# A STUDY ON THE FLOOD CONTROL MEASURES BY EXISTING DAMS IN THE KASE RIVER BASIN IN CONSIDERATION OF GLOBAL WARMING

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## ABSTRACT

Here we discuss flood control adaptation methods in the Kase River basin using the existing Hokuzan Dam and Kasegawa Dam. Currently, the Kasegawa Dam is a multipurpose structure with the roles of flood control and water utilization, while the Hokuzan Dam is used only for water utilization. We investigated using the water utilization capacity of the two dams for flood control by using a prior discharge regime. Future climate conditions in the Kase River basin were set using the Database for Policy-Decision Making for Future Climate Change (d4PDF). The d4PDF is a large ensemble database of simulation results created using global atmospheric models of future climate conditions under scenarios where the global average temperature will have increased by 2 °C and 4 °C since the Industrial Revolution. Future heavy rain events in the Kase River basin on the basis of d4PDF were extracted and used for a flood flow simulation that included the effects of the dams on the flood flow. Our computational results demonstrated that the storage capacity of the two dams is large enough to control flow discharge due to future heavy rains. Therefore, if prior discharges from the existing dams are fully utilized, flood control is possible in the Kase River basin even under future extreme precipitation.

*Keywords*: Flood Control, dam, d4PDF, Kase River

## 1. INTRODUCTION

Recent increases in the frequency of weather-related natural disasters, such as heavy rainfalls, landslides, and typhoons, have been observed in Japan and are considered to be due to global climate change. It is thought that the various effects of global climate change will become more apparent in the future. The occurrence, for example, of catastrophic disasters due to large-scale floods is a major concern, as mentioned by the Science Council of Japan (2008). Much of the disaster prevention infrastructure in Japan was constructed during the country's periods of high economic growth and most of the infrastructure is therefore aging. Although dealing with disasters has recently become a pressing issue following the Great East Japan Earthquake in 2011, it is still unlikely that new construction or major overhauls of large-scale disaster prevention facilities will continue in the long-term. This lack of action is due to worldwide economic conditions and the aging population in Japan. Therefore, intelligent disaster prevention measures, such as the effective use of existing facilities, will be increasingly needed in the future.

It is necessary to cope with the increasing risk of natural disasters while at the same time conserving the natural environment. Large-scale public works projects, such as new dam constructions, have become extremely difficult to implement in Japan due to concerns about the environmental impact of such projects and due to a significant reduction in funding for public works except for those urgently required for disaster recovery and reconstruction following the 2011 earthquake. Therefore, small-scale infrastructure projects will play a significant role in the future.

In view of the above, Oshikawa et al. (2013) proposed a new flood control concept called the "Cascade method", which allows dams constructed in series in a river basin to overflow their emergency spillways. The

conventional concept of flood control using multiple dams, even when constructed in series, is to not use emergency spillways. Each dam discharges at only a design high water discharge and this is equivalent to a discharge that will lead to a design magnitude flood that causes no harm. Oshikawa et al. (2013) compared the flood control effects of multiple dams constructed in series when conventional flood control was used with those when the new Cascade concept was implemented. Using numerical simulations, they demonstrated that the ability to control flooding in the downstream area, which is generally more important than controlling flooding in the upstream area, is significantly enhanced by using emergency spillways at upstream dams located in mountainous areas.

Studies on the Cascade method have previously been conducted through numerical simulations and laboratory experiments using an idealized straight channel with a uniform slope (Oshikawa et al., 2013; Oshikawa et al., 2015; Oshikawa and Komatsu, 2015). Cascade-type flood control offers a significant change to the conventional concept of flood control because it involves the overflow of each dam's emergency spillway. The effects of these changes to flood control on actual rivers must therefore be evaluated if Cascade-type flood control is to be put to practical use.

In this study, future flood control measures in the Kase River basin, which is located in the northern part of Kyushu Island in western Japan (see Figure 1), were modeled using data from the Database for Policy-Decision Making for Future Climate Change (d4PDF), which is a database of simulation results created using global atmospheric models of future climate conditions under scenarios where the global average temperature will have increased by 2 °C and 4 °C since the Industrial Revolution (Mizuta et al., 2017). In particular, we investigated adaptation measures for the existing Hokuzan and Kasegawa Dams, which are constructed in series in the Kase River basin, in ways that effectively uses the existing infrastructure facilities. The storage capacity of the Hokuzan Dam, which is used for water utilization, was also used for flood control in the model, with the assumption that a prior discharge can take place. Thus, the Cascade method allowing overflow of the emergency spillway at the upstream Hokuzan Dam was applied.

In addition, flood control effects were also investigated in cases where the Hokuzan Dam would have an opening in its wall that acts as a spillway for flood control. Thus, in the investigation, the Hokuzan Dam was modeled as a multipurpose dam, serving as both a gateless, freely flowing type through the opening used for flood control and a storage dam used for water utilization because it is considered difficult for the Hokuzan Dam to operate a slide gate to reduce peak flow discharge.

