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# Sedimentation control effect and environmental impact of sediment bypass in Miwa Dam Redevelopment Project

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## Abstract

Since the Miwa Dam was completed in 1959, a huge volume of sediment that flowed into the dam reservoir during flood events has been accumulating. To solve this issue, the sediment bypass facilities including a sediment bypass tunnel, a diversion weir and a check dam have been installed. The sediment bypass facilities were completed in 2005 and 14 test-runs have been conducted by 2016. This paper reviews its sedimentation control effect and environmental impacts resulting from the test-runs by comparing obtained data with the one predicted at the planning stage.

Keywords: Miwa dam, sediment bypass tunnel, diversion weir, environmental impacts

## 1 Overview of the Mibu River basin

The Tenryu River is one of the major rivers in Japan, with the length of its trunk river being approx. 213 km and a catchment area of 5,090 km$^2$. With about 1.21 million people (10 cities, 12 towns and 15 villages) living in its basin, the river is a foundation for the industries, economy, communities and culture in this region (Table 1). It is one of the fastest flowing rivers in Japan, and the rapid stream, combined with vulnerable strata and steep landforms, has caused numerous disasters such as floods and sediment-related disasters in its upper reaches.

Table 1: Characteristics of river basins

| | Tenryu River | Mibu River |
|---|---|---|
| Catchment area | 5,090 km$^2$ | 481.4 km$^2$ |
| Trunk river route length | approx. 213 km | 60.4 km |
| Number of communities in the basin | 10 cities, 12 towns and 15 villages | 1 city (Ina City) |
| Basin population | approx. 1.21 million * | approx. 70,000 (Ina City) |

* FY2015 census (MIC)

The Mibu River, one of the largest tributaries branching from the east bank of the Tenryu River, flows from its source on Mt. Senjogatake in the Southern Japanese Alps (elevation: 3,033 m) through Tsuetsuki Pass and the Miwa Dam lakeside to Bungui Pass. It has complex and vulnerable geological features that are represented by the Median Tectonic Line running north-south (Fig. 1).

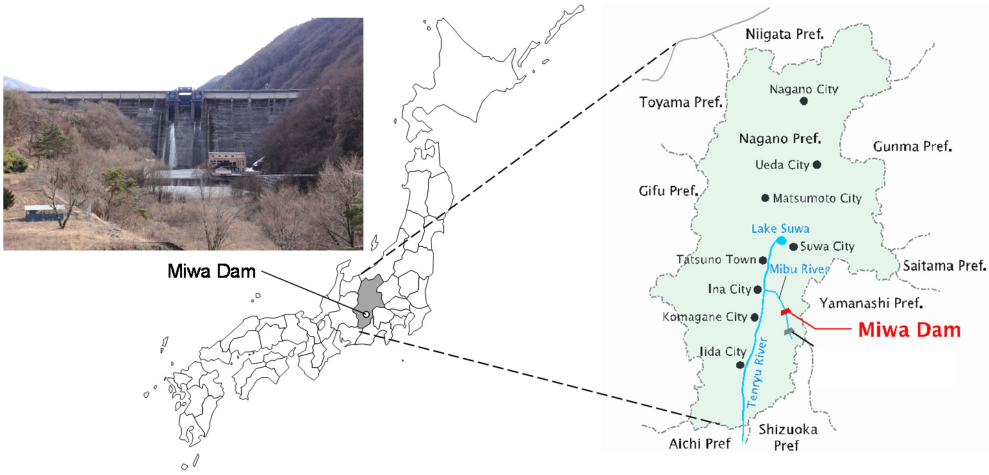



Fig. 1: Mibu River basin map

## 2 Necessity of redevelopment

The Miwa Dam is a multipurpose dam managed by the Ministry of Land, Infrastructure, Transport and Tourism. It was constructed in 1959 on the Mibu River for the purposes of flood control, power generation and irrigation. A dam redevelopment project is currently underway.

Before the Miwa Dam went into operation in December 1959, large floods occurred successively in August that same year and then in June 1961. In just the 3 years after completion of the dam, a huge volume of sediment of about 6.8 million $m^3$ exceeding the initial design storage capacity for sedimentation flowed into the reservoir, therefore, in 1966, the allocation of reservoir capacity was reviewed and the effective capacity was reduced about 5 million $m^3$ for the reservoir operation thereafter.

However, even after that, large floods occurred in July 1972, July 1982 and September 1983, and huge volumes of sediment of about 7.9 million $m^3$ flowed into the reservoir. Because it was predicted that the dam's use in flood control and water utilization would be hindered, drastic measures were required to protect reservoir functions.

Fig. 2 shows the situation of the sediment deposited in the reservoir after the review of reservoir capacity allocation in 1966. At present, the deposited sediment is within the design storage capacity for sedimentation owing to the collection of gravel in the reservoir, excavation and the sediment bypass.

