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# FLOOD CONTROL ON SAMEURA DAM AND ITS EFFECTIVENESS

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## INTRODUCTION

In Japan, heavy rains that fall on steep mountains, flow quickly down to downstream, causing floods not a few times, but on the other hand, severe drought occurs sometimes when precipitation is scarce. For this solution, dams are being constructed in Japan. On the Yoshino River in Shikoku Island located in the southwestern part of Japan, Sameura Dam was constructed for the purpose of flood control, water supply and power generation. Sameura Dam has each storage capacity for flood and non-flood seasons, and the dam is operated under the dam operating rules. The flood discharge operation is carried out based on the "constant rate – constant quantity" method, but it is also flexibly operated according to the inflow into the dam reservoir.

This paper gives an overall picture of the flood control operations and its resultant effects of Sameura Dam during floods caused by Typhoon 23 in 2004 and Typhoon 14 in 2005.

## OUTLINE OF THE YOSHINO RIVER

### Outline of the Yoshino River Basin

The Yoshino River originates at Kamegamori (elevation 1,896m) in Agawa-gun, Kochi Prefecture. The river flows eastward along the mountains of Shikoku, turns north across the mountains of Shikoku after merging with the Ananai River at Shikiiwa, joins with Dozan River and Iya River, then heads east again at Ikeda-cho, Tokushima Pref.. Then it flows the Tokushima Plains through Iwazu, reaches the Daiju Barrage Point by merging with many tributaries, separates the Kyuyoshino River, and empties into the Kii Channel.

The river is a class A river and the total length of main river route reaches 194km. The river basin covers all four prefectures in Shikoku, and its catchment area of 3,750km2 represents nearly 20% of the whole area of Shikoku (approximately 18,804km2).(See Fig. 1)

The upstream section of the Yoshino River is almost covered with mountains, and is extremely steep, with a riverbed slope of 1/15 - 1/400. In the section between Ikeda and Iwazu of the river, a valley plain is formed, and the riverbed slope is gentle at around 1/800. In the downstream section of the river, from Iwazu to the estuary, the riverbed gradient is even gentler at around 1/1,100.(See Fig. 2)

There are four categories of land use in the river basin: forests (78.5%), paddy fields and dry farming fields (15.1%), urban land occupied by housing and factories (4.6%), and rivers (1.8%).

Moreover, the river water is used widely throughout all four prefectures of Shikoku by

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diverting to three prefectures (Tokushima, Ehime and Kagawa).

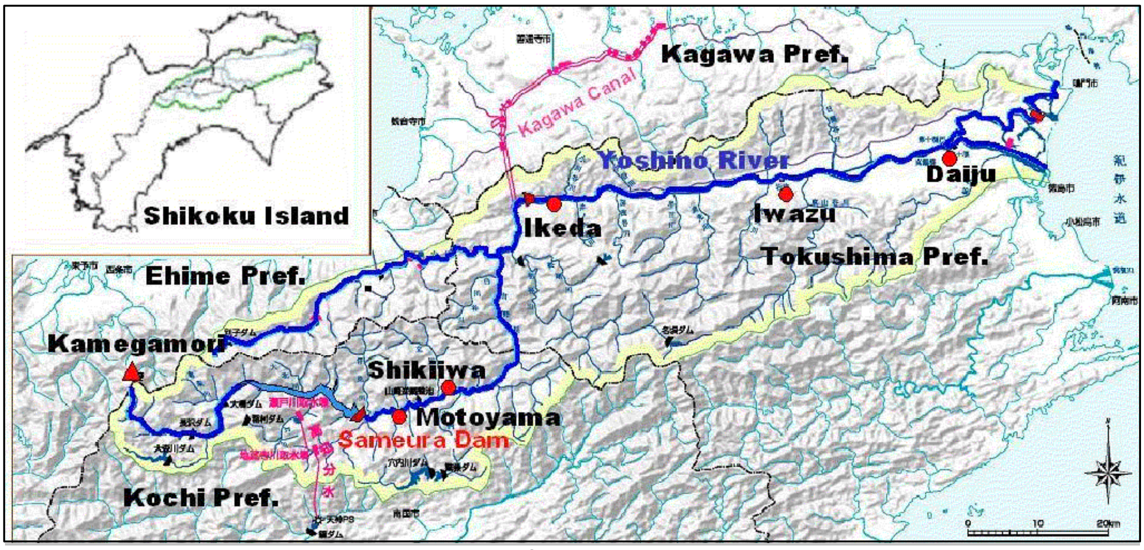



Fig. 1. Map of the Yoshino River Basin

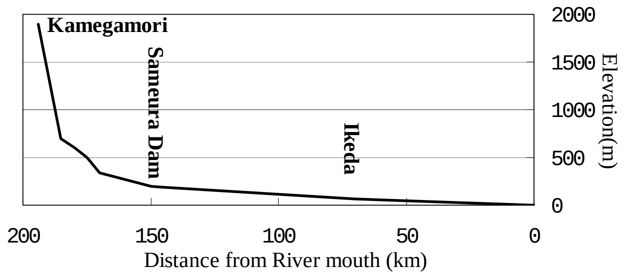



Fig. 2. Longitudinal Outline of the Yoshino River

## CLIMATE OF SHIKOKU AND THE YOSHINO RIVER BASIN

Shikoku is divided topographically into north and south parts by the Shikoku Mountains, and the weather is sharply different on each parts of Shikoku. In the north part, it has little rainfall and the climate is comparatively mild, but in contrast, in the south part, it has considerable rainfall and the temperature is higher. (See Fig. 3)

