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Survey Report:

Effective Flood Control Through Integrated and Collaborative Dam Operation at Three Dams in the Upper Nabari River

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Heavy rain with Typhoon 18 threatened the Nabari River Basin, Kansai region, with inundation early on the morning of October 8, 2009. The Nabari River is a tributary of the Yodo river basin that contains Osaka and Kyoto and runs through Nabari City, which is a residential zone a commutable distance from Osaka city. In the upper reaches of the Nabari, there are three multipurpose dams – Shorenji Dam, Hinachi Dam, and Murou Dam – that are operated by the Kizugawa Integrated Dam Control and Management Office (KIDCMO), a branch office of the Japan Water Agency (JWA). Since it rained heavily downstream from the three dams, regular operation of the dams complying with given flood control regulations appeared unable to save Nabari City from inundation. The JWA and Ministry of Land, Infrastructure, Transport and Tourism (MLIT) therefore conducted collaborative operation of the three dams to avoid inundating the city. In this case, flood control operation of the three dams commenced at an early stage before inflow reached defined flood discharge in consideration of the water level of the Nabari River, rainfall conditions, and the capacity of reservoirs. During operation, discharge from dams was changed in a timely manner and appropriately through collaborative operation of the three dams in order to maximize the effectiveness of all flood control capacities of reservoirs based on the latest rainfall forecast technology and runoff analysis. The use of improved rainfall forecast technology and runoff analysis models enabled effective application of flexible operation protocols. It is estimated that this operation has resulted in a 1.5 m decrease in the water level at the Nabari design control point and saved approximately 1,200 households from inundation. Considering recent climate change, it is possible to have extreme rainfall more often. The proof of the adaptability of this flexible operation is quite meaningful not only for flood damage mitigation in the downstream but also for future prospects of flood control by dams.

Keywords: effective flood control, dam operation. rainfall forecast, runoff analysis, climate change

1. Introduction

The River Bureau of Ministry of Land, Infrastructure, Transport and Tourism, Japan (MLIT) is in charge of flood management and mitigation in Japan. Specifically, 109 large river systems are directly managed by the Ministry. The Japan Water Agency (JWA) is constructing dams, estuary barrages, lake and marsh development facilities, and canals in seven major and legally designated river basins out of the above 109 river systems. It is also operating, managing, and reconstructing completed facilities. The JWA mandate is based on the Water Resources Development Promotion Law and Japan Water Agency Law. The Yodo river is one of seven basins and covers Osaka and Kyoto cities.

Generally, flood control management rules are designed beforehand for each dam, considering rainfall patterns. Operation based on rules is effective for each rainfall pattern generally, but it is not the best operation in particular cases for reducing flood damage and inundation.

October 13, 2009, Typhoon 18, with its heavy rain, came closest to the Kansai and Tokai areas. Its rain affected all of Japan and caused casualties and damage. As of 15:00 on October 8, the Fire and Disaster Management Agency reported five people killed, 127 people injured, and 4328 houses damaged.

Early morning on October 8, heavy rain threatened Nabari City in Mie Prefecture causing significant inundation. Nabari City is located in the commuting area to Osaka and has a population of 80,000. The Nabari River, which is a tributary of the Yodo river, runs through the city center. Since it rained heavily, regular flood control operation based on management rules by three dams – the Shorenji Dam, Hinachi Dam, and Murou Dam on the upper Nabari River and managed by the JWA branch Kizugawa Integrated Dam Control and Management Office (KIDCMO) may not prevent inundation.

KIDCMO and the Yodogawa Integrated Dams Control Office (YIDCO), a branch office of MLIT, therefore conducted collaborative operation of the three dams to avoid inundation in the city area.