## 3 Purposes and contents of Miwa dam redevelopment project

### 3.1 Purposes of the project

The Tenryu River System River Improvement Plan (July 2009) seeks to enhance flood control by means of the Miwa Dam, etc. and, at the same time, to improve the river channel by excavation, forest clearing, etc. It aims at passing flood water safely in the downstream river channel even in the same size of a flood as that in September 1983 or July 2006 which were the almost largest floods recorded after the World War II.

The Miwa Dam Redevelopment Project has the following two objectives.

- To enhance the flood control functions of the existing Miwa Dam and protect people's lives from flooding and inundation in the upper reaches of the Tenryu River.
- To maintain the functions of the Miwa Dam by controlling sedimentation into the dam reservoir.

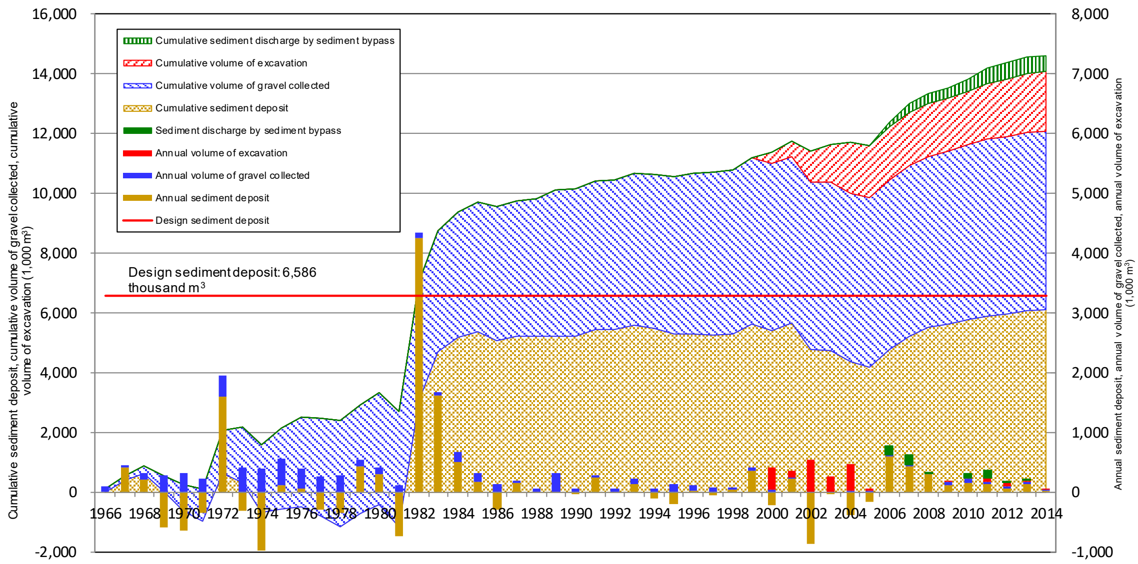



Fig. 2: Yearly changes in sediment deposits (After the change in capacity in 1966)

## 3.2 Contents of the project plan

The plan can be roughly divided into "flood control improvements" and "reservoir sedimentation control measures".

(1) Flood control

The flood control plan for the Miwa Dam states that, at the Tenryu-kyo control point, there will be a reduction of about 200 $m^3/s$ in discharge (a reduction of about 0.4 m in water level) if a flood the same size as the largest flood recorded after the World War II occurs. The discharge downstream of the dam will be reduced to 410 $m^3/s$ by controlling 250 $m^3/s$ against the 660 $m^3/s$ rate of inflow at the dam.

(2) Reservoir sedimentation control measures

As for the reservoir sedimentation control measures, the sediment bypass facilities including a sediment bypass tunnel, a diversion weir and a check dam were installed in order to control the inflow of sediment into the reservoir. At the same time, the continuity of sediment movement at the dam point will be ensured. Fig. 3 shows the sediment discharge plan for the Miwa Dam. It should be noted that this sediment discharge plan shows the average annual inflow and outflow of sediment.

