COMMISSION INTERNATIONALE
DES GRANDS BARRAGES
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VINGT TROISIÈME CONGRÈS
DES GRANDS BARRAGES
*Brasilia, Mai 2009*
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# EFFECT OF SEDIMENT BYPASS SYSTEM AS A MEASURE AGAINST LONG-TERM TURBIDITY AND SEDIMENTATION IN DAM RESERVOIR *

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## 1. INTRODUCTION

Kansai Electric Power Company ("KANSAI")'s Asahi Dam is an arch type dam with the catchment area of 39.2 km$^2$, the dam height of 86.1 m and the gross reservoir capacity of 15.47×10$^6$m$^3$. The dam forms the lower regulating reservoir of Okuyoshino Hydropower Station, a pure pumped storage power plant. The location of the hydropower plant is shown in Fig. 1. Since 1998, the plant has been operated with a sediment bypass system to protect against long-term turbidity and rapid progress of sedimentation in the reservoir as a result of a hill-side landslide induced by a great flood in 1990.

* *Effets du système de dérivation en tant que mesure contre la turbidité à long terme et la sédimentation dans le réservoir du barrage*

This paper summarizes results of various monitoring activities that have been conducted on the sediment bypass system of Asahi Dam since 1998, the first full-scale sediment bypass system in Japan at that time, and evaluates effects of the sediment bypass system based on the monitoring results.

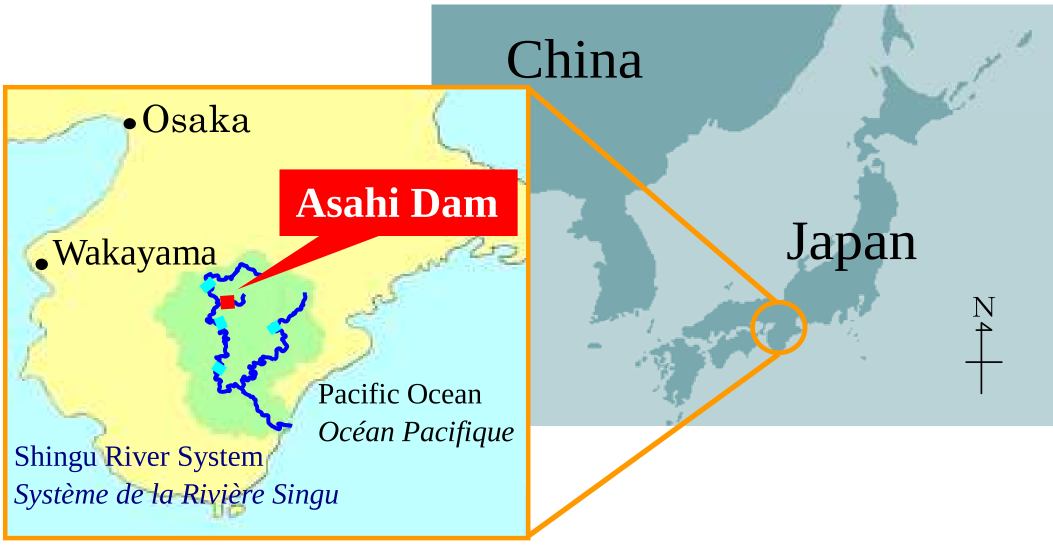



Fig. 1
Location of the Asahi Dam
*Emplacement du Barrage Asahi*

## 2. OUTLINE OF BYPASS SYSTEM

An image illustration, layout and outline of main facilities for the bypass system installed in Asahi Dam are shown in Fig. 2, 3 and 4 respectively. The bypass system is composed of an intake, a weir, a bypass tunnel and an outlet.

The bypass tunnel has a hood-shaped typical cross section (3.8 m (W) x 3.8 m (H)) and a total length of 2,350 m. The maximum discharge of the bypass tunnel is 140m$^3$/s, which is designed in order to not only eliminate the long-term turbidity caused by an annual flood but also completely flush out bed load reaching the intake into the downstream river of the dam during a flood.

