# Reservoir Sedimentation Management at the Asahi Dam

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## 1. INTRODUCTION

The Kansai Electric Power Co., Inc. (the KANSAI) is one of several electric utility companies in Japan, and owns and operates 148 hydropower plants amounting to a capacity of 8,184 MW.

Some of the hydropower plants have been suffering from sedimentation, which is inevitable to dams. The KANSAI has studied various countermeasures against sedimentation to coexist with natural environment and local people.

This paper introduces one good practice of sedimentation management in reservoirs; sediment bypass system at the Asahi Dam. The KANSAI successfully put the bypassing method to practical use, which is highly estimated.

## 2. PLAN AND DESIGN OF THE SEDIMENT BYPASS SYSTEM

### 2.1 Outline of the Asahi Dam

The Asahi Dam is on the lower regulating reservoir of the Oku-yoshino Power Plant, which is the pure-pumped storage type hydropower plant.

The Oku-yoshino Power Plant was designed as a peaking plant to meet augmented electricity demand, and plays an important role for improving the grid efficiency and reliability with thermal and nuclear power plants. The construction started in 1975 and ended in 1980. The specifications are shown in Table-1 and the location is shown in Figure-1.

### 2.2 Background

Since the completion of the Asahi Dam, a prolonged turbidity problem had become serious due to frequent collapse of mountain slopes and heavy rainfalls in the upstream basin. In particular, in 1990, four successive large-scale runoffs caused remarkable prolonged turbidity lasting over 200 days.

Additionally, the mean annual sedimentation from 1989 to 1995 increased sharply to 85,000 $m^3$/year, while the one during 10 years from 1978 to 1988 was approximately 20,000 $m^3$/year. This was caused by widespread collapse of slopes in the upstream due to frequent typhoons in 1989 and 1990. The KANSAI made a simulation to predict the sediment profile and its influence to the power generation. The results showed that the sediment level 10 years after (2003) would rise up to the intake level and would intervene the power generation.

Table-1: Specifications of the Asahi Dam

| | | |
|---|---|---|
| Catchment area | $39.2 km^2$ | |
| Design flood | $1,200 m^3/s$ | |
| Power Plant | Name | Oku-yoshino |
| | Max. output | 1,206MW |
| | Max. discharge | $288 m^3/s$ |
| | Effective head | 505m |
| Dam | Type | Arch |
| | Height | 86.1m |
| | Crest length | 199.41m |
| Reservoir | Gross storage | * $15.47 \times 10^6 m^3$ |
| | Effective storage | * $12.63 \times 10^6 m^3$ |
| | Available depth | 32m |

*: when constructed

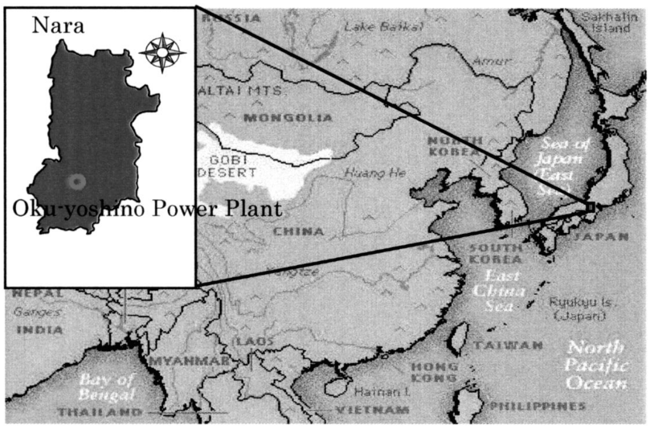



Figure-1: Location of the Asahi Dam

The KANSAI studied countermeasures that would effectively reduce the prolonged turbidity and the advance of sedimentation. From the study, the most appropriate measure for the Asahi Dam was to install sediment bypass system. There are primarily two reasons for this conclusion. First, the Asahi Reservoir does not need to store inflow water because the reservoir is for the pure pumped-storage power plant. Second, the drainage basin of the Asahi Dam is small and the runoff is relatively low.