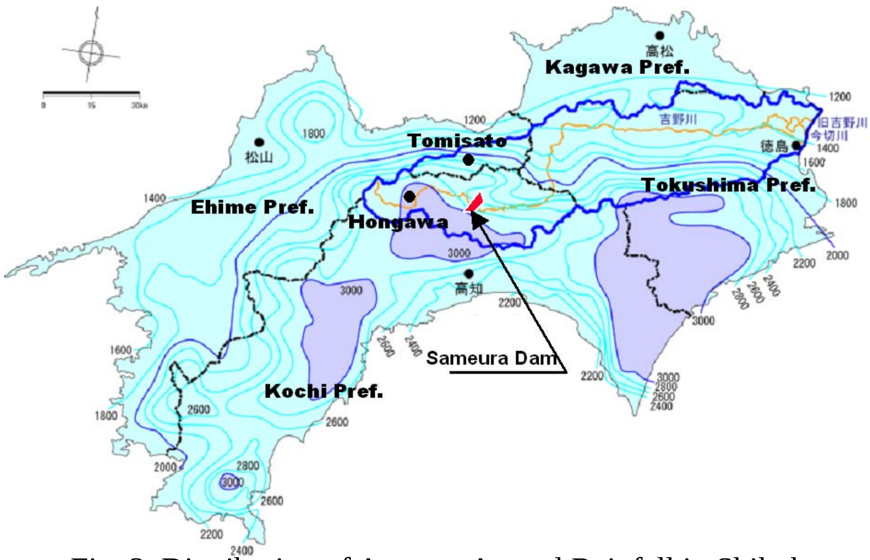



Fig. 3. Distribution of Average Annual Rainfall in Shikoku

Heavy rainfall in Shikoku is mainly caused by typhoons, and atmospheric depressions, seasonal rainfall, rain fronts and thunderstorms in this order. Shikoku is frequently hit by typhoons. On average, 3.6 typhoons strike Japan per year (average from 1940 to 1975). Among these, Shikoku is hit by 1.2 typhoons and affected by 2.7 typhoons per year. (See Fig. 4) The Yoshino River basin is in the typhoon corridor, and most of the river basin is located in the mountainous region in the center of the island. As a result, the rainfall in this region is one of the highest in Japan. Particularly in the region of the upstream of the Yoshino River, annual rainfall reaches more than 3,000mm. Most of the rainfall is concentrated during rainy season in June, and during the typhoon season from July through September. (See Fig. 5)

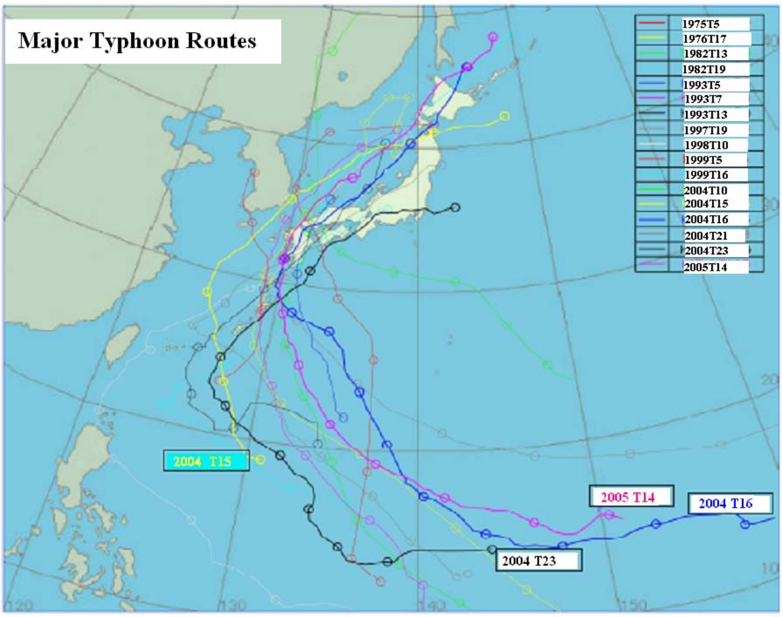



Fig. 4. Courses of Major Typhoons (1975 to 2005)

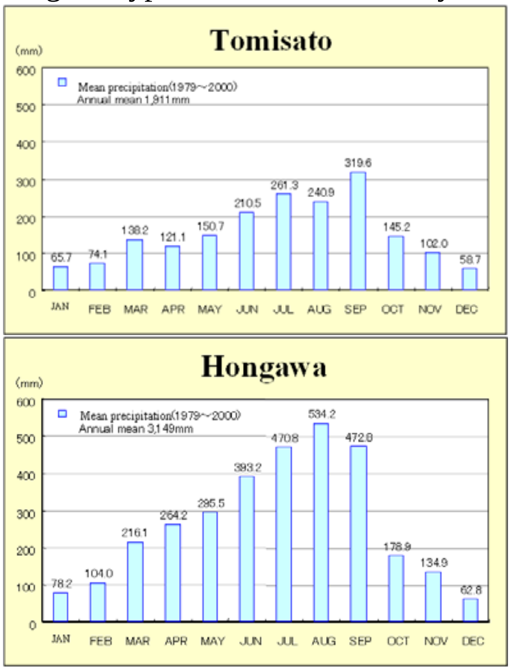



Fig. 5. Rainfall in the Yoshino River Basin

## SAMEURA DAM

### Overview

Sameura Dam forms the nucleus of the Yoshino River Integrated Development Plan.

The dam is a 106-meter-high multipurpose dam constructed on the Yoshino River in the Yoshino River system, with an effective storage capacity of 289 million m3.

It provides flood control and a stable intake of water for various vested rights and, through water development amounting to 863 million m3 per year, supplies water to all four prefectures of Shikoku as well as conducting power generation.

The dam is managed by the Japan Water Agency. The following is an overview of the features of Sameura Dam.

(1)Flood control

Sameura dam performs flood control of 2,700m3/s for design flood discharge of 4,700m3/s in the dam spot and plans reduction of the flood damage of the downstream. As shown in Fig. 8, when an inflow reaches 800m3/s, the dam initiates flood control. When the inflow volume reaches the design flood discharge of 4,700 m3/s, the water of 2,000 m3/s is discharged. This flood control method is called the “constant rate – constant quantity” method.

(2)Water use development (maintenance of normal functions of the river flow and new water use)

In order to maintain the normal functions of the river flow in the Yoshino River, additional water is supplied to secure 43 m3/s during the irrigation season and 15 m3/s during the non-irrigation season at the Ikeda location.

Sameura Dam works with Ikeda Dam, Shingu Dam and Yanase Dam to develop new water of 863 million m3 in one year for irrigation, domestic and industrial water use. This water is provided to all four prefectures of Shikoku through the Tokushima Canal, Kagawa Canal, Ehime Diversion and Kochi Diversion.

(3)Power generation

The dam generates up to 42,000 kW of power within the scope that will not impede flood control, maintenance of normal functions of river flow and new water use.

## CAPACITY ALLOCATION

As shown in Fig. 6, each capacities of Sameura Dam is set according to a purpose every the flood season and the non-flood season.