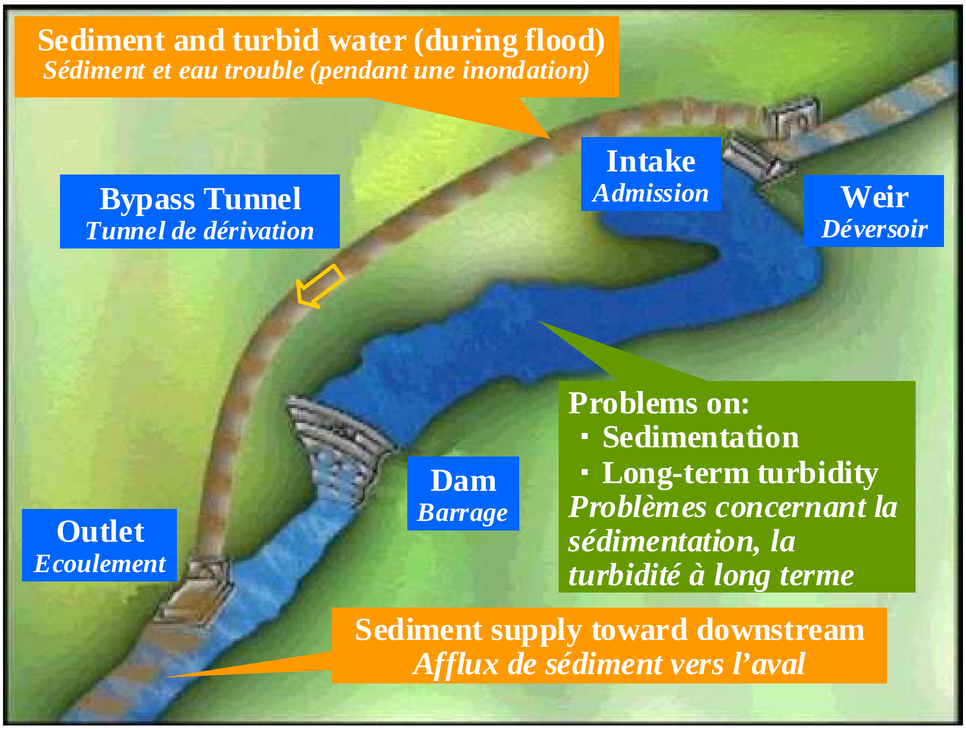



Fig. 2
Image Illustration of Bypass System of Asahi Dam
*Image illustrant le système de dérivation du Barrage Asahi*

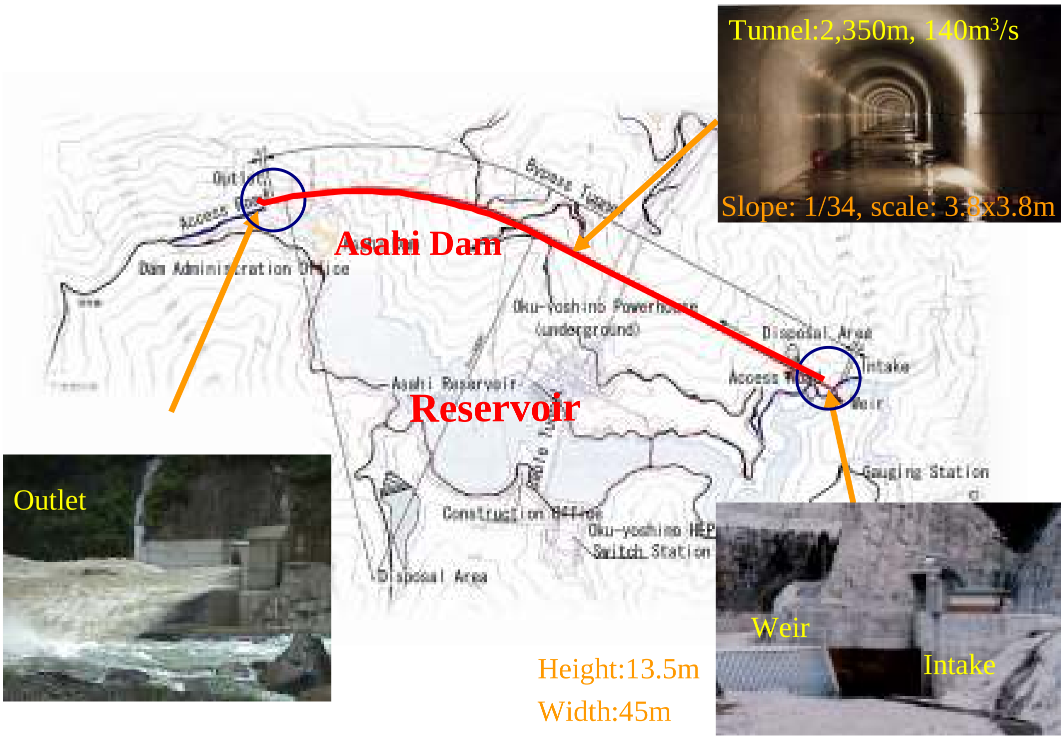



Fig. 3
Layout of Main Facilities for Bypass System
*Disposition des installations principales du système de dérivation*