### 2.3 Design of the Sediment Bypass System

The sediment bypass system at the Asahi Dam was designed to treat bed loads and suspended loads besides wash loads from the purposes of mitigating both prolonged turbidity and sedimentation. There were two requirements for the bypass system. One was to eliminate most of the prolonged turbidity when the peak inflow was 200 $m^3$/sec, which is the 1-year return period inflow at the Asahi Dam. The other was to flush all of bed loads from the upstream when the peak inflow was 660 $m^3$/sec which is the maximum inflow in the past, or when 1,200 $m^3$/sec which is the design flood, at the Asahi Dam. The capacity of the bypass system was determined as 140 $m^3$/sec by performing simulations (1- and 2-dimensional models), which was derived by the former requirement.

The schematic layout of the bypass system was designed in consideration of the site characteristics. Based on the uniform flow calculation, the cross-section of the bypass tunnel was planned so that the tunnel could pass the flow with the water depth of 80 % of the tunnel height. The entrance of the tunnel was composed of a diversion weir and an orifice intake, which would be desirable for flushing bed loads. With these structures, the volume of water and sediment into the tunnel could be naturally regulated. The flow direction from the outlet of the tunnel was set as parallel as possible that of the original river channel. The elevation of the tunnel invert was designed above the flood water level (1,200 $m^3$/sec).

After the schematic design, hydraulic model tests were conducted besides the numerical simulations so as to evaluate the capacity of the bypass tunnel to discharge bed loads.

The specifications of the bypass system, the layout and the outlines of the components are shown in Table-2, Figure-2 and Figure-3 respectively.

Table-2: Specifications of the bypass system

| | | |
|---|---|---|
| Weir | Height | 13.5m |
| | Crest Length | 45.0m |
| Intake | Height | 14.5m |
| | Width | 3.8m |
| | Length | 18.5m |
| | Type | Reinforced Concrete with Steel Lining |
| | Gate | 1 |
| Bypass tunnel | Height | 3.8m |
| | Width | 3.8m |
| | Shape | Hood |
| | Gradient | Approx. 1/35 |
| | Max.Discharge | 140$m^3$/s |
| | Type | Reinforced Concrete Lining |
| Outlet | Height | 15.0m |
| | Width | 5.0～8.0m |
| | Type | Reinforced Concrete |