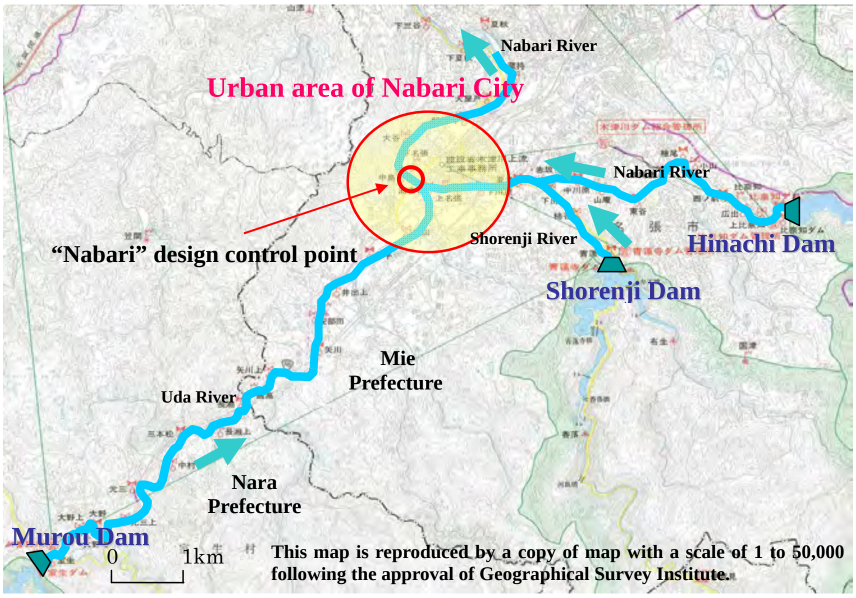

Fig. 1. Locations of three dams on the upper Nabari River.

Table 1. Specifications of three dams on the Nabari River upstream.

Shorenji Dam	Hinachi Dam	Murou Dam
【Dam Data】 Type: Concrete arch dam Dam height: 82.0 m Dam crest length: 275.0 m Catchment area: 100 km^2 Effective capacity: 23,800,000 m^3 Flood control capacity: 8,400,000 m^3 Start of management: July, 1970	【Dam Data】 Type: Gravity concrete dam Dam height: 70.5 m Dam crest length: 355.0 m Catchment area: 75.5 km^2 Effective capacity: 18,400,000 m^3 Flood control capacity: 9,000,000 m^3 Start of management: April, 1999	【Dam Data】 Type: Gravity control dam Dam height: 63.5 m Dam crest length: 175.0 m Catchment area: 136 km^2 Effective capacity: 14,300,000 m^3 Flood control capacity: 7,750,000 m^3 Start of management: April, 1974
【Purposes of dam】 1. Flood control 2. Maintenance of normal function of flow 3. Water supply 4. Agricultural water 5. Power generation	【Purposes of dam】 1. Flood control 2. Maintenance of normal function of flow 3. Water supply 4. Power generation	【Purposes of dam】 1. Flood control 2. Maintenance of normal function of flow 3. Water supply
		

The integrated flood control operation of the three dams started before the volume of runoff reached flood discharge taking the water level in the Nabari River, rainfall intensity, and the capacity of the three dams into considerations. During flood control operation, outflow discharge from dams was under timely and appropriate control by operations to make the most of storage capacities and collaborative operations of the three dams employing the latest rainfall forecast technology and runoff analysis.

The latest rainfall forecast technology and runoff analysis models enabled effective flood control of the three dams. The effect of operations was estimated to lower the water level in the Nabari River by 1.5 m and to prevent inundation of approximately 1,200 households comparing to a case without dams.

Considering recent climate change, heavy rains are more likely to occur than before. The proof of the adaptability of flood control operation in reducing damage downstream means not only the prevention of flood damage downstream but also future prospects for flood control for dams.

This report shows the state of implementation and effects regarding flood control operation (integrated three-dam operation).

The locations of the three dams on the Nabari River upstream are shown in **Fig. 1** and principal features in **Table 1**.