## 2. METHODOLOGY

### 2.1 Outlines of the Kase River basin and the simulation

One dimensional unsteady flow simulation taking flood control effects of the dams into consideration was performed for the upstream region in the Kase River basin shown in Figure 1. The hydrodynamic simulation software MIKE 11 (DHI, 2009), whose basic equations are the continuity equation and the momentum equation in the river flow direction, was used for this study. The Manning roughness coefficient was 0.032 $m^{-1/3}$ s.

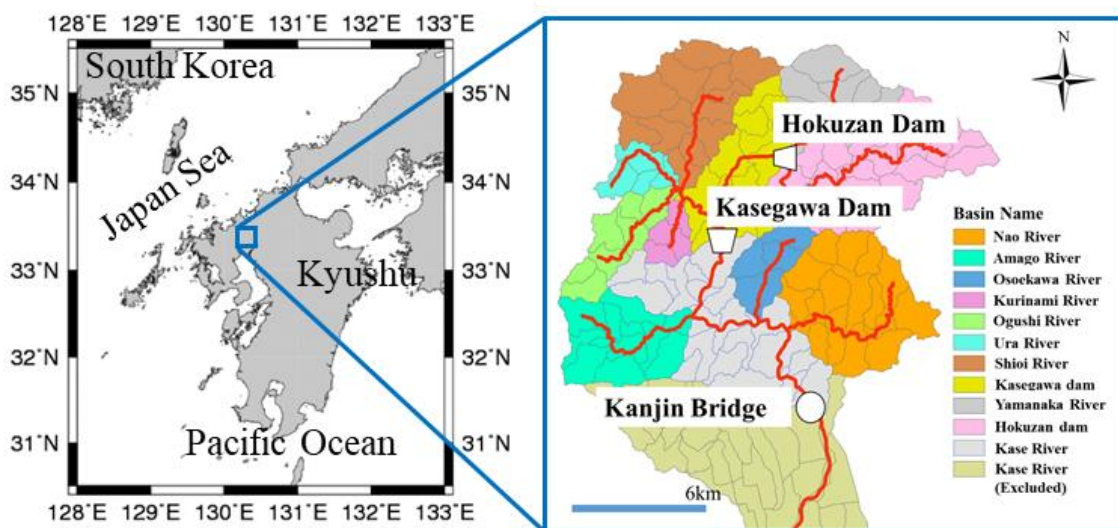

Figure 1. Area of the Kase River basin used for the computation

The total area of the Kase River basin is 368 $km^2$, and the computational area included the minor basins of its main tributaries: Yamanaka River (20.1 $km^2$), Shioi River (27.9$km^2$), Ura River (6.0 $km^2$), Ogushi River (11.7 $km^2$), Kurinami River (4.4 $km^2$), Amago River (19.9 $km^2$), Osoekawa River (9.1 $km^2$), and Nao River (31.6 $km^2$), where the values in parentheses are each minor basin's area. As shown in Figure 1, two dams have

been built in the computational area: the Kasegawa Dam (height, 99 m; effective storage capacity, 68 million $m^3$; flood control capacity, 17.5 million $m^3$); and the Hokuzan Dam, used only for water utilization (height, 59.3 m; effective storage capacity, 22 million $m^3$).

## 2.2 Verification of the accuracy of the calculation models and conditions

The accuracy of our series of hydraulic models and calculation methods was verified for the current flood control plan in the Kase River basin, which has a design rainfall of 615 mm over a duration of two days. The design rainfall has a return period of 100 years and was determined using a hyetograph from a flood disaster in June 1953 taken by Ministry of Land, Infrastructure, Transport and Tourism (MLIT, 2006 and MLIT report). A hyetograph with the design rainfall was spatially uniformly applied to the Kase River basin, and the discharge at the Kanjin Bridge located at the upstream end of the Saga lowland was calculated by a runoff analysis using a storage routing model (SRM) provided by iRIC. In addition, the hydrographs at an upstream point of each of the main tributaries shown in Figure 1 were also calculated using an SRM, which became the upstream boundary conditions for the one-dimensional unsteady flow simulation performed using MIKE 11.