During the flood season (July 1 - October 10), when there is the intense rainfall due to typhoons, the flood control capacity of the dam is increased 10 million m3 than that during the non-flood season (from October 1 to June 30 of the following year). The exclusive power generation capacity is made to decrease by 10 million m3.

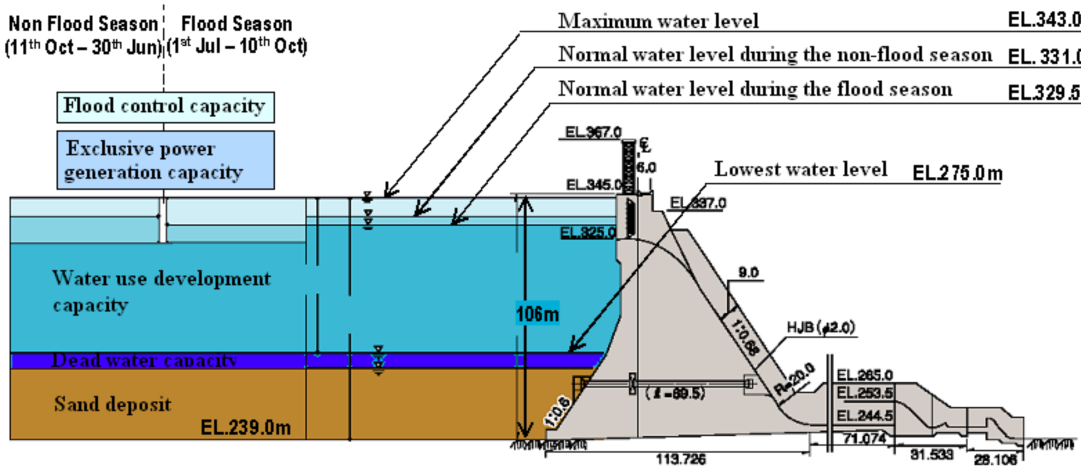



Fig. 6 Storage Capacity Allocation of Sameura Dam

### Flood Control

During the flood season, flood control is conducted using 90 million m3 between EL. 329.5 m(the normal water level during the flood season) and EL. 343.0 m. During the non-flood season, flood control is conducted using 80 million m3 between EL. 331 m( the normal water level during the non-flood season) and EL. 343.0 m.

### Water Use Development

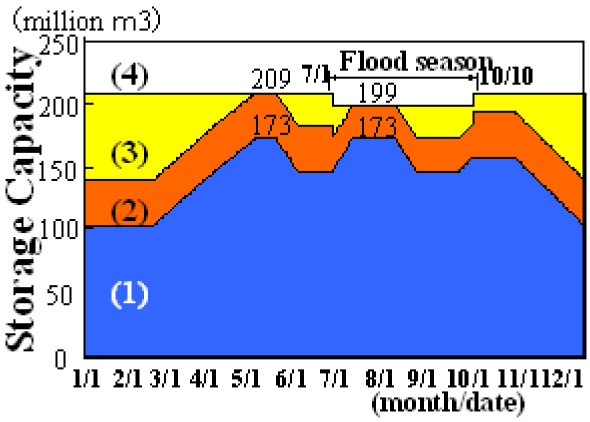
With the water use capacity of 173 million m3 between EL. 275.0 m( the lowest water level) and EL. 325.0 m (the crest gate bed height), it is developed by the dam so that water of 863 million m3 enables stable intake at all four prefectures of Shikoku per year.

### Power Generation

Within the scope that will not impede the maintenance of normal functions of river flow in the Yoshino River and the water use for the Tokushima Canal and Kagawa Canal, the generation of max power 42,000kw uses capacity of maximum 199 million m3 (those 26 million m3 are capacity for exclusive use of generation) between EL275.0m and EL329.5m during the flood season and uses capacity of maximum 209 million m3 (those 36 million m3 are capacity for exclusive use of generation) between EL275.0m and EL331.0m during the non-flood season .

### Secured Storage Capacity

The secured storage capacity that must be secured to prevent disruption of water use operation throughout the year is set in each period as shown Fig.7, and the reservoir is operated for the capacity not to fall below this secured storage capacity.




(1) Secured storage capacity
(2) Exclusive power generation capacity
(3) Capacity used for both water use and power generation
(4) Flood control capacity

Fig. 7 Secured Storage Capacity at Sameura Dam

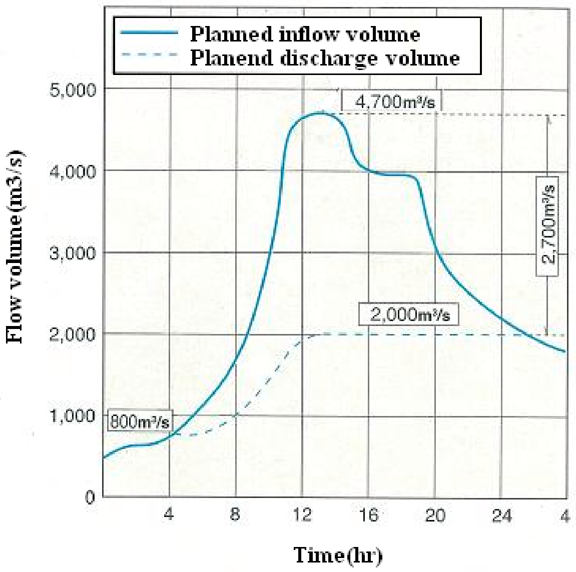



Fig. 8 Flood Control Plan at Sameura Dam

## PREVIOUS OPERATION RESULTS OF SAMEURA DAM

### Reservoir operation

Sameura Dam, completed in April 1975, has been operating for 30 years to controll floods, supply water, and generate electricity according to the operating rules. Fig. 9 shows the results of the operation of the reservoir until 2005. The normal water level during the flood season and that during the non-flood season are shown in the figure, and the reservoir is operated to prevent flood, when the reservoir level is equal to or higher than these water levels. And discharge operation is done to supply supplementary water or to generate electric power during the reservoir level falling.

In a year when a large scale flood inflow equivalent to the planned max inflow occurred, the reservoir level rose near the full water level at EL. 343.0m. And in a year when a large scale discharge equivalent to the planned scale occurred, the reservoir level falls to near the minimum water level. (See Fig. 9)

Fig. 11 shows the results of operation in 2004, when flood control was performed many times. And fig.12 shows the results of operation in 2005, when unprecedented flood control operation was begun from a low water level caused by drought.

