be undertaken.

However, since Katsura river downstream was in a dangerous state, prescribed flood control operations were maintained and about 90% of the maximum inflow volume (approximately 1,540 m^3/s) was stored in the reservoir by special operations of delaying the start of ego as long as possible and flood waters was retained exceeding the s.w.l. of El. 201.0 m.

After this, confirming that the water level at Kameoka Hozu bridge point and Arashiyama point at the downstream of the dam had subsided, discharge was increased through emergency flood disaster prevention operations (Fig. 9, Fig. 10).

As a result, Hiyoshi dam retained approximately 44,600,000 m^3 of water in the dam reservoir until water level rose to El. 201.87 m exceeding the s.w.l., however, it is estimated that the water level of the Katsura river was lowered and enabled the lowering of the water level at the three rivers merging point.

Fig. 9
Hiyoshi dam utilized at full capacity
Utilisation maximale de la capacité de rétention du barrage d'Hiyoshi

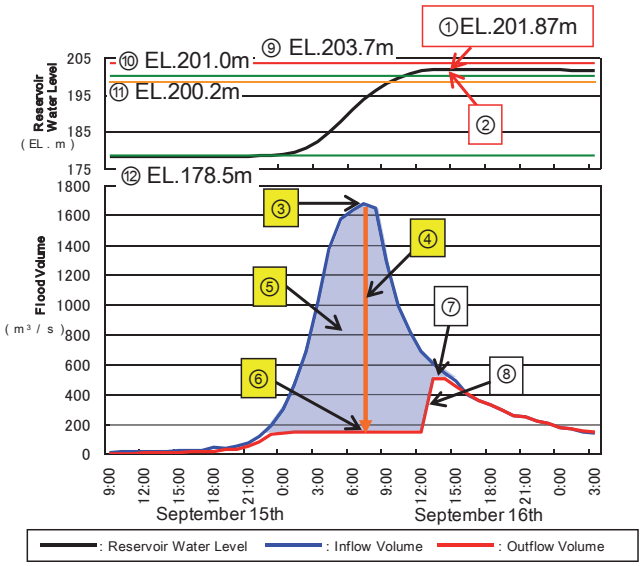

Fig. 10
Hiyoshi dam flood control diagram
Graphique de régulation de la crue du barrage d'Hiyoshi

1 highest water level
2 exceeding the highest water during flood approximately 2,430,000m³ retention
3 maximum inflow approximately 1,690m³/s
4 approximately 90% of inflow volume was stored in dam
5 amount stored in dam approximately 44,600,000m³
6 150m³/s during maximum inflow volume
7 maximum approximately 500m³/s
8 discharge was increased while observing downstream conditions
9 design water level
10 s.w.l.
11 water level to start emergency operation
12 water level in flood season

1 Plus haut niveau de l'eau
2 Dépassement du niveau le plus haut en crue avec une rétention d'environ 2 430 000 m³
3 Apport maximal environ 1 690 m³/s
4 Environ 90% des entrées ont été stockées dans le barrage
5 Quantité stockée dans le barrage environ 44 600 000 m³
6 150 m³/ s pendant le volume maximum
7 Maximum environ 500 m³/s
8 Décharge augmentée tout en respectant les conditions en aval
9 Niveau de projet
10 s.w.l.
11 Niveau d'eau de déclenchement des opérations d'urgence
12 Niveau d'eau en saison des crues

7.3. COORDINATED OPERATIONS OF KIZU RIVER UPSTREAM DAM GROUP

The Takayama dam and the Nunome dam of the Kizu river carried out operations to reduce the flood damage at downstream by increasing the residual volume for flood control more than prescribed flood control operations and the Murou dam, Shorenji dam, and Hinachi dam of the upstream of Takayama dam also coordinated and carried out the same operations for lowering the water level of the Nabari river downstream.

However, because downstream of Katsura river was overflowing at the embankment and the situation became dangerous, the 5 dams upstream of Kizu river operations were reconsidered to increase their retention volume.

It was decided the 5 dams could be operated to increase their retention volume because accumulated rainfall in Kuzu river basin was smaller than it of the Katsura river and the Uji river basin, 5 dams carried out coordinated operation for lowering the water level where the 3 rivers merged as much as possible with monitoring and checking the residual volume for flood control in dam reservoirs. (Fig. 11)

During this operation, the Murou dam, Shorenji dam and Hinachi dam carried out operation of reducing discharge volume to lower the water level of downstream for increasing residual volume for flood control in the Takayama dam reservoir. By this operation, the Takayama dam also carried out operation of reducing discharge volume.