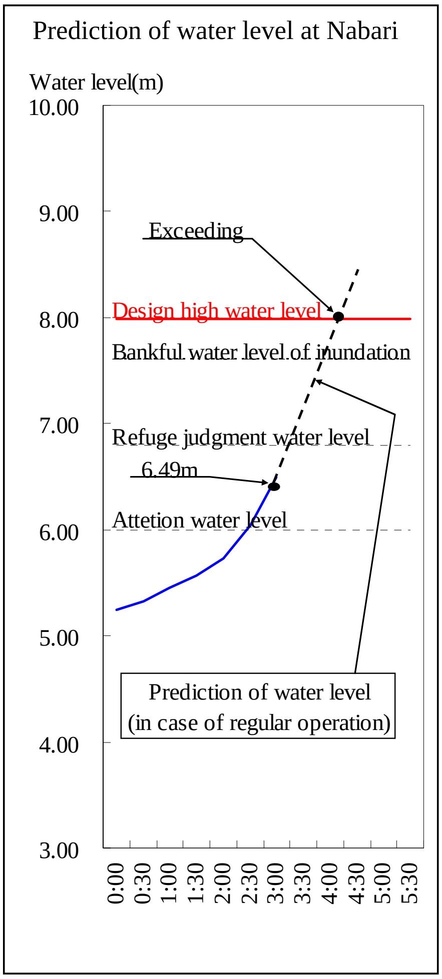

Fig. 2. Prediction and judgment at 03:00.

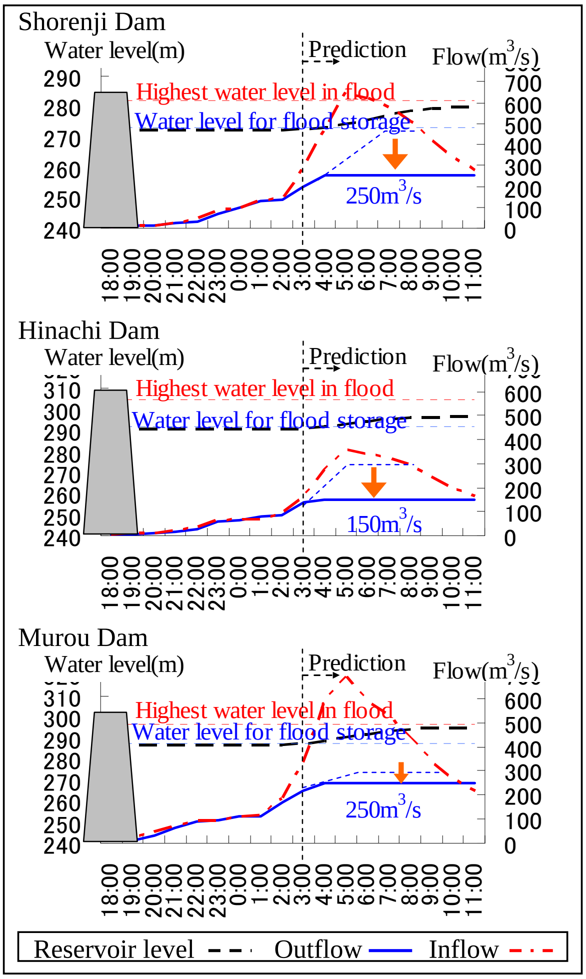

Fig. 3. A prediction and the dam operation at 03:00.

2. Summary of Flood Control by JWA

Incorporated administrative agencies are established and given objectives and missions by the national government to carry out "administrative tasks and projects where implementation should ensure public benefits such as stable public life and social and economic activities." The JWA is one of this type of agency mandated to construct and manage facilities for water resource development based on Japan Water Agency Law.

For dams, the JWA carries out flood control following the management rules of each dam based on Japan Water Agency Law. Each management rule has two types of operation: one is regular operation that regulates outflow discharge from dams to cope with an expected large flood in dam basins and the other is special operation that carries out the most suitable flood control considering the situation of rain and downstream rivers.

For special operation, the management rule does not have any rule regarding the outflow discharge from a dam, but when the JWA carries out special operation, an instruction from the Integrated Dam Control and Management Office (MLIT) is necessary. This cooperative flood control operation of the three dams in this report was carried out following instructions from YIDCO after KIDCMO and YIDCO thoroughly examined and adjusted such as rainfall forecast, runoff analysis, and operation plan.