In 2004, many typhoons approached or crossed Shikoku and the dam performed flood control operation 9 times. In June and July of 2005, the early summer seasonal rain front brought little rainfall, causing drought conditions, and water replenishment operations lowered the reservoir level. Then a large flood triggered by typhoons struck the river basin, the reservoir level was raised from near the minimum water level to near the maximum water level during the flood to restore the reservoir level and control the flood.

### Previous Results of Flood Control Operation

During a period of 31 years from 1975 to 2005, Sameura Dam controlled flooding 81 times, and 61 times of these occasions were triggered by typhoons. At 4 times of those occasions the maximum flow volume exceeded the design flood discharge (4,700$m^3$/s): during typhoon 5 of

1975, typhoon 17of 1976, typhoon 8 of 1993, and typhoon 14 of 2005. (See Fig. 10)

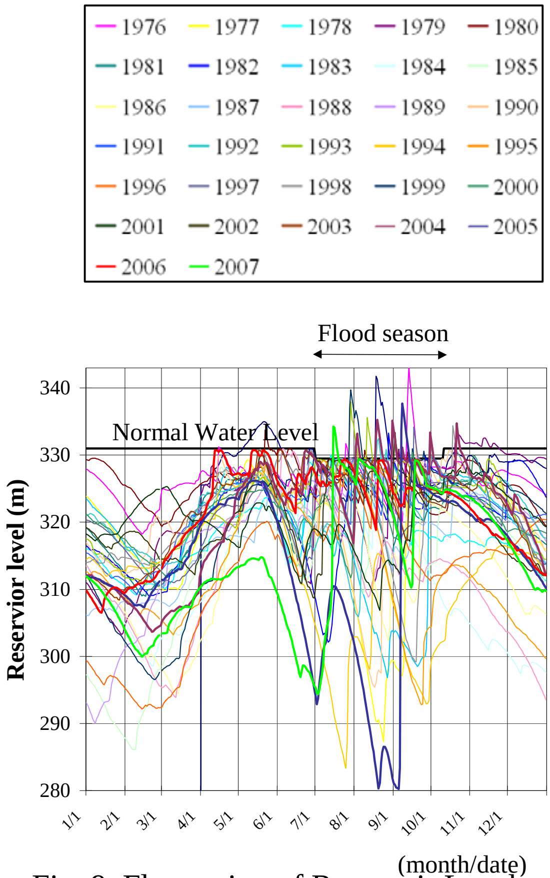



Fig. 9. Fluctuation of Reservoir Level at Sameura Dam

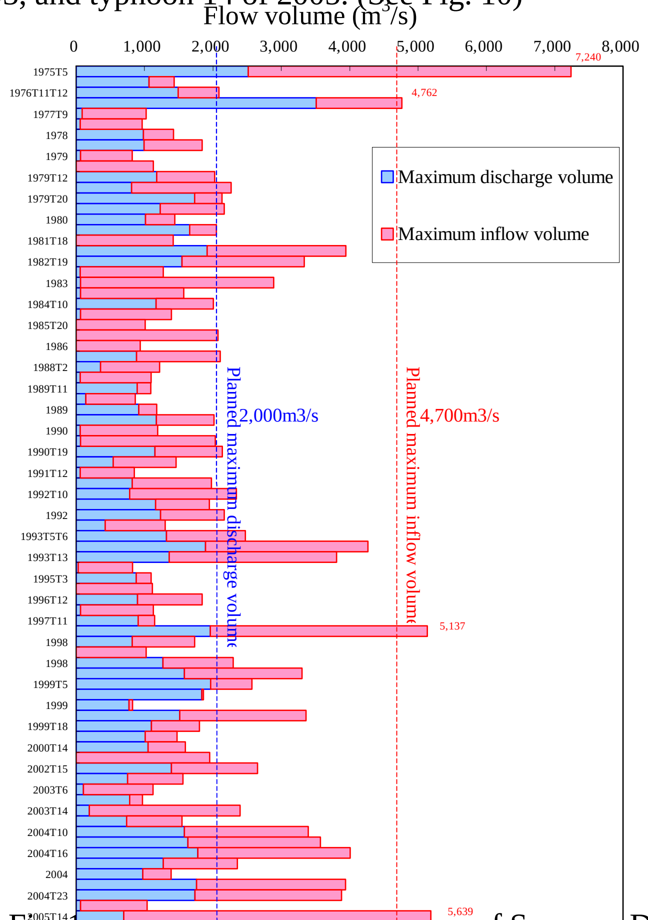



Fig. 10. Flood Control Performance of Sameura Dam (max. inflow and max. discharge flow)

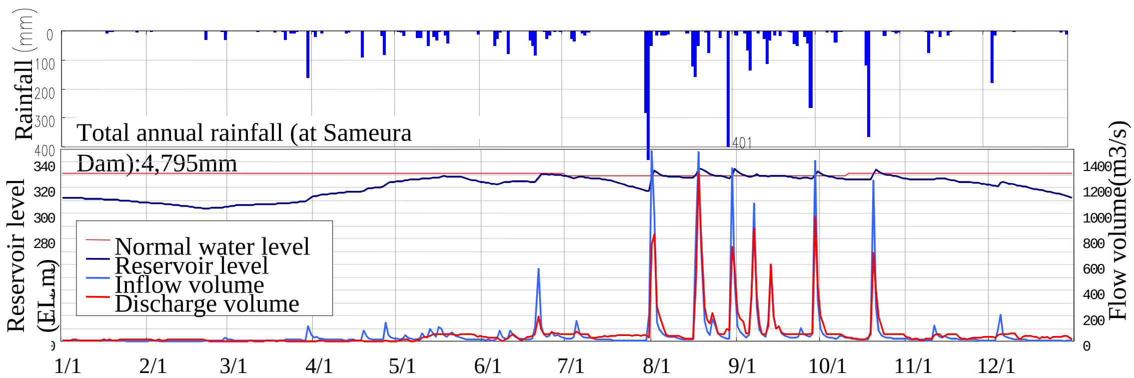



Fig. 11 Operating Records of Sameura Dam (2004)