As a result, the 3 Nabari river dams retained 14,900,000 m^3 in the reservoirs, the Takayama dam stored a maximum of approximately 70% (approximately 1,130 m^3/s) of the maximum inflow of 1,600 m^3/s of the flood, and retained 23,700,000 m^3 in the reservoir and the Nunome dam stored a maximum of approximately 70% (approximately 150 m^3/s) of the maximum inflow volume of 200 m^3/s, and retained 2,700,000 m^3 in the reservoir. Retaining volume of total of the 5 dams was 3.4 times of prescribed flood control operations, it led to lower the water level of downstream of the 5 dams and the point where the 3 rivers merge.

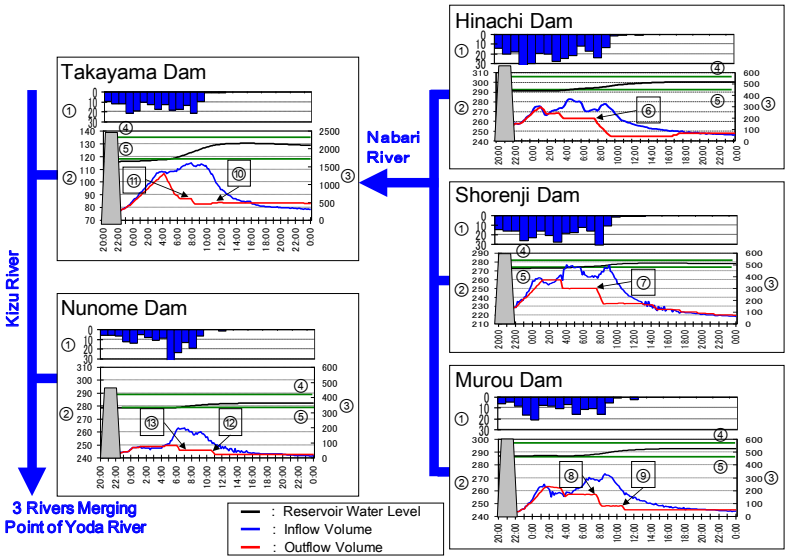

Fig. 11
Coordinated operations of Kizu river upstream dam group
Graphiques donnant l'augmentation du volume d'eau retenu par les 5 barrages de la rivière Kizu-Gawa

1	rainfall per hour (mm)	*1*	*Précipitations par heure (mm)*
2	reservoir water level (m)	*2*	*Niveau réservoir (m)*
3	flow volume (m^3/s)	*3*	*Débit (m^3/s)*
4	s.w.l	*4*	*s.w.l*
5	water level in flood season	*5*	*Niveau d'eau en saison des crues*
6	200 m^3/s → 20 m^3/s	*6*	*200 m^3/s → 20 m^3/s*
7	300 m^3/s → 100 m^3/s	*7*	*300 m^3/s → 100 m^3/s*
8	80 m^3/s → 50 m^3/s	*8*	*80 m^3/s → 50 m^3/s*
9	170 m^3/s → 80 m^3/s	*9*	*170 m^3/s → 80 m^3/s*
10	450 m^3/s → 480 m^3/s	*10*	*450 m^3/s → 480 m^3/s*
11	600 m^3/s → 450 m^3/s	*11*	*600 m^3/s → 450 m^3/s*
12	50 m^3/s → 20 m^3/s	*12*	*50 m^3/s → 20 m^3/s*
13	50 m^3/s (continue)	*13*	*50 m^3/s (suite)*

8 . DAM COORDINATED OPERATIONS CONTRIBUTING TO AVOID CATASTROPHIC DAMAGE

Near the confluent point of the Katsura river and the Kamo river, for approximately a maximum of 400m long and about a water depth of 10-20 cm, overflow was caused at the embankment, however through the diligent activities of flood fighting corps and the self defense force, sandbags were stacked and the worst case scenario of embankment collapse was prevented. (Fg. 12)

If there had been no dams on the Yodo river system, and the seta river barrage had been completely open, the depth of the water at the point of overflow downstream of the Katsura river would have been tens of centimeters higher than it actually was and the sandbag stacking activities would have been judged to be difficult and the possibility of the embankment collapse also would have been very high.