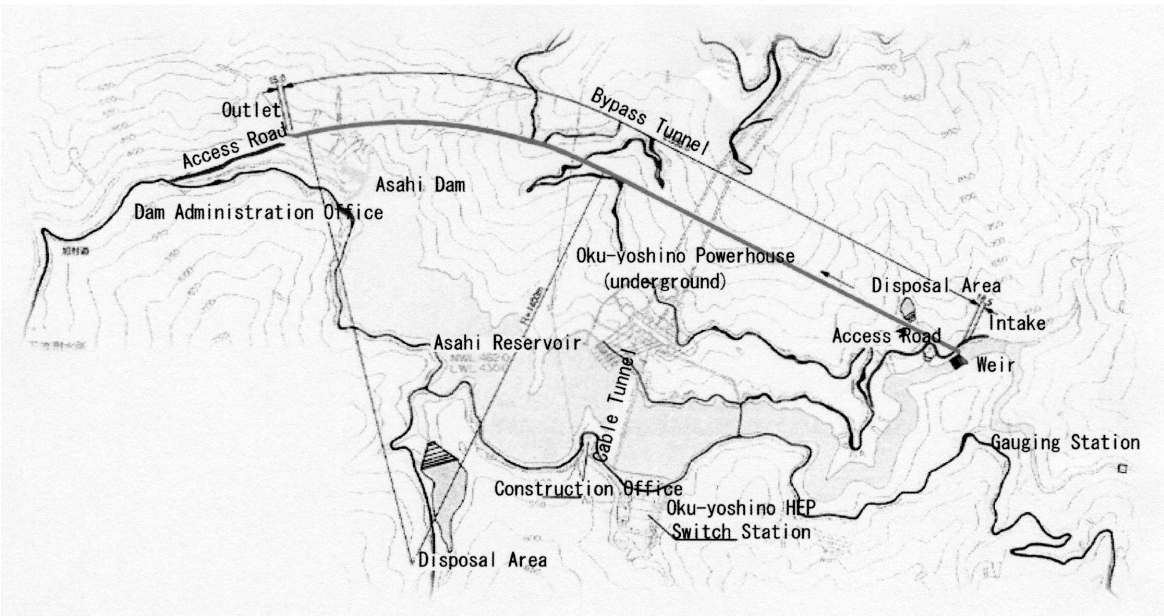



Figure-2: General layout of the bypass system

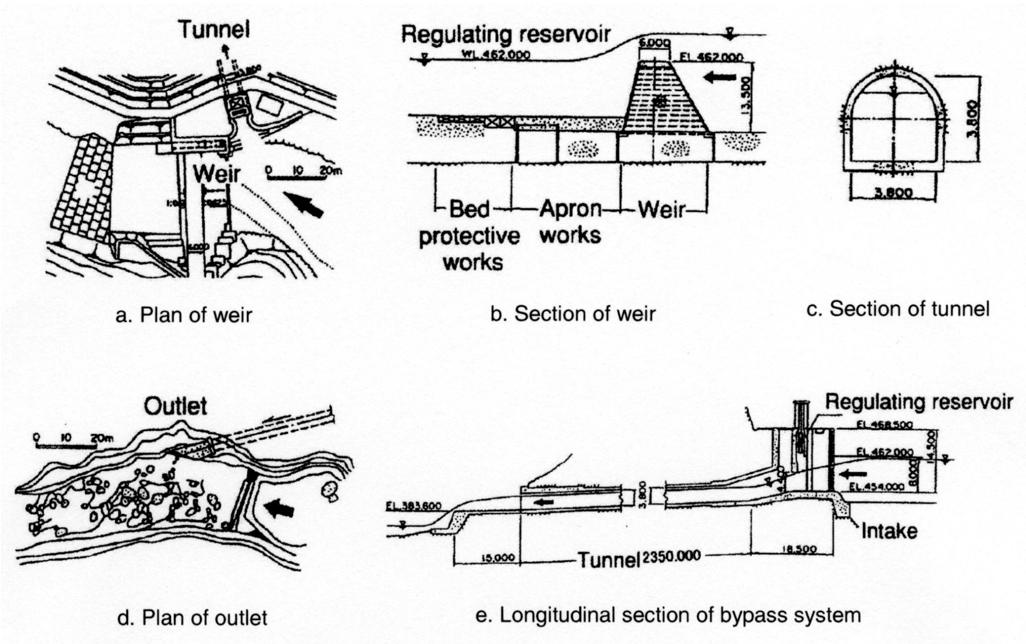



Figure-3: Main components of the bypass system

## 3. PERFORMANCE AND EFFECT ON THE BYPASS SYSTEM

### 3.1 Actual Results of Operation

Figure-4 shows the monthly inflow to the Asahi Dam and the monthly discharge through the bypass tunnel in 2004. This figure tells us that approximately 62 percent of the total inflow to the Asahi Dam is directly bypassed to the downstream.

Figure-5 summarizes the yearly operation of the bypass system from 1999 to 2004. This figure tells us that approximately 60 percent of the total inflow to the Asahi Dam is directly bypassed to the downstream every year. We should notice that the inflow in 2004 is larger than that in the other years. We have encountered large flood over 330 m$^3$/sec three times in 2004, which is 5-year return period flood.

### 3.2 Effect on Prolonged Turbidity

Figure-6 reveals that the bypass system mitigated the prolonged turbidity problem. Suspended solid concentration (SS) has been observed once a day at the two points, 4.3 km upstream and 1.6 km downstream from the Asahi Dam. The number of days when SS is over 5 ppm at the downstream measuring point drastically decreased to less than about 10 days on average after the operation of the bypass system in 1998. Please note that the year 2000 was a dry year and that the year 2004 was a wet year.

Let us focus on the cases on June 20, 2001 (the peak inflow of 288 m$^3$/sec) and on July 13, 1987 (the peak inflow of 271 m$^3$/sec). The results measured 1 week later from the peak inflow at the two points are represented on Figure-7 and Figure-8 respectively. The SS at the downstream measuring point in 1987 is about 20 ppm, when the bypass system was not constructed. On the other hand, the SS at the point in