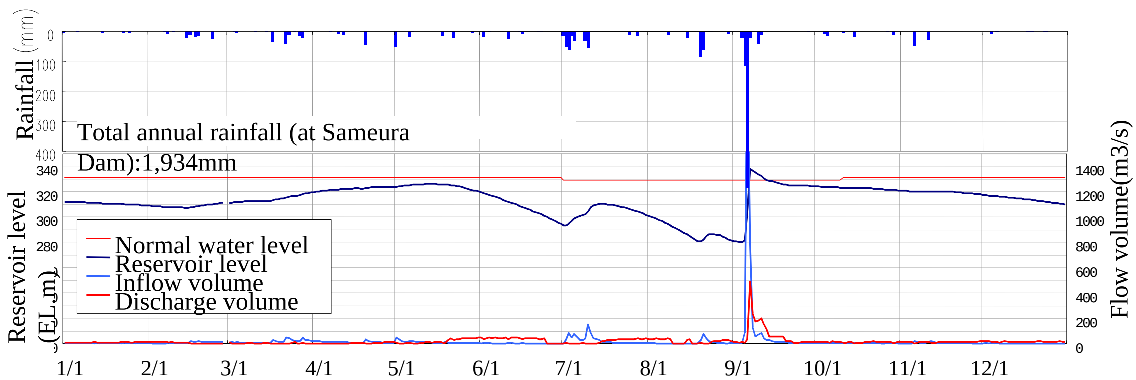



Fig. 12. Operating Records of Sameura Dam (2005)

**Advanced operation for more appropriate flood control**

By the regulations of flood control of Sameura Dam, as shown above, flood control operation is started at 800m$^3$/s, and is basically performed by the “constant rate – constant quantity” method—discharging 2,000 m$^3$/s when the inflow is the design flood discharge of 4,700m$^3$/s. And more appropriate flood control operation can be performed according to the state of the flood.

Two examples are presented below, operations during typhoon 23 of 2004 and typhoon 14 of 2005, when the quantity discharged from the dam was lowered even more than that stipulated by the said “constant rate – constant quantity” method.

**TYPHOON 23 , 2004**

It was predicted that Typhoon 23 of 2004 would cause flooding. Therefore, preparations for the flooding were taken on October 19, and observations of the rainfall and flow condition were collected along with meteorological reports.

Typhoon 23 moved north with its large high wind speed zone and its power, made landfall in Kochi Prefecture in Shikoku, then crossed Shikoku, dumping an average of 428mm of rain in the Sameura Dam catchment area. The Nurui Rainfall Observation Station, about 4km south of Sameura Dam, recorded torrential hourly rainfall of 87mm/hr. At the time that the maximum inflow to Sameura Dam was 3,883m$^3$/s, the dam discharged 1,743m$^3$/s.

Fig. 13 shows the distribution of rainfall in the Yoshino River Basin. As torrential rain in downstream from Sameura Dam, the Motoyama Water Level Observation Station in Motoyama-cho downstream from Sameura Dam recorded a water level of 9.2m at 2:00 pm on October 19, and it was afraid that disastrous inundation would strike urban districts. The inflow at Sameura Dam had already recorded the peak volume at about 13:40 pm on October 20, and based on the radar, no strong rainy areas were found and no torrential rain forecasted in the Sameura Dam catchment area. Therefore, the later discharge was reduced to approximately 1,000m$^3$/s, about 700m$^3$/s less than that of 1,743m$^3$/s decided by regulations, for further mitigating flood damage downstream. (See Fig. 14)

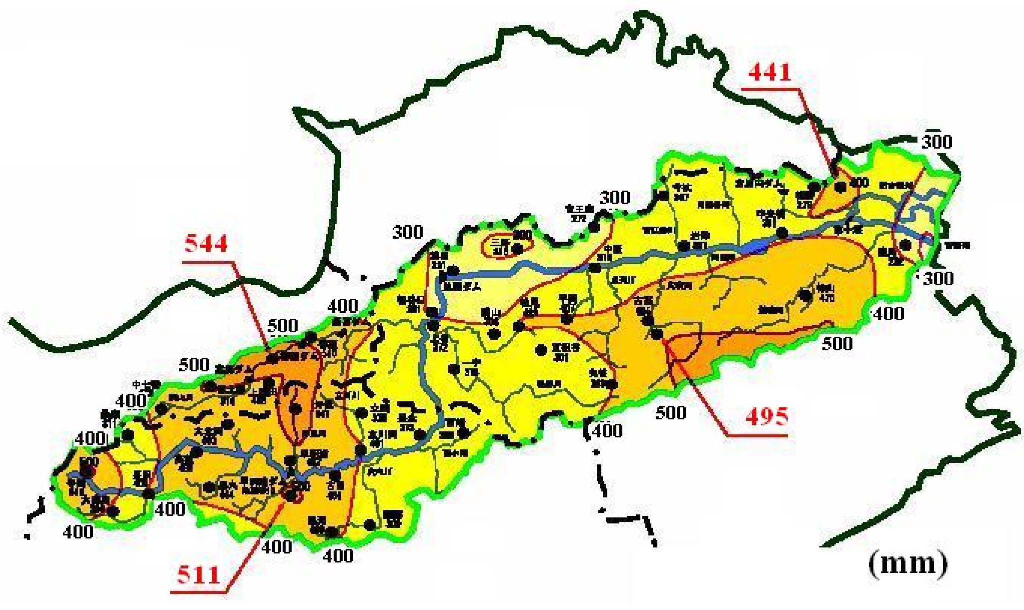



Fig. 13. Distribution of rainfall in the Yoshino River Basin (Typhoon 23 of 2004)

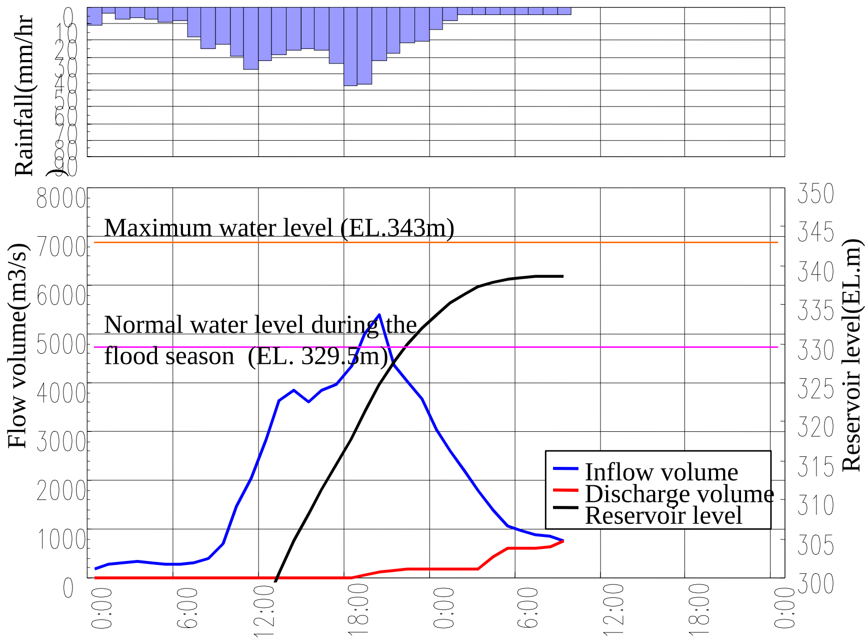



Fig. 14. Flood Control by Sameura Dam (Typhoon 23 of 2004)