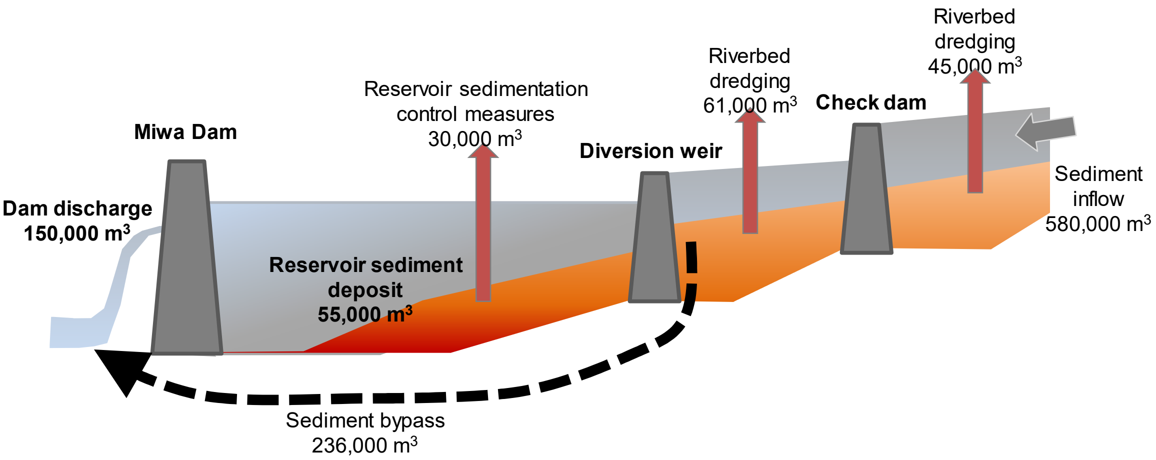



Fig. 3: Average annual inflow and outflow of sediment in the sediment discharge plan of Miwa Dam

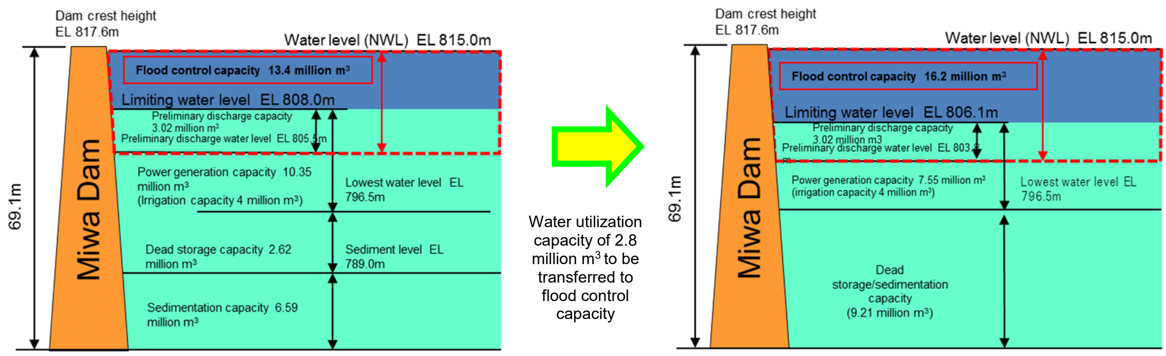
(3) Parameters before and after the Miwa Dam redevelopment project

Basic parameters before and after the redevelopment are as shown in Table 2 and Fig. 4.

Table 2: Basic parameters before and after the Miwa Dam redevelopment project

| | Miwa Dam (Before redevelopment) | Miwa Dam (After redevelopment) | Difference |
|---|---|---|---|
| **Type** | Gravity concrete dam | Gravity concrete dam | |
| **Dam height** | 69.1m | 69.1m | |
| **Catchment area** | 311.1km$^2$ | 311.1km$^2$ | |
| **Total reservoir capacity** | 29.95 million m$^3$ | 29.95 million m$^3$ | |
| **Flood control capacity** | 13.40 million m$^3$ | 16.20 million m$^3$ | 2.8 million m$^3$ increase |
| **Water utilization capacity *** | 10.35 million m$^3$ | 7.55 million m$^3$ | 2.8 million m$^3$ increase |

* Capacities during a flood are shown.




<Allocation of reservoir capacity before redevelopment> <Allocation of reservoir capacity after redevelopment>

Fig. 4: Change in the allocation of reservoir capacity

## 4 Test-runs of the sediment bypass facilities

The sediment bypass facilities consist of a check dam (height: 10.2 m, sediment storage capacity: 280,000 $m^3$), a diversion weir (height: 20.5 m, sediment storage capacity: 520,000 $m^3$), an inlet, a tunnel (length: 4,308 m, maximum discharge: 3,000 $m^3$/s) and an outlet. Since there is a lot of fine sediment in the deposited one in the Miwa Dam, a plan has been devised so that only fine sediment will be bypassed in order to prevent damages by coarse sediment impacts on the tunnel invert concrete. Coarse sediment will be trapped by the upstream check dam, while the sediment that flows through the check dam will be captured in the trap weir (submerged weir) upstream of the inflow, and they will be removed by excavation. In the upper reach of the inflow area, a debris fence consisting of steel pipes arranged in an arc shape is installed in order to prevent debris from flowing into the tunnel. In the inflow area, two gates are installed to control the discharge. In order to facilitate gate operation during a large flood, the bypass discharge is controlled to 300 $m^3$/s with the gate fully open by way of a side overflow weir that is installed downstream of the gate. The tunnel is 7 m high and 7.8 m wide, and has a U-shaped cross-section and a gradient of 1/100. It is designed so that, when the channel is open and water flows at the design discharge of 300 $m^3$/s, water will flow downstream at a velocity of 10.8 m/s. At the outlet, a decelerating work in the form of a semicircular pool is installed to prevent scouring of the downstream river as caused by the discharged from the bypass (Fig. 5).