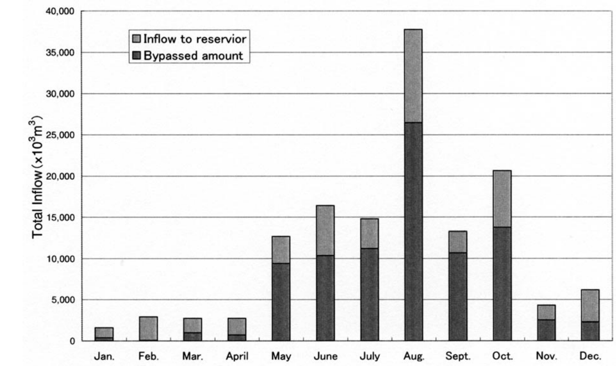



Figure-4: Monthly inflow in 2004

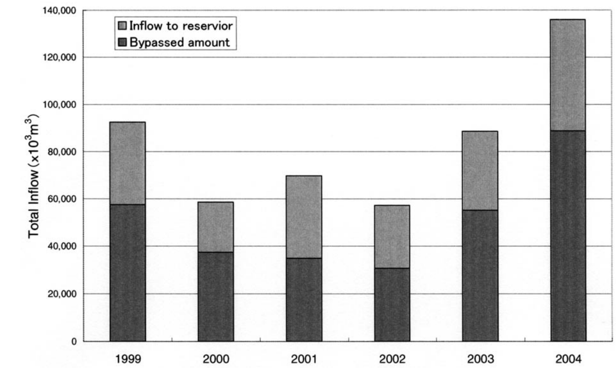
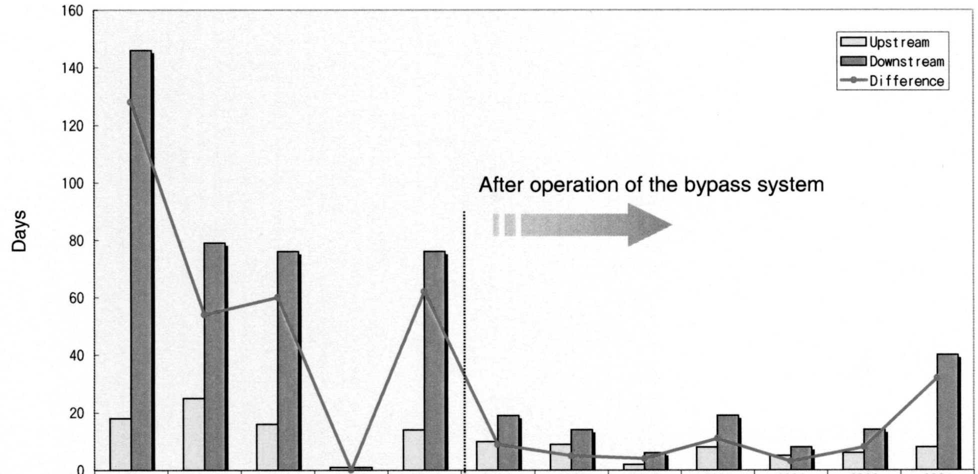



Figure-5: Yearly inflow in 1999 ~ 2004

2001 is below 5 ppm, when the bypass system was installed. These results clearly show that the bypass system is mitigating the prolonged turbidity.

### 3.3 Effect on Reservoir Sedimentation

Figure-9 shows the changes of sedimentation volume in the reservoir. After the operation of the bypass system in 1998, the reduced sediment volume with the bypass system is calculated by the total sediment




| | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Upstream | 18 | 25 | 16 | 1 | 14 | 10 | 9 | 2 | 8 | 5 | 6 | 8 |
| Downstream | 146 | 79 | 76 | 1 | 76 | 19 | 14 | 6 | 19 | 8 | 14 | 40 |
| Difference | 128 | 54 | 60 | 0 | 62 | 9 | 5 | 4 | 11 | 3 | 8 | 32 |