Figure 2 shows the hyetograph and three hydrographs at the Kanjin Bridge calculated using data from MLIT, the runoff analysis using iRIC, and the one-dimensional unsteady flow simulation. The hydrograph calculated using the runoff analysis (broken line) agrees with the hydrograph based on MLIT data (dotted line) at their respective peaks. It is of particular interest that, as calculated by the runoff analysis, the maximum discharge, which is important in a flood control plan, coincides with the maximum discharge based on the MLIT data. In addition, the hydrograph generated in the one-dimensional unsteady flow simulation (solid line) is almost the same as the hydrograph calculated using the runoff analysis. Therefore, the series of calculations in this study, including the runoff analysis, was expected to provide appropriate results.
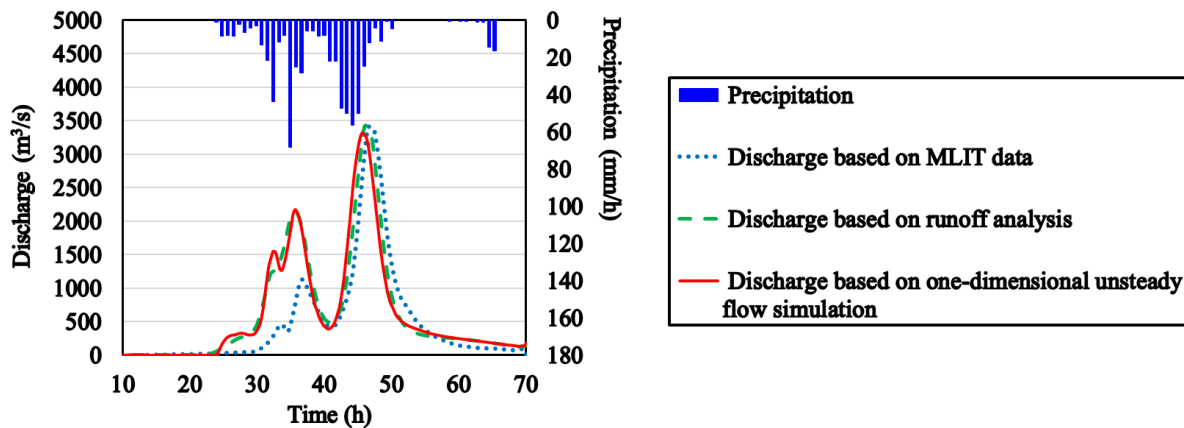


Figure 2. Design rainfall and design flood hydrograph at the downstream evaluation point at the Kanjin Bridge

## 2.3 Extraction of future heavy rainfall events from d4PDF

Heavy rainfall events were extracted from the d4PDF in order to consider flood control measures in view of climate change. Because the current flood control plan in the Kase River is based on rainfall over a period of two days (MLIT report), 48-h precipitation in the Kase River basin was arranged in descending order of magnitude from future rainfall projections for 3240 years in the d4PDF under the scenario where the global average temperature will have increased by 2 °C since the Industrial Revolution. Figure 3 shows the time series of the top five 48-h rainfall precipitation events.
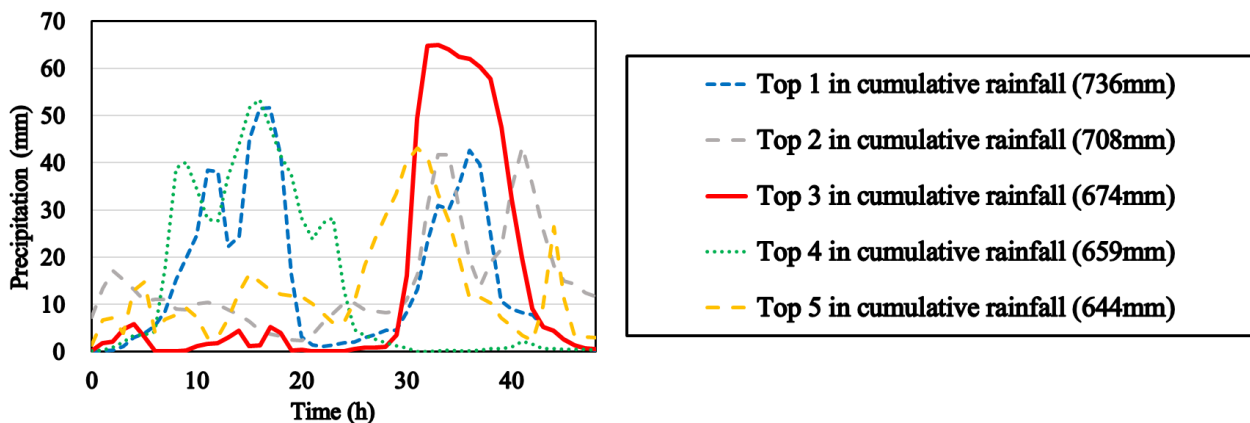


Figure 3. Future heavy rainfall events in the Kase River basin

In this study, the third heaviest rainfall event of 674 mm in the Kase River basin was used for developing future flood control measures because the peak discharge is a maximum during this event at the Kanjin Bridge, which is a downstream reference point for the MLIT data. The runoff analyses using the SRM demonstrated that the maximum discharge during the event at the Kanjin Bridge is 4696 m³/s, which is 38% greater than the flow rate of 3400 m³/s for the case where the design rainfall is 615 mm (MLIT report). In contrast, the first (736 mm) and the second (708 mm) heaviest rainfall events do not show such a large peak discharge at the reference point, with maximum discharges of 2681 m³/s and 2240 m³/s, respectively. This study uses the third heaviest rainfall event, and the results will be used to develop countermeasures for a flood exceeding the design level in the future.