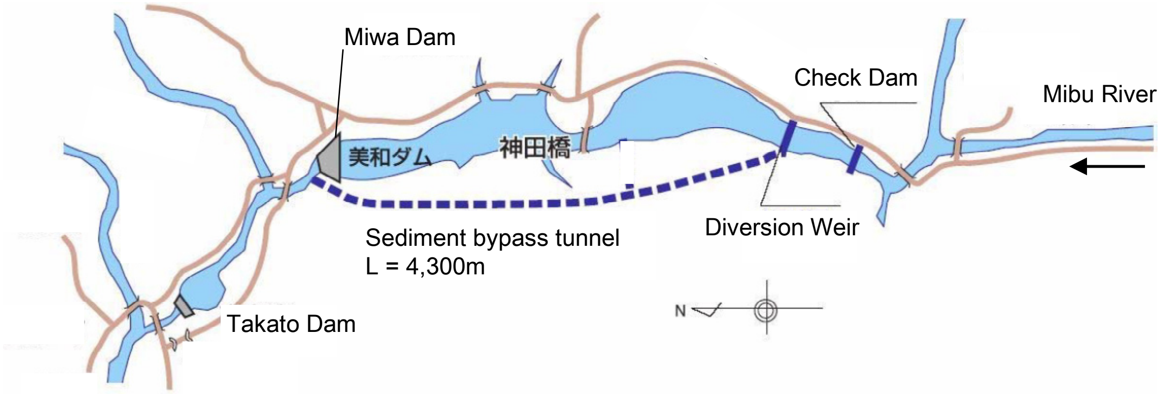



Fig. 5: Overview of the sediment bypass facilities (Plan view)

The sediment bypass tunnel is operated by coordination with water utilization and flood control. Specifically, bypass discharge starts when it is expected that the volume of inflow will exceed 100 $m^3$/s after the reservoir water level recovery and continues up to the maximum of 300 $m^3$/s (Fig. 6). Bypass discharge ends when the volume of inflow passes its peak and is less than 100 $m^3$/s. Also, during discharge by the dam, 25 $m^3$/s of discharge is used for power generation. The effect of sedimentation control and the impact on the downstream environment as a result of the operation were confirmed by carrying out monitoring surveys during the test runs.

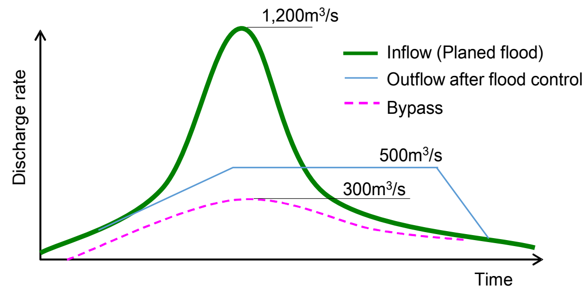



Fig. 6: Concept Graphic representation of flood control and bypass discharge

# 5 Results of the test-runs for the sediment bypass facilities

## 5.1 Effect of sedimentation control using the sediment bypass facilities

The sediment bypass facilities have been operated 14 times in all over a period of 12 years from 2005 when the test-runs were started until the present. The total volume of sediment bypassed is about 550,000 $m^3$ and, if this bypassed volume is added to the roughly 1.19 million $m^3$ of sediment captured by the check dam and the diversion weir (Table 3 and Fig. 7), it confirms that sediment inflow of about 1.74 million $m^3$ is prevented from entering the dam reservoir.

Table 3: Operation records of the sediment bypass facilities

| № | Flood name | Maximum discharge during flood | Situation of bypass test-run | | | | |
|---|---|---|---|---|---|---|---|
| | | | Max. discharge | Discharge time | Total discharge | Max. SS concentration | Sediment discharge |
| 1 | July 2006 flood | 366m3/s | 242m3/s | approx.47hours | 22.989million $m^3$ | 12,200mg/L | 150,000$m^3$ |
| 2 | July 2007 flood | 166m3/s | 136m3/s | approx.35hours | 7.553million $m^3$ | 2,810mg/L | 14,000$m^3$ |
| 3 | September 2007 flood | 568m3/s | 264m3/s | approx.48hours | 16.617million $m^3$ | 20,200mg/L | 155,000$m^3$ |
| 4 | June 2008 flood | 105m3/s | 30m3/s | approx.6hours | 0.461million $m^3$ | 1,000mg/L | 300$m^3$ |
| 5 | June 2010 flood | 145m3/s | 57m3/s | approx.14hours | 2.624million $m^3$ | 1,880mg/L | 3000$m^3$ |
| 6 | July 2010 flood | 229m3/s | 199m3/s | approx.146hours | 36.746million $m^3$ | 1,2100mg/L | 80,000$m^3$ |
| 7 | May 2011 flood (1) | 293m3/s | 205m3/s | approx.51hours | 14.746million $m^3$ | 8,270mg/L | 43,000$m^3$ |
| 8 | May 2011 flood (2) | 141m3/s | 102m3/s | approx.27hours | 6.210million $m^3$ | 1,940mg/L | 5000$m^3$ |
| 9 | September 2011 flood (1) | 218m3/s | 178m3/s | approx.87hours | 22.768million $m^3$ | 12,590mg/L | 60,000$m^3$ |
| 10 | September 2011 flood (2) | 317m3/s | 215m3/s | approx.25hours | 7.678million $m^3$ | 7,230mg/L | 22,000$m^3$ |
| 11 | June 2012 flood | 128m3/s | 74m3/s | approx.28hours | 3.922million $m^3$ | 3,000mg/L | 4000$m^3$ |
| 12 | September 2013 flood | 244m3/s | 179m3/s | approx.25hours | 3.67million $m^3$ | 3,540mg/L | 8000$m^3$ |
| 13 | September 2015 flood | 194m3/s | 99m3/s | approx. 5hours | 1.32million $m^3$ | 2,820mg/L | 3000$m^3$ |
| 14 | September 2016 flood | 66m3/s | 34m3/s | approx.17hours | 1.361million $m^3$ | 420mg/L | 400$m^3$ |
| | Total | - | - | approx. 561 hours | 148.665million $m^3$ | - | 548,000 $m^3$ |