**TYPHOON 14, 2005**

As flooding due to Typhoon 14 was predicted, preparations for flooding began on September 5. The rainfall and flow condition were monitored, information on weather conditions was collected and so on.

Typhoon 14 was an extremely large typhoon that had a large storm zone and maintained its intensity as it moved northward. On the 6th, it came ashore in Nagasaki Prefecture on the island of Kyushu, after when it passed over western Kyushu and moved northeast across the Japan Sea. Even after it had passed through Hokkaido on the 8th, it maintained its intensity and still kept typhoon status. Average rainfall of 708 mm was recorded in the Sameura Dam Basin, and the highest hourly precipitation of 56 mm was recorded at the Nagasawa Rain Gauge Station upstream from Sameura Dam.

Maximum inflow volume of 5,640 m3/s (design flood discharge 4,700 m3/s), the second highest ever recorded after management began at Sameura Dam in 1975, was recorded. Before the flooding, as a result of the drought, the storage rate of the reservoir was completely 0%. So, in the early stage of flooding, all of the floodwater was stored in the dam.

Subsequently, as the storage volume exceeded secured storage volume, discharge from both power station and the water supply discharge pipes was initiated. At the maximum inflow of 5,640 m3/s, 100 m3/s (comprising both power generation discharge and discharge from the water supply discharge pipes) was discharged to adjust the level to 5,540 m3/s. After the reservoir level exceeded the crest bed height of EL. 325m, discharge from the crest gate was initiated. When the reservoir level reached the normal water level during the flood season of EL. 329.5m, approximately 200 m3/s was discharged.

Fig. 15 shows the distribution of rainfall in the Yoshino River Basin. As the typhoon was very large and powerful, there was heavy rainfall not only in the areas upstream from the dam but also in the middle and lower reaches of the Yoshino River. Notwithstanding the discharge from the dam was approximately 200 m3/s, the water level in the river downstream from the dam increased rapidly, and there was concern that the houses, etc. in the downstream would be flooded. Though the discharge from the dam must be increased up to the inflow according to the operation rule, the discharge was operated up to approximately 700 m3/s in order to reduce the flood damage in downstream area. It was because it was predicted that the rainfall would be decreased and remaining storage capacity of the reservoir would be sufficient to the necessity for the operation.(See Fig. 16)

In the flooding caused by Typhoon 14, the reservoir level before the execution of flood control was low due to a drought, as shown in Fig. 17, and the storage volume was approximately 248 million m3, which is about 86% of the effective storage capacity of 289 million m3.

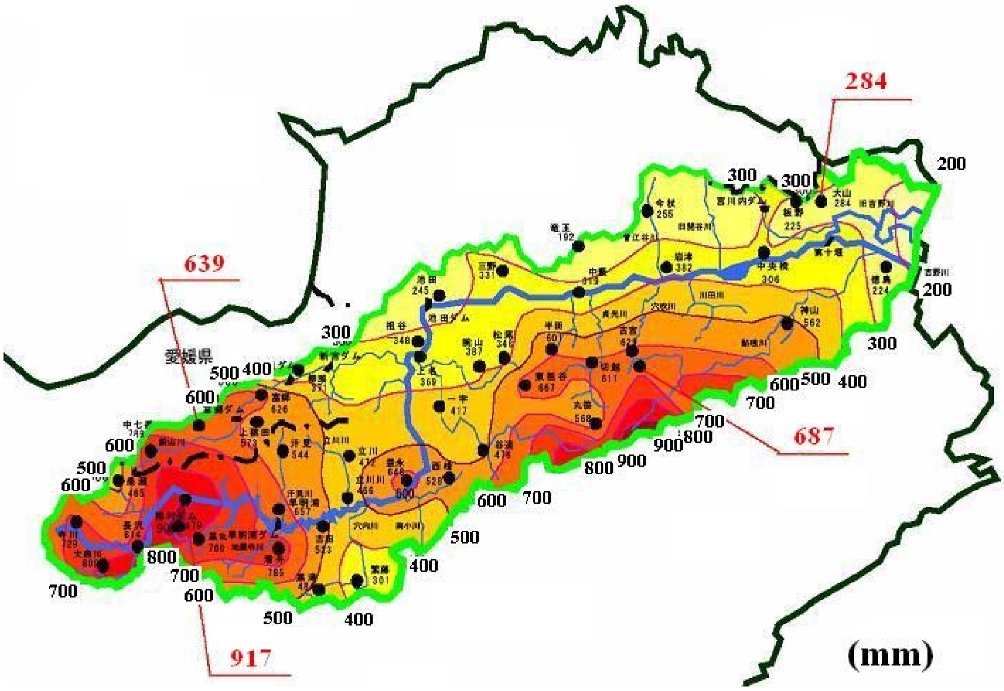



Fig. 15 Distribution of Rainfall in the Yoshino River Basin, etc. (Typhoon 14, 2005)