2.4  Calculation of upstream inflow discharges in the future heavy rainfall event as boundary conditions

To obtain upstream boundary conditions for inflow discharges, hydrographs at the Kanjin Bridge downstream were calculated under many upstream conditions with a one-dimensional unsteady flow simulation performed using MIKE 11. The hydrographs at each upstream point including the tributaries shown in Figure 1 were determined such that the hydrograph at the Kanjin Bridge agrees with the hydrograph with the peak discharge of 4696 m³/s during the third heaviest rainfall event. Figure 4 shows the hyetograph during this event and the hydrographs at the Kanjin Bridge calculated using runoff analysis with the SRM and flow simulation. The hydrograph with the peak discharge of 4707 m³/s according to the flow simulation coincides well with the hydrograph with a peak discharge of 4696 m³/s according to the runoff analysis.



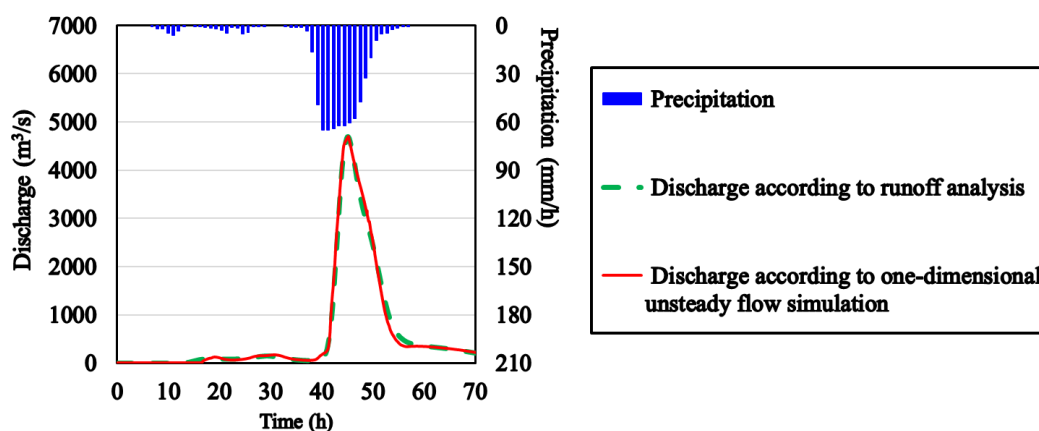Figure 4. Time series of future heavy rainfall and corresponding discharges at the Kanjin Bridge

## 3.    RESULTS AND DISCUSSION

The effects of flood control adaptation measures in the Kase River on dams constructed in series were verified by using the one-dimensional unsteady flow simulation. This study demonstrates what will happen in certain cases if the Basic River Development Policy in the Kase River is fully implemented in the future and the river's flood control is strengthened (MLIT, 2006). The Basic River Development Policy is a long-term flood control plan in Japan focusing on roughly the next 100 years.

The design high water discharge of the Kasegawa Dam $Q_{a2}$ is set as 770 m³/s, which is equivalent to a harmless discharge (MLIT, 2006). Table 1 shows the main computational conditions and results.

Table 1. Computational conditions and results

| Case No. | Method | Flood control capacity of the Hokuzan Dam [million m³] | Flood control capacity of the Kasegawa Dam [million m³] | $Q_{a1}$ of the Hokuzan Dam [m³/s] | $Q_{a2}$ of the Kasegawa Dam [m³/s] | Maximum discharge of the Hokuzan Dam [m³/s] | Maximum discharge of the Kasegawa Dam [m³/s] | Maximum discharge at the Kanjin Bridge [m³/s] |
|---|---|---|---|---|---|---|---|---|
| Case 0 | Present flood control | 0 | 17.5 | 0 | 770 | 1024 | 1975 | 4441 |
| Case 1 | Extension of present flood control | 0 | 37.0 | 0 | 770 | 1024 | 770 | 3268 |
| Case 2 | Conventional flood control (SGD) | 16.3 | 21.8 | 300 | 770 | 300 | 770 | 3268 |
| Case 3 | Cascade method (SGD) | 16.3 | 21.8 | 198 | 747 | 468 | 747 | 3244 |
| Case 4 | Conventional flood control (GD) | 18.8 | 20.6 | 300 | 770 | 300 | 770 | 3268 |
| Case 5 | Cascade method (GD) | 18.8 | 20.6 | 145 | 736 | 471 | 736 | 3235 |
| Case 6 | Conventional flood control using all the effective capacities (SGD) | 22.0 | 68.0 | 168 | 23 | 168 | 23 | 2519 |
| Case 7 | Cascade method using almost all the effective capacities (SGD) | 17.7 | 68.0 | 0 | 4 | 528 | 4 | 2500 |

The current flood control level is insufficient for a future heavy rainfall of 674 mm. The discharge at the Kanjin Bridge was examined as Case 0, where only the current flood control capacity of the Kasegawa Dam (17.5 million m³) is used to handle a future heavy rainfall of 674 mm. In this case, the reservoir of the Hokuzan Dam, which has no flood control capacity, was always full. Figure 5 shows the inflow discharge at the most upstream point of the computational area, the outflow discharges from the Hokuzan Dam and Kasegawa Dam,