3. Flood Control Operation

3.1. Day Before Typhoon 18 hit Nabari

From the afternoon of October 7, in order to prepare for the approach of Typhoon 18, KIDCMO inspected discharge facilities and warning facilities of dams and started forecasting rainfall and the amount of inflow of each dam based on the typhoon course forecast.

With the increase in the amount of inflow into dams, KIDCMO started contacting related institutions and patrolling the river downstream sequentially from 18:00 at Murou Dam and from 20:30 at Shorenji Dam and Hinachi Dam. One hour later, each dam started discharge from spillways facilities.

While each dam started discharge from spillways facilities, Typhoon 18 was heading more easterly, which meant it would not rain heavily in the Nabari River basin based on the typhoon course forecast.

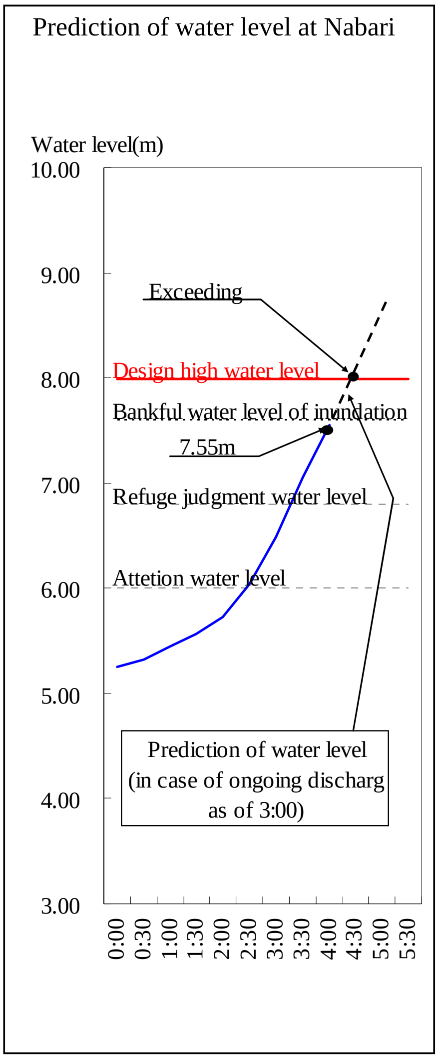

Fig. 4. Prediction and judgment at 04:00.

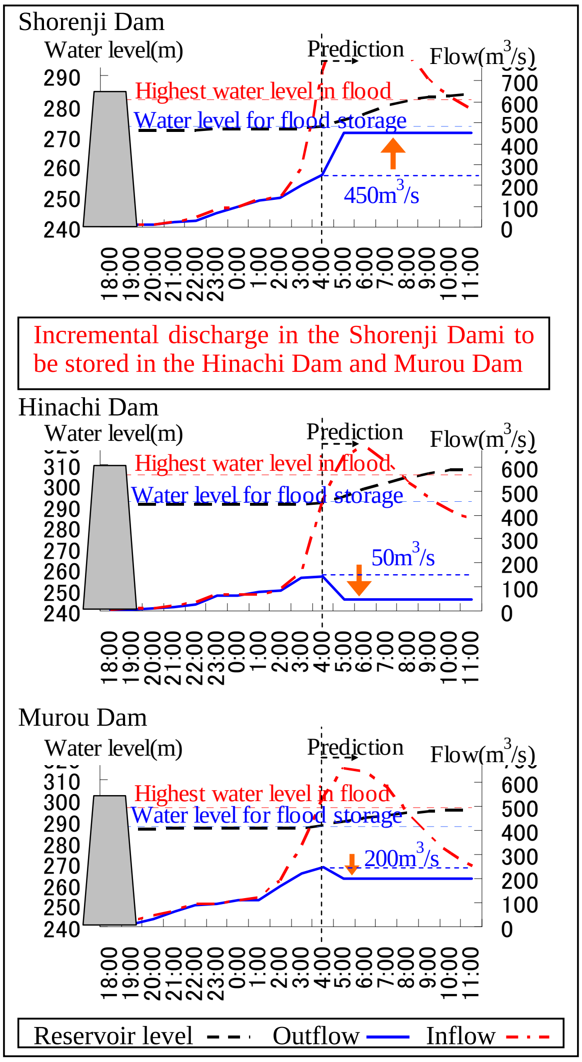

Fig. 5. Prediction and dam operation at 04:00.