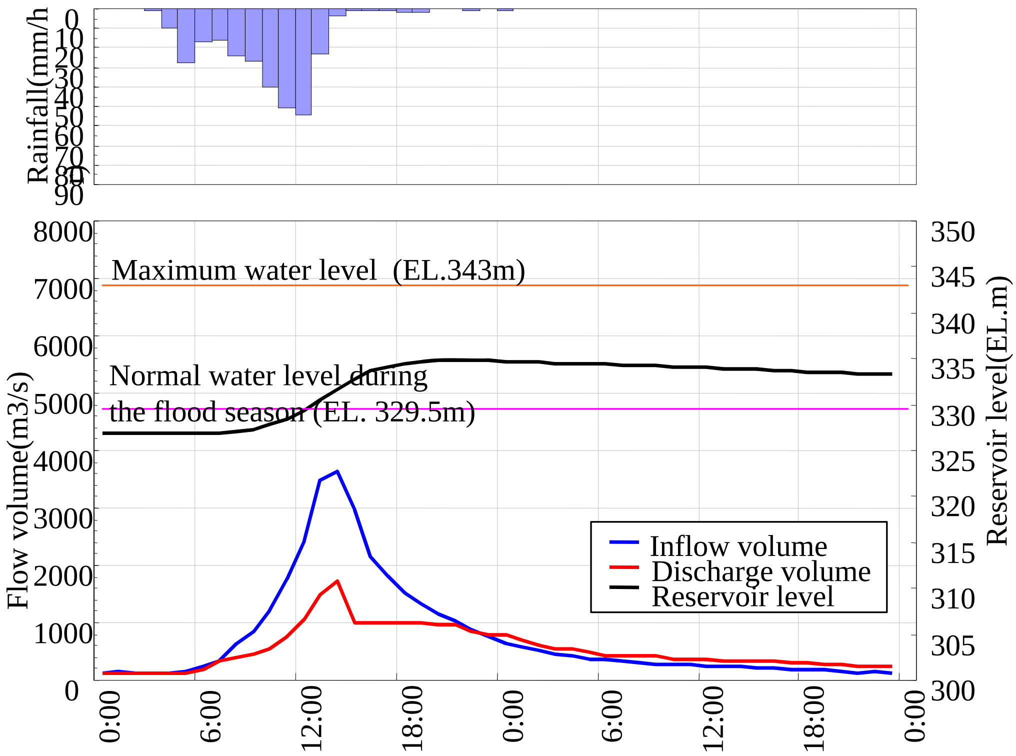



Fig. 16 Flood Control at Sameura Dam (Typhoon 14, 2005)

Fig. 17 Sameura Dam Before and After Flood Control at the Time of Typhoon 14 in 2005 (Secured storage rate: 0% (before flood control as shown in left photo), 100% (after flood control as shown in right photo))

**Effectiveness of Flood Control at Sameura Dam, Etc. at the Time of Typhoon 14 in 2005**

An assessment was made of the effectiveness of flood control at the Motoyama Bridge River Water Level Observation Station located approximately 5 km downstream from Sameura Dam. At a maximum inflow of 5,640 m3/s, 100 m3/s was discharged from the dam. Taking the maximum volume of 5,540 m3 /s, which was reduced by the dam , into consideration, it is estimated that not only the hospital adjacent to the right bank of the Yoshino River (as shown in Fig. 18) but also houses, etc. in central Motoyama-cho would be flooded without dam. Therefore, it can be presumed that the dam was very effective in reducing flood damage.

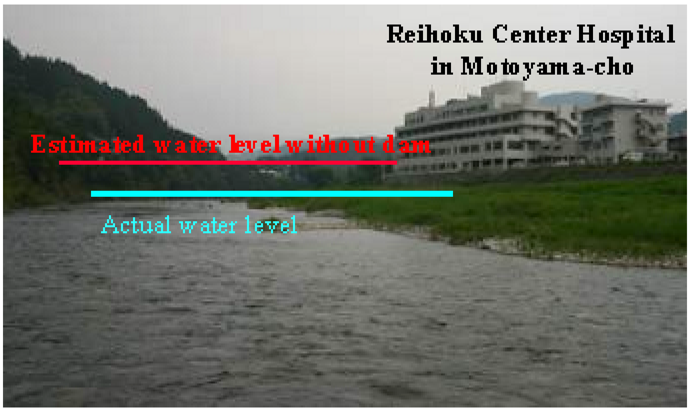



Fig. 18 Effect of Water Level Reduction (at Motoyama Bridge Location, Motoyama-cho)

In addition to Sameura Dam, there are other dams on the Yoshino River (Tomisato Dam, Yanase Dam and Shingu Dam). An assessment was conducted to determine the effectiveness of the reduction of flood damage in the downstream areas of the Yoshino River due to these dams.

As shown in Fig. 19, it was possible to reduce the flooded area by approximately 620 ha and reduce the number of houses by approximately 2,110. Accordingly, dams are presumed to have been effective in reducing flood damage. However, as a result of the flooding, some flood damage occurred in the lower reaches of the river because embankments have not been constructed in some areas. 30 houses and 850 ha of farmland, etc. were flooded in the low-lying areas along the river.