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and discharges just before the Kasegawa Dam and at the Kanjin Bridge. The peak discharge at the Kanjin Bridge is 4441 m³/s, greatly exceeding the current design high water discharge of 2500 m³/s, and an overflow occurs from the Kasegawa Dam. Therefore, with the effects of global warming, some flood control adaptation measures will be required in the future.
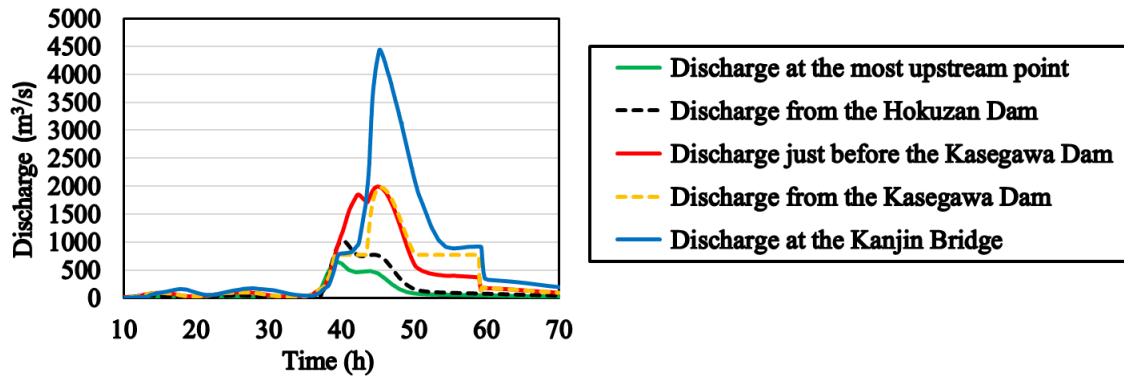


Figure 5. Flow discharges in the present flood control method (Case 0)

It will be difficult for the Kasegawa Dam to provide adequate flood control by itself during future heavy rainfall. In Case 1, the flood control capacity of the Kasegawa Dam (17.5 million m³) was increased so as not to overflow the dam. The reservoir of the Hokuzan Dam was left full, and the normal water level in a flood season in the Kasegawa Dam was adjusted so as not to overflow its emergency spillway in order to determine the dam's flood control capacity. This revealed that the required capacity is 37 million m³ (54% of the effective storage capacity), which is 2.1 times larger than the current flood control capacity of 17.5 million m³ (see Table 1). However, the peak discharge at the Kanjin Bridge in Case 1 was 3268 m³/s, which is much larger than its design high water discharge of 2500 m³/s. Therefore, relying on the flood control ability of only the Kasegawa Dam will be insufficient even though the peak discharge at the Kanjin Bridge was 26% lower in Case 1 than in Case 0.

In Case 2, each minimum flood control capacity that controlled the flood without overflow from each emergency spillway of the Hokuzan Dam and the Kasegawa Dam was examined. This was conventional flood control where multiple dams are constructed in series (Oshikawa and Komatsu, 2015) and the storage capacity of the Hokuzan Dam in addition to the Kasegawa Dam was partially used for flood control with a prior discharge by operating a slide gate. In this study, the design high water discharge $Q_a$ of each dam is written as $Q_{ai}$, where subscript i = 1, 2 indicates points on the upstream side. The design high water discharge of the Hokuzan Dam $Q_{a1}$ was 300 m³/s, which is almost the same as the present conditions. In contrast, the design high water discharge of the Kasegawa Dam was 770 m³/s, which corresponds to Basic River Development Policy for the Kase River basin (MLIT, 2006).

Figure 6 shows the results for Case 2, which demonstrates discharges at the same main points as Figure 5. Outflow discharges from the Hokuzan Dam and Kasegawa Dam are both within $Q_a$ of each dam. The discharges are constant at $Q_a$ of each dam for a relatively long time due to a gate operating during the flood. In Case 2, the Hokuzan Dam requires a flood control capacity of 16.3 million m³ (74% of its effective storage capacity) and the Kasegawa Dam requires 21.8 million m³ (32% of its effective storage capacity). The peak discharge at the Kanjin Bridge in Case 2 is 3268 m³/s, which is the same as in Case 1.
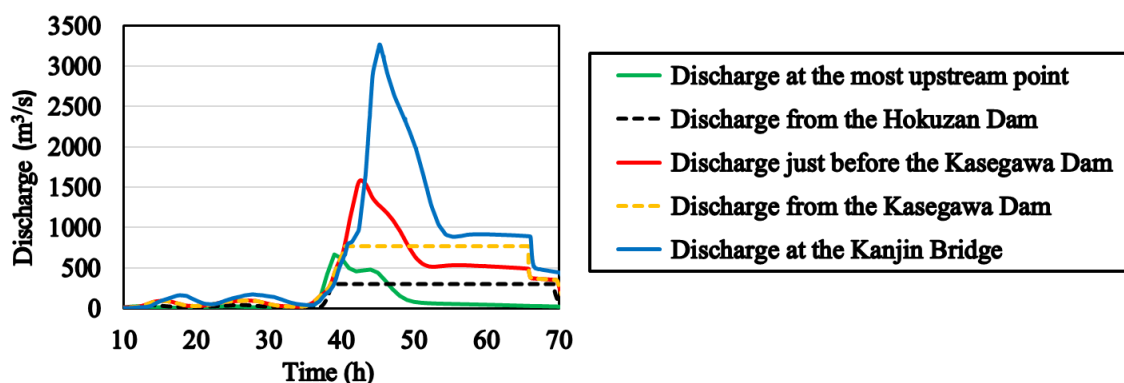