The flooding situation for if there was no Hiyoshi dam and the right embankment collapsed near the Kamo river merging point area was calculated in a flooding simulation.

The results estimated that approximately an area of 980ha and approximately 13,000 households would be flooded and approximately 1.2 trillion yen of damage would occur as shown in Fig. 13 and Fig. 14.

The conditions of the calculations were, the point of collapse was assumed to be a point at the right embankment overflowing for this flood and in the 400 m section overflowing from a point approximately 7 km, and approximately 100 m would overflow in the planned high water level.

Additionally, the assumed amount of damage was calculated based on the flood control economic research manual (proposed) and the data used in the calculations were from the national census 2005, business statistics 2006.

Fig. 12
Flood control activities of the self defense force
Activités de lutte contre les inondations par les forces d'autodéfense japonaises

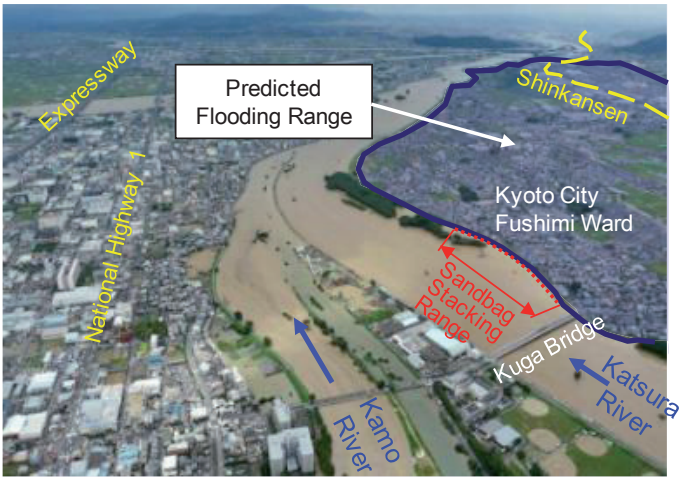

Fig. 13
Expected range of flood
Ampleur de la zone inondable

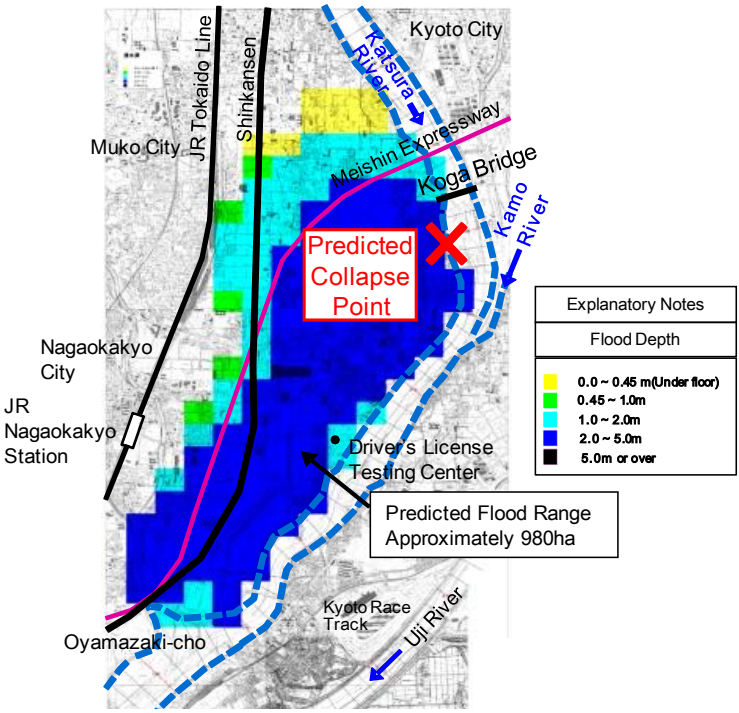

Fig. 14
Results of flood analysis
Résultats d'analyse de la zone inondable

9 . CONCLUSION

In recent years, damage from flooding caused by rains never experienced before has been occurring, and even more is expected from the operations of dams than previously.

However, in operations of the dams, the situation is that the accuracy of predicting rains is still not sufficient and the management of rivers and dams requires a high level of technical skills.