In September 2007, the test-run was conducted during the large flood caused by typhoon from the time at which the inflow discharge exceeded about 450 $m^3/s$ to the time at which it became less than about 50 $m^3/s$. During the period of the bypass operation, about 16.6 million $m^3$ out of ca. 30 million $m^3$ of inflow sediment was discharged by bypassing, and about 55% of the turbid water from the upper reaches was bypassed to the lower reaches. The Suspended sediment concentration (SS) of the bypass discharge water (max. 20,200 mg/L) was slightly lower just after the start of discharge compared to the one of the inflowing water from the upper reaches (max. 25,000 mg/L). However, during the latter half of the flood, these concentrations were nearly the same resulting that the turbid water of a higher concentration during the flood was bypassed (Fig. 8).

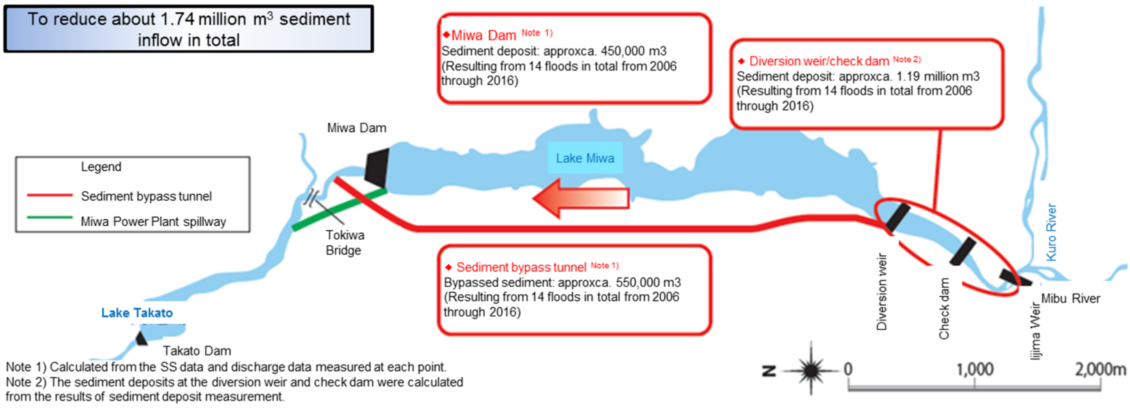



Fig. 7: Sediment management effects with the sediment bypass facilities

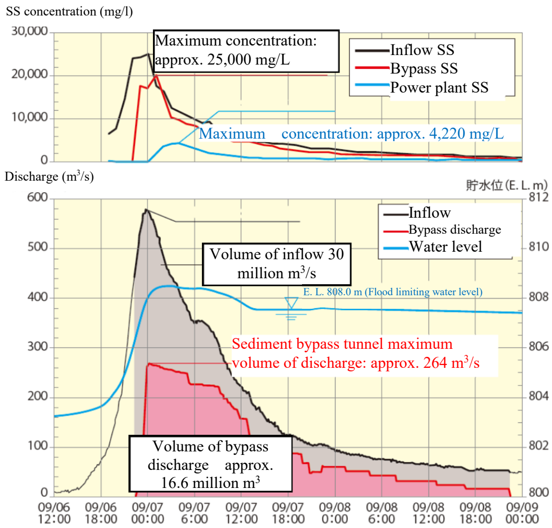



Fig. 8: Changes in discharge and turbidity over time (September 2007)

## 5.2 Overview of environmental surveys

In order to identify any environmental changes caused by the test-runs of the sediment bypass facilities, the items shown in Table 4 were monitored. The monitoring points are shown in Fig. 9. It should be noted that the water quality, mainly SS, and surveys of the aquatic environment have been conducted continually even beyond 2010, during the operation of the sediment bypass facilities.