3.2. Rise of Nabari River Water Level

The rain forecast changed significantly around 02:00 on October 8. The forecast showed that the water level in the Nabari River downstream from the dams, would exceed "Attention water level," and continue rising (**Fig. 2**).

For this reason, MLIT instructed KIDCMO to start operation to prevent inundation in the city area by controlling the water level in the Nabari River. In order not to raise the water level in the Nabari River, three dams on the Nabari River upstream were required to reduce outflow discharge downstream from the dams. In this case, outflow discharge from dams was carefully arranged because storage capacity for flood control would be filled if heavy rain continued.

Although the speed of the typhoon was accelerated, it was still forecast that heavy rain would continue, so it was necessary to adjust outflow discharge based on observed precipitation and changing forecasts.

At 03:15, KIDCMO started special operation to keep outflow discharge (Shorenji Dam 250 m^3/s, Murou Dam 250 m^3/s, Hinachi Dam 150 m^3/s) less than outflow discharge during regular operation that means increase outflow discharge of Shorenji Dam 450 m^3/s, Murou Dam 300 m^3/s, Hinachi Dam 300 m^3/s in consultation with Nabari City (**Fig. 3**).

Subsequent operations were implemented by KIDCMO under the instructions from MLIT after close consultation.

3.3. Integrated and Collaborative Dam Operation at Three Dams on Nabari River Upstream

At 03:40, Shorenji Dam's storage capacity for flood control might possibly be filled if Shorenji Dam continued to store water without increasing outflow discharge in this heavy rain. On the other hand, the water level in the Nabari River continued rising, and it was forecast that if this continued, the water level in the Nabari River would reach the "Bankful water level" of inundation and bring inundation damage to the city area. For this reason, it was difficult to increase outflow discharge from dams although inflow the dams largely increased (**Fig. 4**).

At 04:00, the water level in the Nabari River was not expected to rise too quickly due to the gradual increase

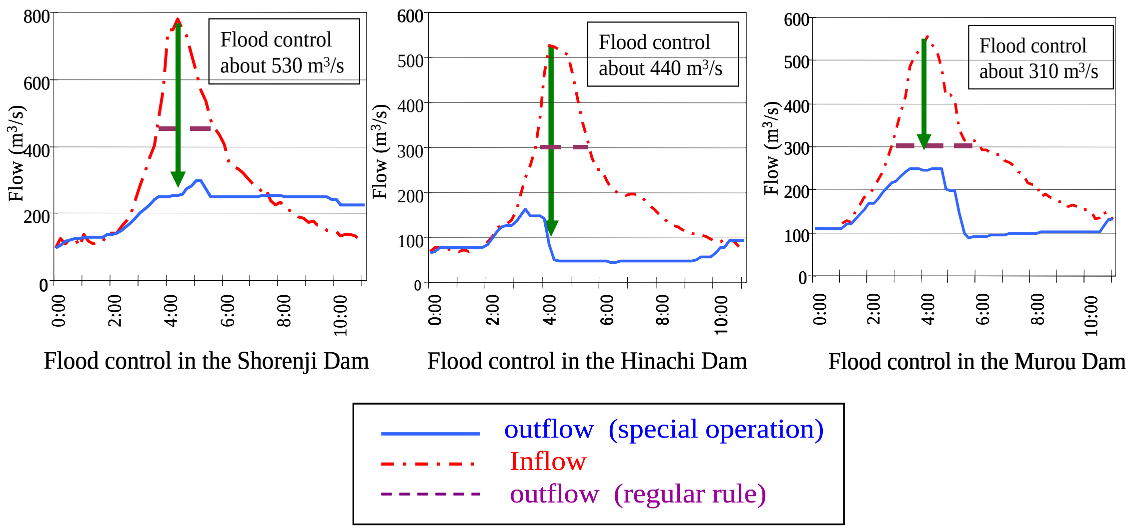

Fig. 6. Flood control operation of three dams.