Figure-6: Number of days with turbidity over 5 ppm

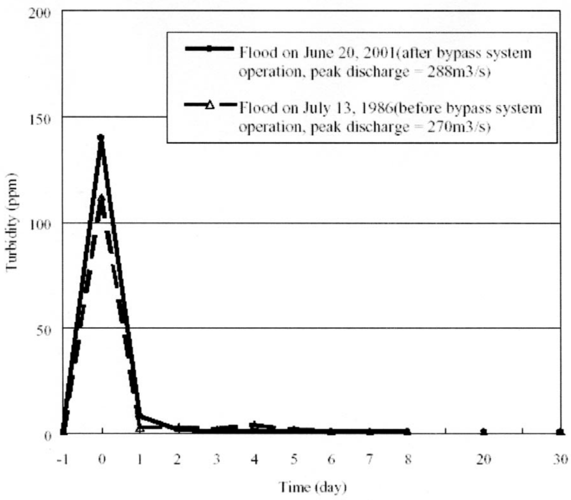



Figure-7: Turbidity 4.3 km upstream from the Asahi Dam

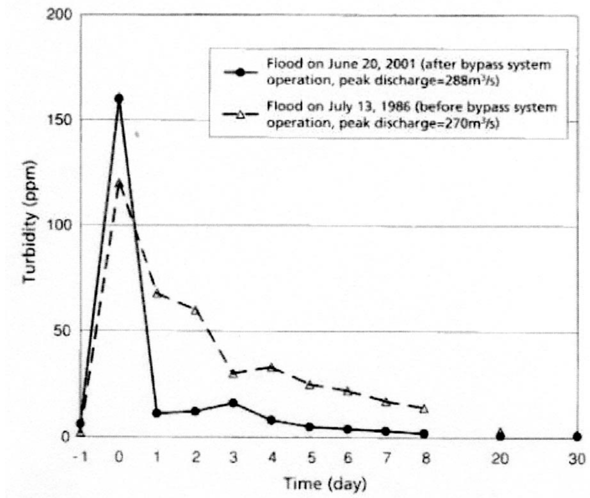



Figure-8: Turbidity 1.6 km downstream from the Asahi Dam

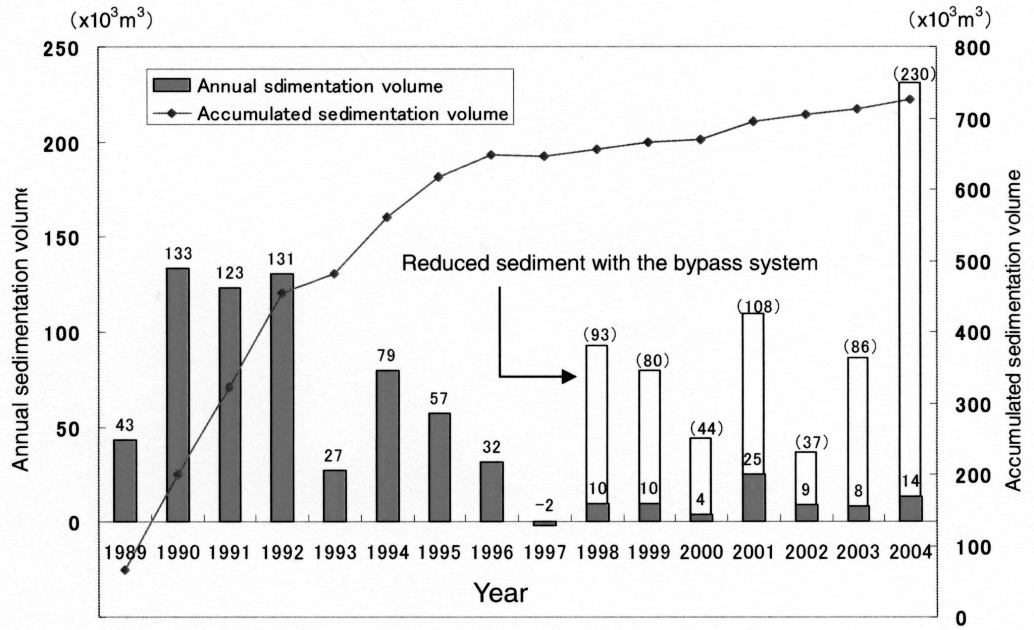



Figure-9: Sedimentation volume in the Asahi Reservoir inflow minus the difference of the volume between successive years through the bathymetric survey. The total sediment inflow is calculated with the Ashida-Michiue Formula, which shows the volume of bed load. In the calculation, the grain size distribution is derived from a field survey ($D_{50}$ = 5 cm) and the porosity of the bed loads is assumed to be 0.4. For labor saving, the inflow under 30 $m^3$/sec is neglected.

It can be concluded from Figure-9 that only 10 to 20 % of the total sediment is deposited in the reservoir, while 80 to 90 % is discharged through the bypass tunnel.