From the flood response experience until this time at the Yoda river system, operation process with close monitoring of flood situation for retaining flood water

more than prescribed flood control operations to lower the water level of the downstream were set for each dam and the coordinated operations of the 3 dams in Nabari river.

However, this time for the additional lowering of the water level at the confluent point of the 3 rivers merge, coordinated operations of all facilities for flood control (the 7 dams and the seta river barrage) were carried out with the goal of lowering the water level of the Yodo river for the first time.

In order to respond to these situations, large amounts of information must be organized and analyzed for the weather, rivers, and dams with a limited number of people and time, and from the newest predictions for rain, the best possible operations for the dams must be considered and such high technical skills with close cooperation adjustments between concerning organizations are required.

The response to the flooding this time through the high level of technical skills demonstrated by the of all the organizations, implemented an cooperative operation of the 7 dams without precedence and the catastrophe of the collapse of the embankment at downstream of the Katsura river was prevented by the flood response for the flooding that accompanied the typhoon that affected the overall Yodo river system, and this is thought to have demonstrated the very significant effect of dams and the effect of integrated management.

SUMMARY

On september 16, 2013, the heavy rains of typhoon 18 caused an overflow in a section of at the most 400 m on the right embankment of Katsura river downstream area close to confluence point of the 3 rivers, the Katsura river, Uji river, and the Kizu river in Yodo river system.

At this time, the Hiyoshi dam upstream was utilizing its dam capacity to the fullest and was storing floodwater to implement flood control (disaster prevention operations) and also even at the Uji river, the seta river barrage was completely closed and the Amagase dam was undertaking flood control and additionally, the dam group upstream of kizu river (Takayama dam, Murou dam, Shorenji dam, Nunome dam and Hinachi dam) were also coordinating to lower the water level at the confluence point of the 3 rivers.

Because it was possible to utilize all the facilities in Yodo river system to full capacity for flood control, the overflow downstream of the Katsura river was held to a level where stacked sandbags were able to avoid the worst case of collapse of embankment.

The flood response this time, through the close coordination adjustments and the high level of technical skills demonstrated by the dam operations and maintenance offices, the dam integrated management offices, the Kinki regional development bureau, and the Kansai regional bureau of japan water agency (Jwa), the collaboration of 7 dams in Yodo river system were able to undertake the unprecedented operation and demonstrates the very significant effect of the dams and the operation of the dams can be thought to have prevented a mayor disaster.

RÉSUMÉ

Le 16 septembre 2013, les pluies torrentielles provoquées par le typhon Man-Yi au japon ont entraîné un débordement de la Katsura-Gawa au-dessus de sa digue droite sur une longueur maximale de 400 m dans sa partie avale, près de son point de confluence avec l'uji-Gawa et la Kizu-Gawa, les trois rivières faisant partie du réseau hydrographique de la Yodo-Gawa.

Au même moment, le barrage d'Hiyoshi en amont de la Katsura-Gawa a procédé au remplissage maximal de son réservoir pour compenser la crue (manœuvre d'urgence), alors qu'au niveau de l'Uji-Gawa, le déversoir de la Setagawa était totalement fermé et que le barrage d'Amagase procédait également à une manœuvre de régulation de la crue. De surcroit, les barrages en amont de la Kizu-Gawa (barrages de Takayama, de Murou, de Shorenji, de Nunomé et d'Hinachi) s'efforçaient conjointement de réduire le niveau de la crue au point de confluence des trois rivières.

Grâce à une gestion de la crue reposant sur une utilisation optimum de l'ensemble des installations du réseau hydrographique de la Yodo-Gawa, les inondations ont pu être limitées en aval de la Katsura-Gawa de façon à pouvoir être contenues par des sacs de sable et on a pu ainsi éviter une situation catastrophique telle qu'une rupture de digue.

On peut considérer que la gestion de cette crue par les services de chaque barrage, le service général de gestion des barrages, le bureau régional de développement du Kinki, et le bureau du Kansai de l'agence japonaise de l'eau, ayant fait preuve d'une communication et d'une coopération étroites ainsi que d'une extrême compétence technique pour mettre en œuvre de manière solidaire des mesures sans précédent sur les 7 barrages du réseau hydrographique, a démontré l'efficacité tout à fait remarquable des barrages et a permis d'éviter une catastrophe majeure.