Figure 6. Flow discharges during the conventional flood control method (Case 2)

In Case 3, the Cascade-type flood control method was adopted in order to reduce peak outflow discharge from the downstream Kasegawa Dam. A minimum value of $Q_{a2}$ was calculated so as not to overflow the emergency spillway of the Kasegawa Dam although overflow of the Hokuzan Dam was permitted. Each design

high water discharge $Q_{ai}$ was then independently changed in a case where the flood control capacity of each dam was the same as the conventional type in Case 2 (16.3 million m³ for the Hokuzan Dam and 21.8 million m³ for the Kasegawa Dam).

Figure 7 shows the result for Case 3, where $Q_{a1}$ = 198 m³/s and $Q_{a2}$ = 747 m³/s. The maximum outflow discharge 747 m³/s from the Kasegawa Dam, which is same as $Q_{a2}$, can be reduced by 3.0% compared to 770 m³/s in Case 2. The peak discharge at the Kanjin Bridge in Case 3 (3244 m³/s) is 27% lower than that in Case 0 (4441 m³/s).
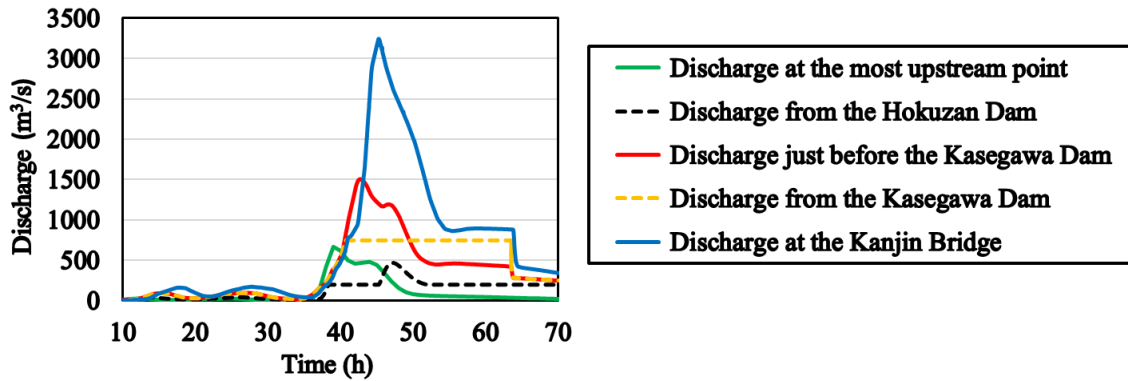


Figure 7. Flow discharges in Cascade-type flood control method (Case 3)

Flood control effects were compared for cases in which the Hokuzan Dam, which be a multipurpose dam, has a slide gate for flood control (hereinafter referred to as a slide gate dam (SGD)) or has no slide gate (hereinafter referred to as a gateless dam (GD)). An SGD is a general multipurpose dam with a slide gate for flood control and water utilization. In contrast, a GD, which has a hole in its wall that acts as a spillway for flood control, is a gateless, freely flowing type through the hole for flood control and a storage dam for water utilization. It will likely be difficult for Hokuzan Dam to be operated as an SGD in order to reduce peak flow discharge because it was originally built as a water utilization dam.

The flood control effect with a GD was examined in Case 4, which is the same as Case 2 except that the SGD is replaced with a GD in the Hokuzan Dam. In Case 4, the flood control capacity of the GD and the Kasegawa Dam is 18.8 million m³ and 20.6 million m³, respectively, giving a total of 39.4 million m³ (see Table 1). The total flood control capacity is larger in Case 4 with the GD than in Case 2 with the SGD as the latter is 38.1 million m³. The upstream Hokuzan Dam requires more flood control capacity in Case 4 compared with Case 2. In contrast, the downstream Kasegawa Dam requires more flood control capacity in Case 2 compared with Case 4. As shown in Figure 8, this is due to the difference between the hydrographs of outflow discharge from the GD and the SGD. In Case 4, the gentle peak of the hydrograph indicates that the period of the time is short in which the maximum outflow discharge from the GD is at $Q_{a1}$ of 300 m³/s and the reservoir is at its high water level. In contrast, the outflow discharge from the SGD in Case 2 is at a $Q_{a1}$ of 300 m³/s for a considerably longer time. Therefore, the hydrograph is more severe in Case 2 than in Case 4 at the downstream Kasegawa Dam.
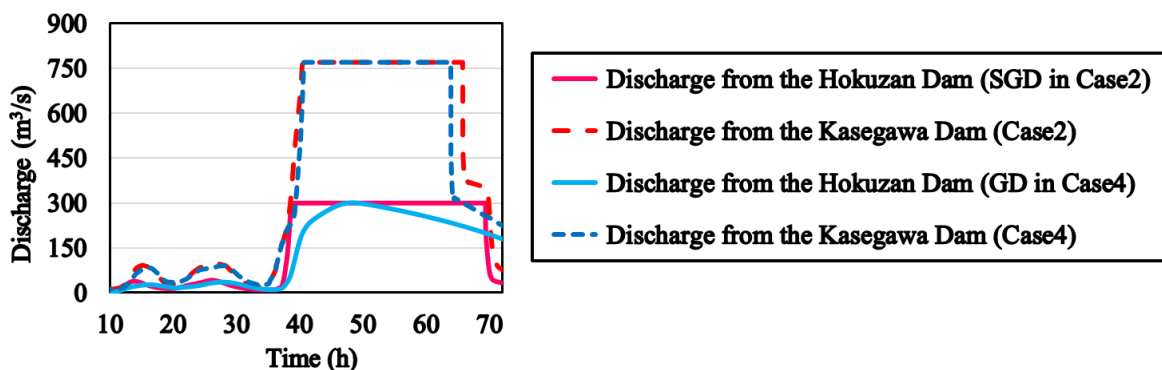