Table 4: Contents of the environmental monitoring survey

| Classification | Monitored item | Monitoring point | Before test-run | | | | | After test-run | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010～2016 |
| Aquatic environment | Water quality (SS) | Reservoir/River channel | | | | | ● | ● | ● | ● | ● | ● | ● |
| Physical environment | Bottom deposition | River channel | | | | | | ● | ● | ● | | | |
| Biological environment | Attached algae | River channel | | | | ● | ● | ● | ● | ● | | | |
| | Benthos | River channel | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | |
| | Fishes | River channel | | | ● | ● | ● | ● | ● | ● | ● | ● | |

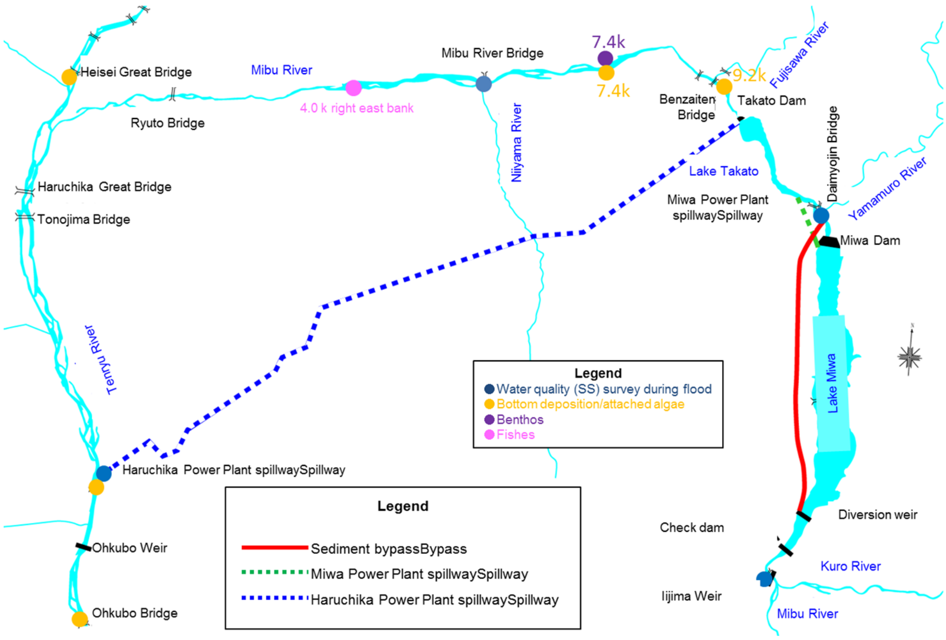



Fig. 9: Monitoring points of the environmental survey

## 5.3 Evaluation of the environmental impacts

(1) Assumed environmental impacts

As a result of the operation of the sediment bypass facilities, the discharge of water flowing downstream of the Miwa Dam remains unchanged from that prior to the operation. However, as a result of the turbid water that has flown downstream from the upper reaches due to flood waters being directly discharged, turbidity in the lower reaches has been increased compared with the one before sediment bypass operation.

(2) Evaluation of the environmental impacts

In order to evaluate environmental changes before and after the test-runs of the sediment bypass facilities, several monitoring surveys have been conducted.

1) Concentration of turbid water in the river downstream of the dam

In order to investigate the changes in turbidity in the downstream river after the sediment bypass operation, several surveys were conducted of the post-flooding turbidity of the water discharged from the Miwa Power Plant, which takes its water from the Miwa Dam, and the water discharged from Haruchika (to the Tenryu River), which comes from the Takato Dam.

From a comparison with the flood in October 2004 that occurred before the sediment bypass operation, it has been confirmed that the magnitude of floods in July 2006 and September 2007 were greater than that in October 2004. Even though high turbid water flowed from the Iijima weir into the Miwa dam, the turbidity of the water discharged from the Miwa Power Plant remained low which did not affect the downstream river (Fig. 10).