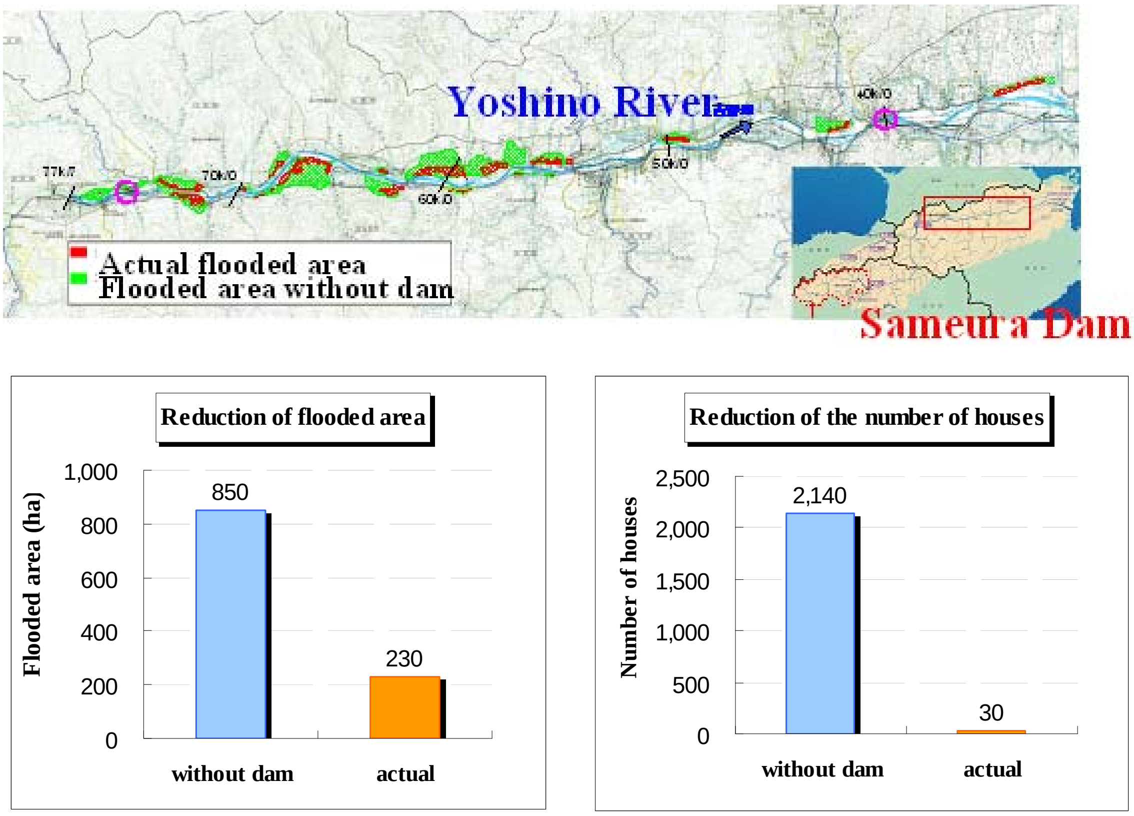



Fig. 19 Effectiveness of Reducing Flood Damage in Downstream Areas (Typhoon 14, 2005)

**Water supply Replenishment in 2005 and its Effectiveness**

Sameura Dam is the major water source for all four prefectures of Shikoku. As the rainfall in the area upstream from the dam in May 2005 was dramatically low compared to an average year, the water level of the reservoir decreased rapidly, while until mid-May the storage rate was 100%. Restrictions against water withdrawal were set in force. At first, the reduction rate of withdrawal were limited to 20%, but the rate were increased from 20% to 35%, to 50% and ultimately to 75% as the storage rate decreased.

All the efforts such as conservation of the water resources and coordination of water use among the water users were being made, but nevertheless, at 8:00 p. m. on August 19, the water use capacity of Sameura Dam eventually dropped to zero, and only the exclusive power generation capacity remained.

From August 19 to September 5, the water use capacity kept around 0. On five days during this period, discharge for water use conducted by courtesy of power company. On September 5, as previously mentioned on 4.5, the storage volume was recovered by the typhoon 14.

Fig. 20 shows the resultant reservoir level in Sameura Dam in 2005 and inflow into Ikeda Dam (actual volume with Sameura Dam and the estimated volume without Sameura Dam). This shows how Sameura Dam contributed to stabilize amount of flow throughout the year.

In 2005, replenishment from Sameura Dam was conducted on 284 days in order to maintain the normal flow and to provide water, and the total volume came to 450.44 million m3. This was 2.6 times the water use capacity of Sameura Dam of 173 million m3 and shows how Sameura Dam was being used effectively for water use.

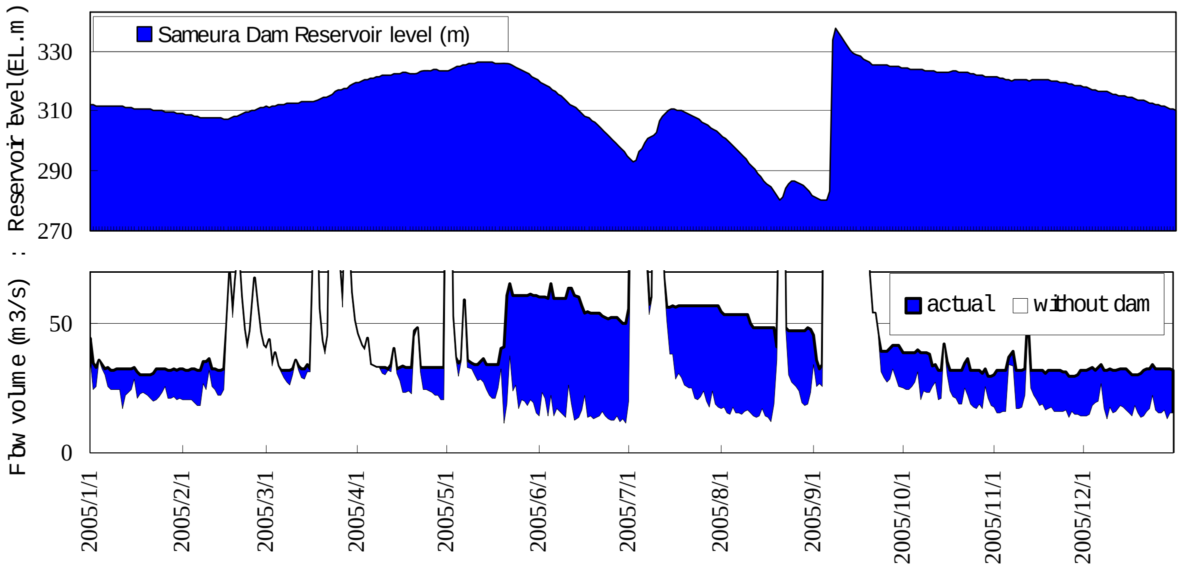



Fig. 20 Water Supply Replenishment in 2005 (Sameura Dam Reservoir level and Ikeda Dam inflow volume)

**FUTURE ISSUES**

It has been approximately 30 years since operations began at Sameura Dam. This paper has dealt with the achievements of the dam as regards flood control and water supply replenishment, focusing on the results of 2004 and 2005. In the flood control executed during Typhoon 14 in 2005, the reservoir level had been low prior to flooding due to a severe drought, and the dam had sufficient storage capacity to store the floodwater. However, if the reservoir level prior to flooding had been approximately equal to the normal water level during flood season, there would have been insufficient capacity for such big amount of floodwater, and the discharge would exceed the design flood outflow discharge of 2,000m3/s. In the past, at Sameura Dam, the discharge exceeded the design flood outflow discharge of 2,000m3/s as a result of flooding during Typhoon 5 in 1975 and Typhoon 17 in 1976. Accordingly, during the past 30-odd years, flooding that exceeded the design flood outflow discharge has already occurred three times.

As a result, improved flood control functions are urgently needed for Sameura Dam. A study should be conducted with a view to increasing the flood control capacity of Sameura Dam and renovating the discharge facilities, and renovation work should be conducted at the earliest opportunity.