After several operations of the bypass system, the elevation of the upstream riverbed was almost no change. Thus the weir of the bypass system does not trap the sediment and almost all of bed loads are discharged through the bypass tunnel.

### 3.4 Effect on Water Quality

The bypass system does not give any significant harmful effect on the water quality of the reservoir. Figure-10 shows the changes of turbidity (SS), total nitrogen (T-N) and total phosphorus (T-P) in the reservoir.

Turbidity has been low because the total amount of the turbid water into the reservoir has decreased after the operation of the bypass system. For the T-N and T-P values, there is no significant problem regarding the water quality of the reservoir.

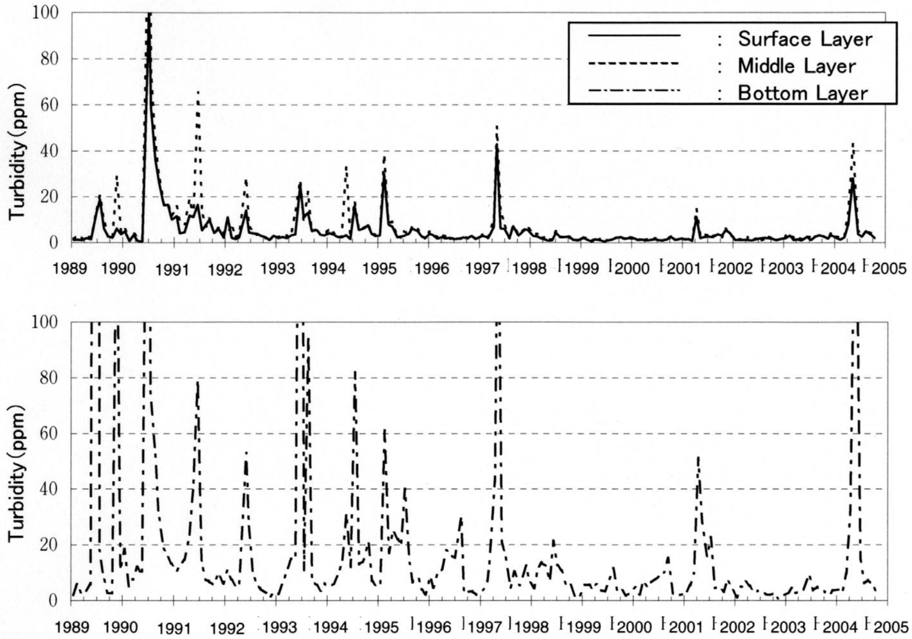



Figure-10(a): Variations of Turbidity

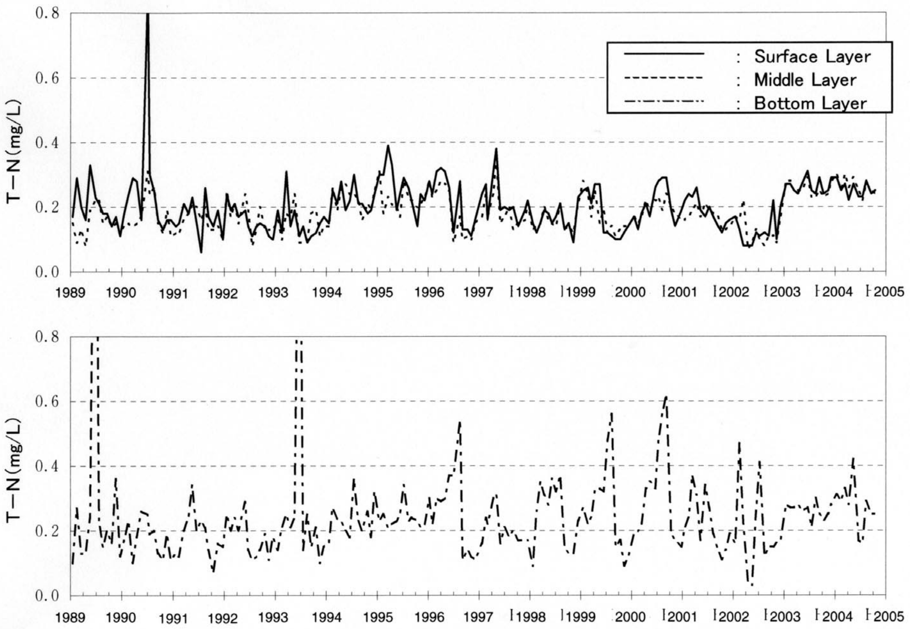



Figure-10(b): Variations of T-N

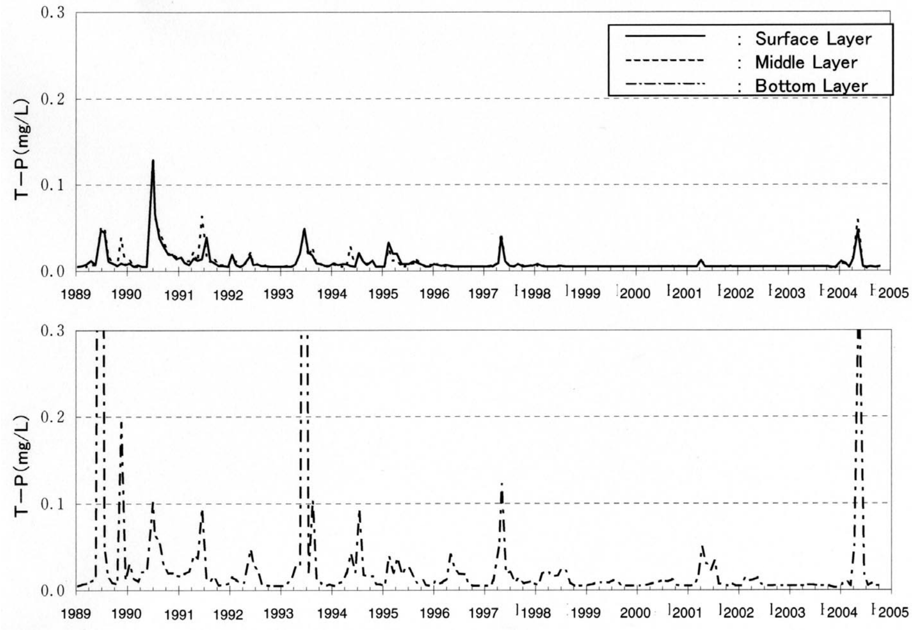



Figure-10(c): Variations of T-P

### 3.5 Effect on the Downstream River

To examine the impact on the downstream river caused by the bypass system, the distribution of the grain size was investigated for three years after the operation of the bypass system. Figure-11 shows the distributions of the grain size at the riverbed 400 m downstream from the bypass tunnel outlet. The results reveal that gravel of which diameter is more than 200 mm exists after 1999, although gravel with the same size does not exist in 1998. The site reconnaissance survey also shows that the amount of gravel with medium and small size on the downstream riverbed is increasing.

Figure-12 shows survey results of the elevations on the downstream riverbed. Before the bypass operation there was a tendency to scour the riverbed, after the operation the elevations of the riverbed have increased up to those of the river before the dam construction. It is estimated that the bypass operation is effective in preventing the downstream riverbed from being scouring and effective in maintaining the elevations of the downstream riverbed.

### 3.6 Abrasion of the Tunnel Invert

Figure-13 shows the measured volume of the bypassed sediment (the porosity  equals 0.4) and the mean abrasion depth on the tunnel invert (about 9,000m$^2$ in area) after the sediment bypass system was operated. It can be found that the quantity of abrasion on the invert concrete, of which the design strength is