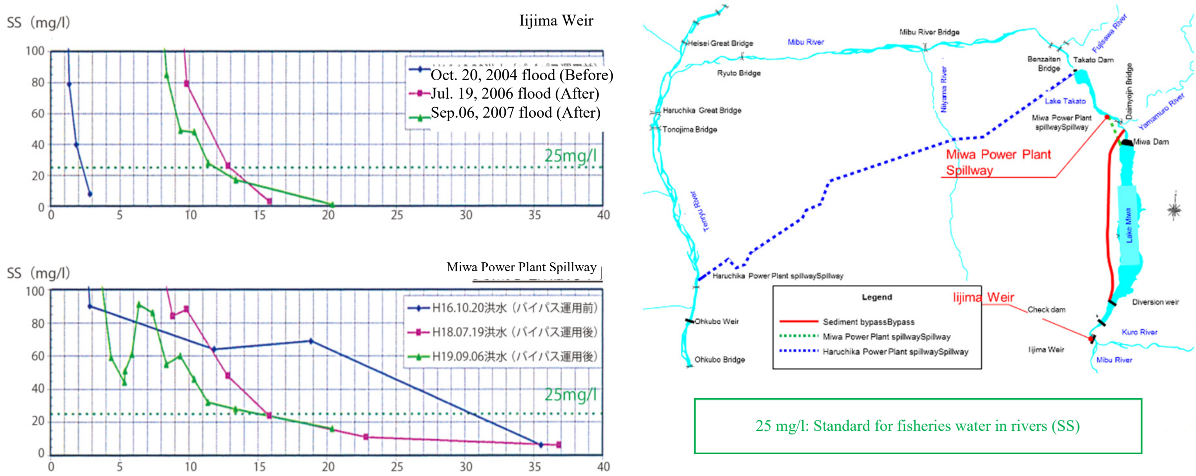



Fig. 10: Decreasing trend of flood-related turbidity (SS) before and after test-runs of the sediment bypass

2) Deposition of wash load

Although there were changes in the flow of water and vegetation resulting from the floods, no deposition of wash load was identified. No impact on the downstream river was identified as a result of a huge amount of wash load having been bypassed during floods (Fig. 11).

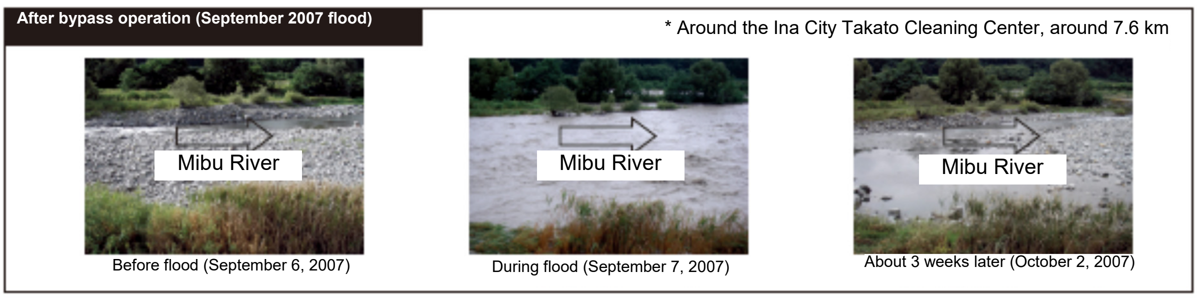



Fig. 11: Deposit of wash load

3) Algae attached on the stone surfaces

In order to confirm the impact of the operation of the sediment bypass on the aquatic lives before and after the test-runs, the recovery of attached algae was evaluated from the quantity of chlorophyll a. Subsequently, it was confirmed that algae in both the Tenryu

River and Mibu River recovered in a similar manner before and after the test-runs of the sediment bypass, and no change resulted from the test-runs of the sediment bypass (Fig. 12).

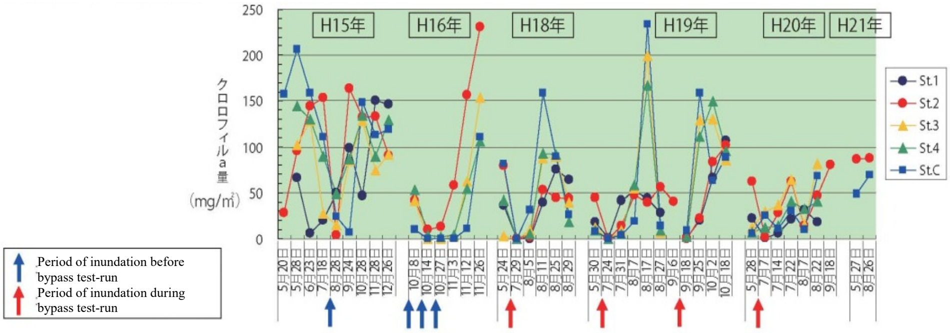
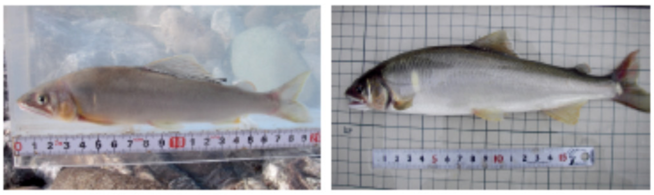



Fig. 12: Attached algae on stone surfaces

4) Fishes and benthic animals

Although the growth of sweet fish was tentatively delayed by the flood, it grew favorably thereafter (Fig. 13). The populations of the following fishes remained small in 2006 and 2007 when there were consecutive large floods as well as thereafter. Surveys that were conducted in 2011 and 2012 showed that populations had recovered to the same level as that before the sediment bypass was put into operation.

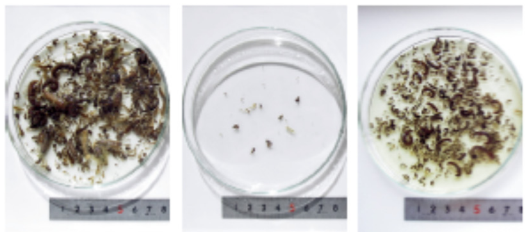
The number of benthic animals decreased immediately after the flood. However, it recovered about four weeks after the flood to a level similar to that before the sediment bypass was put into operation. Also, there was no great change in the number of aquatic lives in winter time before and after the sediment bypass operation (Fig. 14).