Figure 8. Outflow discharges from the dams in Case 2 with an SGD and those in Case 4 with a GD

In Case 5, the Cascade-type flood control method with a GD was performed in order to model reducing the peak outflow discharge from the downstream Kasegawa Dam. A minimum value of $Q_{a2}$ was calculated such that there was no overflow from the emergency spillway of the Kasegawa Dam while overflow of the Hokuzan Dam with a GD was permitted. In Case 5, each design high water discharge $Q_{ai}$ was independently changed. Case 5 is the same as Case 3 except that the SGD is replaced with a GD. The respective flood control capacities of the Hokuzan Dam and Kasegawa Dam in Case 5 are the same as in Case 4. When $Q_{a1}$ = 145 m³/s and $Q_{a2}$ =

736 m³/s, a peak discharge of 3235 m³/s is obtained at the Kanjin Bridge (see Table 1). Therefore, the peak flow discharge of 736 m³/s from the Kasegawa Dam is reduced by 4.4% compared to that of 770 m³/s in Case 4. The flood control ability when using the Cascade-type method is more effective with a GD than with an SGD because the difference in $Q_{a2}$ between Case 4 and Case 5 is larger than that between Case 2 and Case 3.

The peak discharge at the Kanjin Bridge must be reduced to 2500 m³/s to be in accordance with the Basic River Development Policy for the Kase River basin (MLIT, 2006). However, all the peak discharges in Case 0 through Case 5 at the Kanjin Bridge exceed the design high water discharge of 2500 m³/s (see Table 1). This is because the Nao, Osoekawa, and Amago Rivers, which are tributaries that flow into the Kase River downstream of the Kasegawa Dam, have a combined total peak inflow discharge of 2496 m³/s, which is almost equal to 2500 m³/s.

Conventional flood control using the total effective storage capacity of the Hokuzan Dam and the Kasegawa Dam was applied as Case 6 in order to reduce the peak flow discharge at the Kanjin Bridge to 2500 m³/s. The flood control capacity is 22 million m³ for the Hokuzan Dam and 68 million m³ for the Kasegawa Dam. This gives a total effective storage capacity of 90 million m³. Each $Q_a$ was changed independently to prevent overflow of the emergency spillways at each of the Hokuzan Dam and the Kasegawa Dam. The Hokuzan Dam was assumed to be an SGD. Figure 9 shows that in Case 6, where $Q_{a1} = 168$ m³/s and $Q_{a2} = 23$ m³/s, the peak discharge at the Kanjin Bridge is 2519 m³/s, which is almost the same as the design flood discharge of 2500 m³/s. This means that the conventional type will, however, still inadequately control flooding.
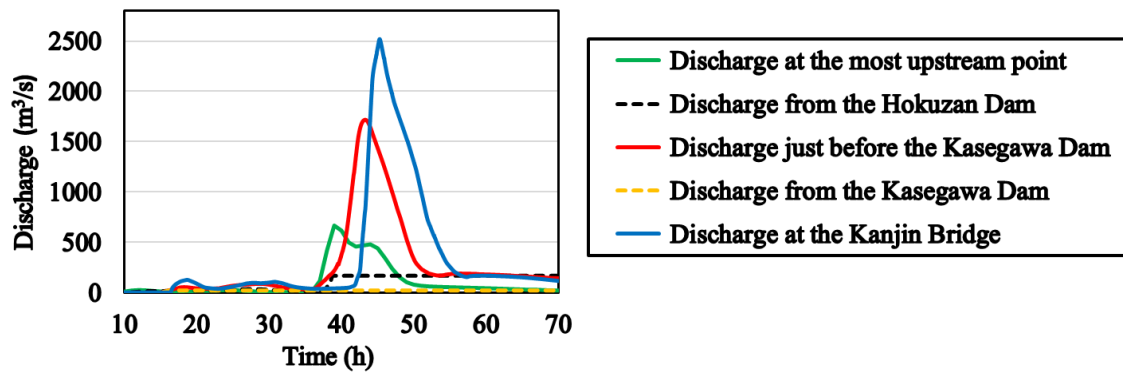