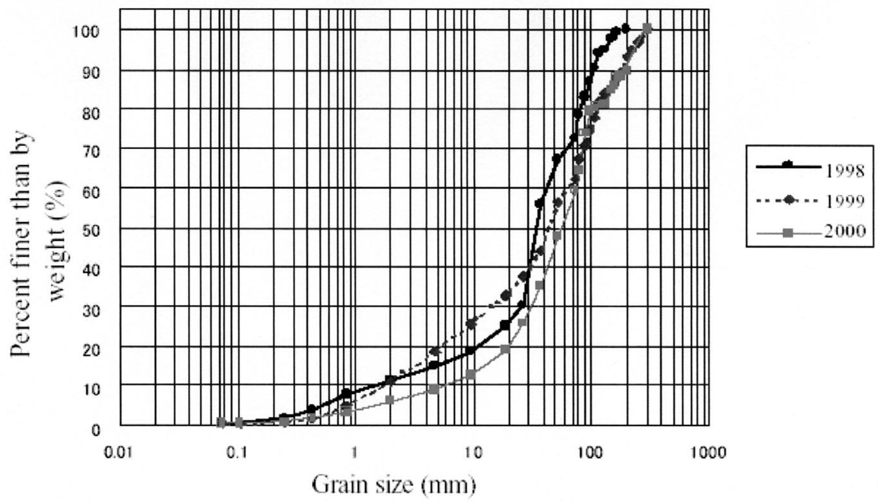



Figure-11: Grain size distribution at the downstream riverbed

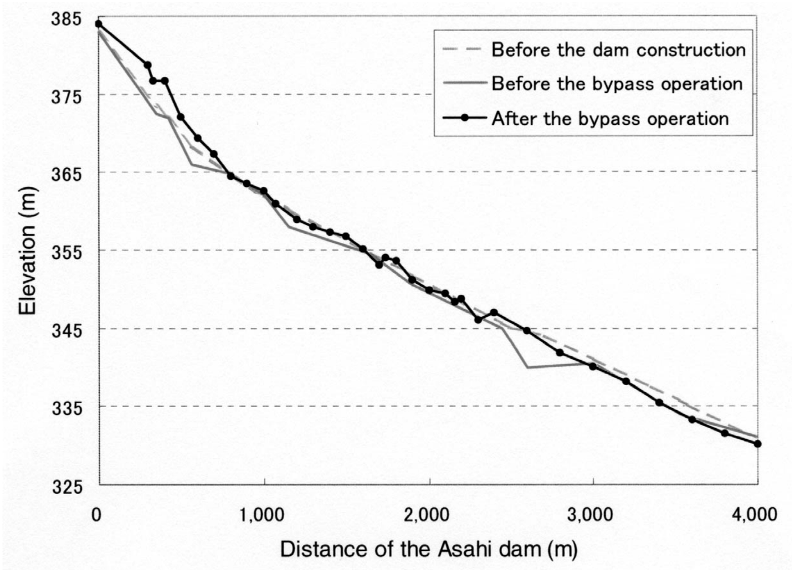



Figure-12: Survey results of the elevations on the downstream riverbed

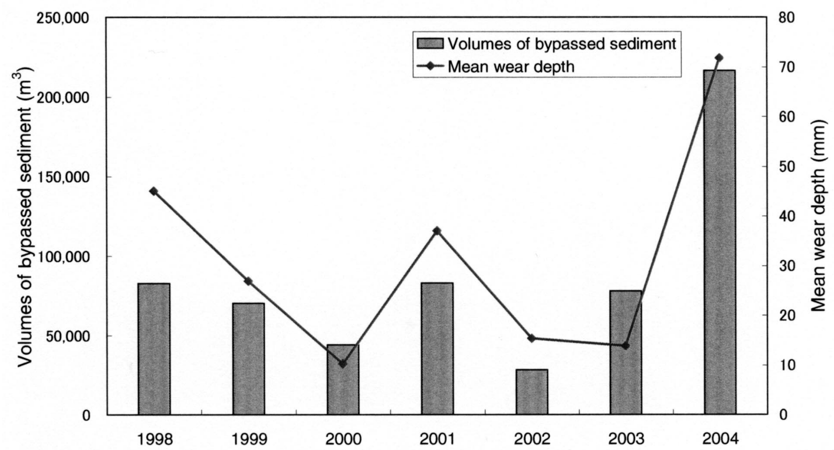



Figure-13: Amount of the bypassed sediment and the mean abrasion depth on the tunnel invert

36 N/mm$^2$ varies with the volumes of the bypassed sediment. The abrasion depth is within the range which was forecasted at the design stage. The sections worn seriously on the bypass tunnel invert are repaired during the non-flood season.

## 4. CONCLUSIONS

The environmental investigation into the river and reservoir clearly reveals that the sediment bypass system at the Asahi Dam can mitigate the prolonged turbidity and sedimentation problems. And it is likely that a downstream river state has been gradually restored to its former state since much sediment was supplied to through the bypass tunnel.

Furthermore, the KANSAI is planning for medium- and long-term investigation and measurement to research the effects of the bypass system, focusing on the following items;

a) water quality and sedimentation status in the reservoir and river
b) changes in the downstream river ecosystem
c) abrasion in the bypass tunnel and its countermeasures through in-situ tests

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