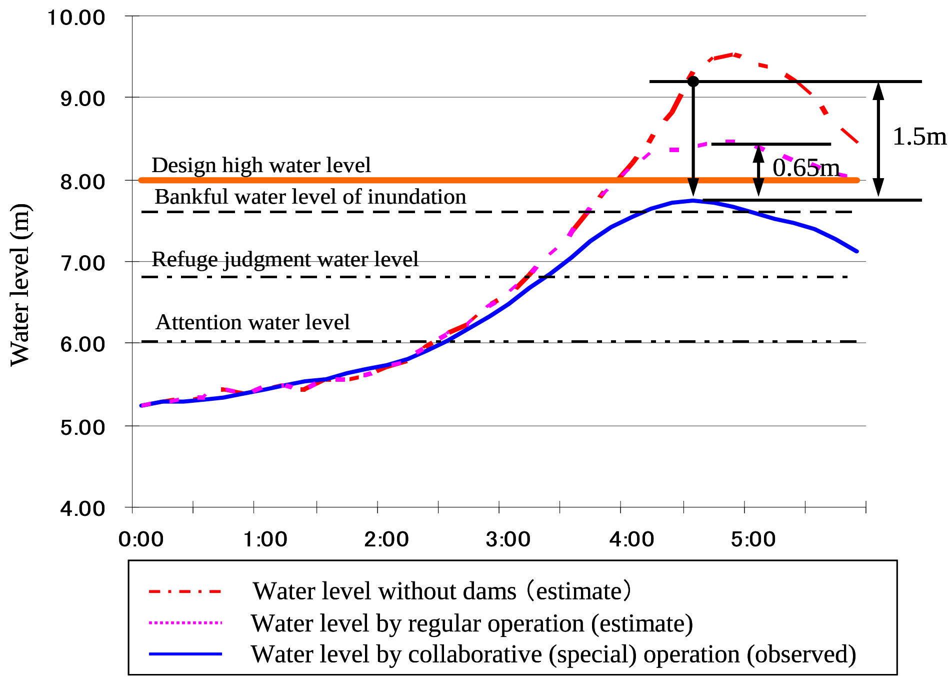

Fig. 7. Water level at Nabari design control point.

in outflow discharge from Shorenji from current 250 m^3/s to 450 m^3/s. After considering the rainfall forecast, water level prediction in the Nabari River, flood control capacity and inflow prediction of the three dams, it was decided that outflow discharge from Hinachi Dam would be reduced by 100 m^3/s to 50 m^3/s, instead of gradually increasing the amount of discharge from Shorenji (**Fig. 5**).

3.4. Decline of Water Level in Nabari River

At 04:40, since rainfall in the Murou Dam basin was less than forecast, it was decided to make the water level in the Nabari River lower by decreasing outflow discharge from Murou Dam to 200 m^3/s by quick examination based on observed data and the amount of inflow because there is no time to examine considering rainfall forecast.

As a result of repeated examination and operation forecasting the water level in the Nabari River and so on, outflow discharge was finally decreased to 250 m^3/s from Shorenji Dam, 100 m^3/s from Murou Dam, and 50 m^3/s from Hinachi Dam. This operation made the water level at the Nabari design control point lower than "Bankful water level" at 05:00 and lower than the refugee judgment water level at 06:20.

Afterwards, flood control operation was continued until the water level in the Nabari River became lower than the warning water level and flood control operation was shifted to integrated control operation to decrease the water level in the three dams in order not to raise the water level in the Nabari River (**Fig. 6**).

Table 2. Comparison with Isewan Typhoon in 1959.