Figure 9. Flow discharges during conventional flood control in cases where all the effective storage capacities of the existing dams are used (Case 6)

Case 7 involved the Cascade method and the minimum $Q_{a2}$ for the Kasegawa Dam in the case where peak discharge at the Kanjin Bridge becomes 2500 m³/s was calculated so as not to overflow its emergency spillway, which also determined the flood control capacities required for the Hokuzan Dam and the Kasegawa Dam. In Case 7, where $Q_{a1} = 0$ and $Q_{a2} = 4$ m³/s as shown in Figure 10, the Hokuzan Dam and the Kasegawa Dam require flood control capacities of 17.7 million m³ and 68 million m³, respectively, totaling 85.7 million m³. Therefore, the total storage capacity of the existing dams is large enough for Cascade-type flood control to be used in this case.
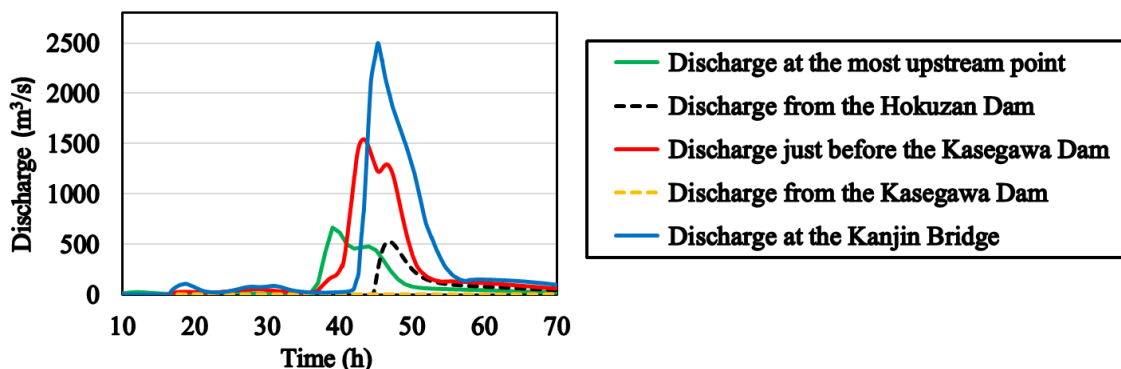


Figure 10. Flow discharges in Cascade-type flood control in the case where peak discharge at the Kanjin Bridge becomes 2500 m³/s (Case 7)

The future heavy rainfall of 674 mm over 48-h in this study is the upper limit precipitation that can be controlled using the existing dams in the Kase River basin. The maximum flow discharge at the Kanjin Bridge in Case 6 slightly exceeds the design level of 2500 m³/s, whereas flood control is possible in Case 7. The total amount of future heavy rainfall happens to almost match the total storage capacity. Therefore, other

countermeasures, such as a full-scale river improvement, will also be needed in the Kase River basin because it will be difficult to use the total storage capacity including, the water utilization capacity, for flood control.

## 4. CONCLUSIONS

This study simulated the flood control measures provided by the existing dams in the Kase River basin in view of the effects of global warming. Data on a heavy rainfall event of 674 mm over a 48-h period in the Kase River basin were extracted from the d4PDF, with the target being flood control of an excessive flood. Our simulation revealed that the peak discharge at the Kanjin Bridge downstream can be reduced to 2500 m$^3$/s, which corresponds to its design flood discharge, by using the Hokuzan Dam, which is a water-utilization dam, and the Kasegawa Dam only if almost all of their total storage capacity is used in controlling the excessive flood. However, in order to perform such a flood control, both of the dam reservoirs must be empty before the excessive flood, with the dams being emptied by a prior discharge. Therefore, some flood control adaptation measures including not only changes in the dams but also river improvements will be needed in the future.

This study also revealed that Cascade-type flood control with multiple dams constructed in series is more effective than conventional flood control in the Kase River basin. The maximum outflow discharge from the Kasegawa Dam downstream can be reduced by adopting the Cascade method although this means overflow of the emergency spillway at the Hokuzan Dam upstream occurs. Because the Cascade method can strengthen flood control ability merely by altering the gate operation of existing dams, this method will be extremely useful in responding to disaster hazards as they increase due to the effects of global warming.

In addition, flood control effects were compared in cases in the Kase River basin where the upstream dam is an SGD, which has a slide gate for flood control, and where the upstream dam is a GD. A GD is another type of multipurpose dam, but it has a hole in its wall acting as a spillway for flood control and its storage capacity is used for water utilization. It will likely be difficult for the Hokuzan Dam, which is used for water utilization, to operate a slide gate in order to reduce peak flow discharge. Our simulation demonstrated that the flood control ability of Cascade-type flood control when applied to a GD is more effective than when applied to an SGD. The former is more effective because the peak flow discharge from the downstream Kasegawa Dam in the case with an upstream GD is lower than that with an upstream SGD when the Cascade method is used.

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