▲ About 1 week after flood (July 26, 2007)

▲ 6 weeks after flood (August 30, 2007)

Fig. 13: Sweet fish



▲ Immediately before flood (September 6, 2007)

▲ Immediately after flood (September 18, 2007)

▲ About 4 weeks after flood (October 18, 2007)

Fig. 14: Benthos

## 5.4 Evaluation of influence on the facilities

(1) Structure of the facilities

During the test-runs, the functions of the facilities were evaluated such as accuracy of the observed discharge data etc., performance of the debris fence and the energy dissipater at the sediment bypass outlet etc. As a result, it was found that each of the facilities functioned as designed. In the September 2007 flood, peak discharge was up to 264 $m^3/s$ which is about 90% of the design maximum discharge of $300 m^3/s$. However, there was no damage in the facilities (Fig. 15) and up until now 14 test-runs have been conducted smoothly without any troubles in the facilities (Fig. 16).

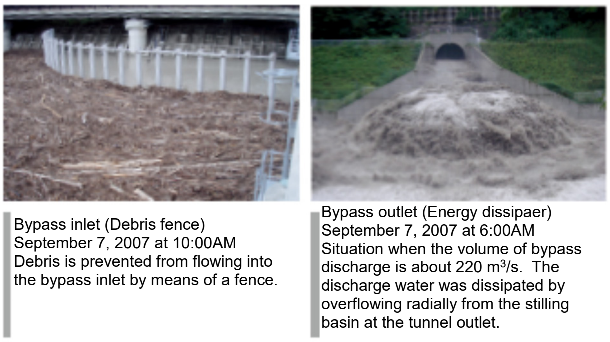



Fig. 15: Facilities during flood


Fig. 16: Wear inside the sediment bypass tunnel (As of January 2016)

(2) Characteristics of discharge at the diversion weir

In the July 2006 flood, data was obtained of discharge at 240 $m^3/s$, with the design discharge for the bypass being 300 $m^3/s$. The bypass discharge measured with a water gauge/current meter was the same as the designed value. In addition, side overflow started about the time when the discharge exceeded 200 $m^3/s$ in the same manner as with the model experiment (Fig. 17).

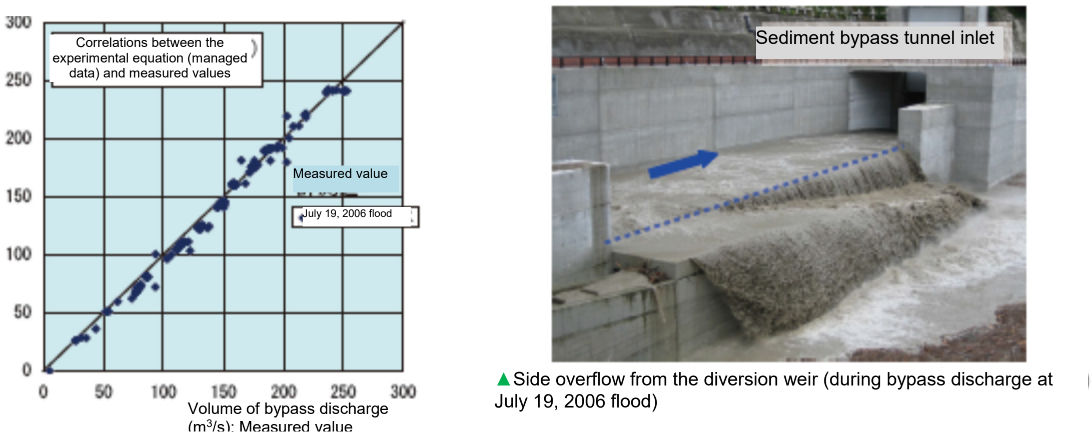



Fig. 17: Discharge characteristics of the diversion weir

## 6 Conclusions

The results of the test-runs of the sediment bypass facilities are summarized below.

- During the 12 years operation from 2006, a total of 14 test-runs were conducted and about 1.74 million $m^3$ of inflow sediment was bypassed to prevent flowing into the dam reservoir.
- As a result of the environmental surveys conducted from 2000 to 2009, the following was confirmed.

(1) During bypass discharge, the deposition of wash load on the river bank or on river bed stones did not occur.

(2) There was no significant impacts on the attached algae, fishes and benthic animals.

In addition to the sediment bypass facilities described in this paper, further sediment control measure has been studied and its construction work has been started in 2015. This additional measure is to temporally stock dredged sediment in normal time which will be flushed out and guided to the sediment bypass tunnel in flood time. This additional sediment control measure will increase the bypass efficiency which may have unknown environmental impacts caused by high sediment concentration. The plan for this additional measure for reservoir sedimentation control and the assumed environmental impacts will be discussed in a separate paper.

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