<table>
<tr><th colspan="3">Details</th><th>Typhoon No.18, 2009</th><th>Isewan Typhoon, 1959</th></tr>
<tr><td rowspan="6">Scale</td><td rowspan="3"></td><td>Period</td><td>Sep 29 (21:00) to Oct 9 (15:00)</td><td>Sep 21 (21:00) to 27 (21:00)</td></tr>
<tr><td>Lowest pressure</td><td>910 hPa</td><td>895 hPa</td></tr>
<tr><td>Maximum wind</td><td>55 m/s</td><td>75 m/s</td></tr>
<tr><td rowspan="3">At land-fall</td><td>Central pressure</td><td>955 to 960 hPa</td><td>925 hPa</td></tr>
<tr><td>Maximum wind</td><td>40 m/s</td><td>50 m/s</td></tr>
<tr><td>Radius storm wind</td><td>220 km (SW), 170 km (NW)</td><td>250 km</td></tr>
<tr><td colspan="2" rowspan="3">Rainfall in the upper Nabari</td><td>1-hour rainfall</td><td>65 mm</td><td>58 mm</td></tr>
<tr><td>3-hour rainfall</td><td>145 mm</td><td>137 mm</td></tr>
<tr><td>Cumulative rainfall</td><td>315 mm</td><td>393 mm</td></tr>
<tr><td rowspan="10">Nabari city</td><td rowspan="2">Rainfall</td><td>1-hour rainfall</td><td>41 mm</td><td>43 mm</td></tr>
<tr><td>Cumulative rainfall</td><td>239 mm</td><td>342 mm</td></tr>
<tr><td rowspan="8">Damage</td><td>Death</td><td>-</td><td>11</td></tr>
<tr><td>Missing</td><td>-</td><td>1</td></tr>
<tr><td>Swept houses</td><td rowspan="2">1</td><td>102</td></tr>
<tr><td>Demolished houses</td><td>180</td></tr>
<tr><td>Partially destroyed</td><td>-</td><td>525</td></tr>
<tr><td>Inundated above floor level</td><td>1</td><td>1434</td></tr>
<tr><td>Inundated blow floor level</td><td>27</td><td>848</td></tr>
</table>

Reference: Meteorological Agency, History of the Kizu River (1980), Interviews by Nabari City Material about flood in the Yodo River and the Yamato River (liaison council of flood forcasting, August 1960)

4. Flood Control Effect

Flood control regarding special operation of three dams on the Nabari River upstream made the water level approximately 1.5 m lower than the water level without the three dams, and for approximately 0.6 m lower than regular operation. With this special operation, it is assumed that approximately 1,200 households in the Nabari City area were saved from inundation damage (**Fig. 7**).

There is a comparison in damage between Typhoon 18 and the Isewan typhoon that hit Nabari City 50 years ago. Despite rainfall in three hours this time being equal to that of the Isewan Typhoon, the damage Nabari City suffered was completely different (**Table 2**).

5. Conclusion

The use of improved rainfall forecast technology and runoff analysis model enabled the effective application of this flexible operation protocols. It is estimated that this operation has resulted in 1.5 m decrease of the water level at Nabari design control point, and prevented approximately 1200 households from inundation.

KIDCMO received a letter of appreciation from the mayor of Nabari City on October 20, 2009, extolling the "great contribution for reduction of flood damage on the Nabari River by quick and appropriate flood control operation." In fact, during special operation, outflow discharge was arranged ten times in only 2 hours by collecting and considering data observed every ten minutes.

In addition, this flood control operation was highly evaluated by the Japan Society of Civil Engineers (JSCE) because of its crisis controllability and performance. KIDCMO and YIDCO won the Outstanding Civil Engineering Achievement Award of 2009 from JSCE on May 28, 2010. It was the first splendid achievement that dam operation won with the JSCE Award.

Considering the recent climate change, it is possible to have extreme rainfall more often. The proof of adaptability of this flexible operation is quite meaningful not only for flood damage mitigation in the downstream, but also for future prospects of flood control by dams.

This special operation was able to be carried out by understanding the capacity of flow in the river downstream from dams and using the outflow forecast system based on observed rainfall and forecast rainfall. KIDCMO will improve the outflow prediction system to target a higher stage of flood control operation in the future.

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