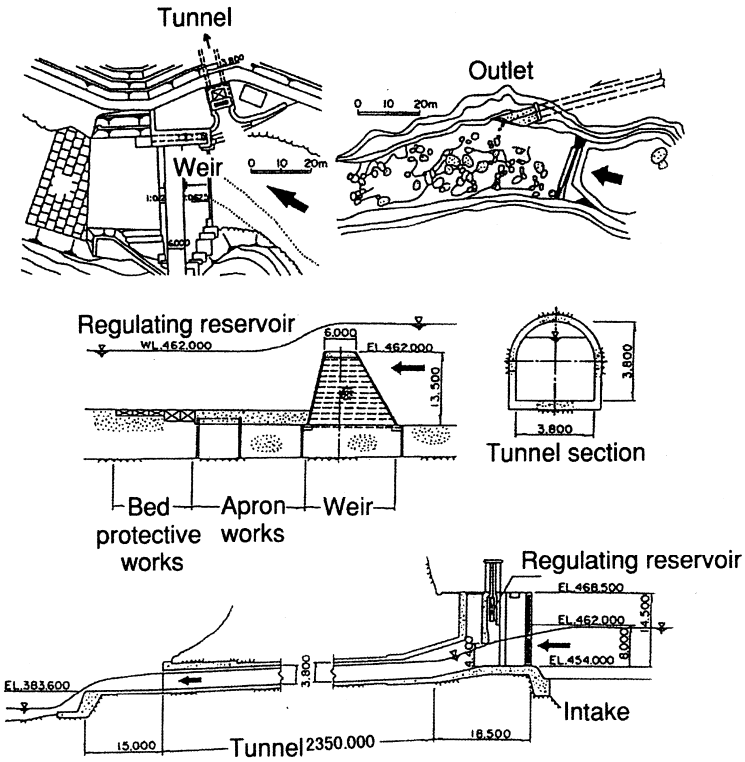



Fig. 4
Outline of Main Facilities for Bypass System
*Profil des installations principales du système de dérivation*

Table 1
Specifications of 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 | 140m$^3$/s |
| | Type | Reinforced Concrete Lining |
| Outlet | Height | 15.0m |
| | Width | 5.0～8.0m |
| | Type | Reinforced Concrete |

*[*]Spécifications du système de dérivation*

## 3. EFFECT AND IMPACT OF BYPASS SYSTEM

### 3.1. Operation Record of Bypass System

Operation record of the bypass system for each year from 1999 to 2006 is shown in Fig. 5. Approximately 50-70% of river inflow into the reservoir (regulating reservoir) was discharged to the downstream river through the bypass tunnel each year. In August 2004 when the greatest flood occurred since the installation of the bypass system, the peak discharge was 466m$^3$/s at the reservoir.

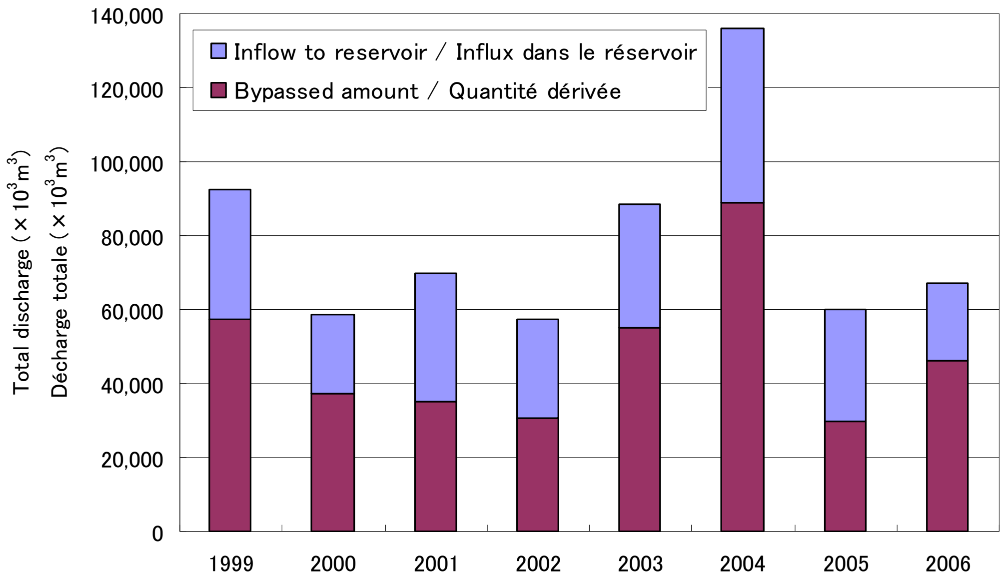



Fig. 5
Operation Record of Bypass System in Asahi Dam
*Historique de fonctionnement du système de dérivation du Barrage Asahi*

### 3.2. Alleviation Effect of Long-term Turbidity in Reservoir

#### *3.2.1. Long-term effect*

Fig. 6 summarizes the number of days when turbidity of more than 5 ppm was monitored at downstream and upstream areas of the reservoir in each year, based on monitoring results on turbidities of river water sampled once a day at downstream and upstream flow gauging stations of the dam which are located about 1.6 km downstream and about 4.3 km upstream from the dam respectively. In the case that the difference of the above-mentioned number of days between the downstream and upstream flow gauging stations is small, the bypass system could give alleviation effect on long-term turbidity.

Focusing on the term after the large-scale landslide had stabilized slightly in 1993 prior to the installation of the bypass system in 1998, the differences of the number of days range from approximately 50 to 130 days except for a drought year of 1996, which suggests long-term turbidity occurred in the reservoir every year. However, after the installation of the bypass tunnel, the differences decreased to about 10 days except for 2004 when the greatest flood occurred after the installation and other floods occurred more frequently than the other years. From these data, the alleviation effect on long-term turbidity by the bypass system is obviously observed.

Meanwhile, changes in annual average turbidity monitored at the downstream and upstream flow gauging stations are shown in Fig. 7. By comparison with turbidities monitored in the following periods; (a) 1978-1988, (b) 1988-1997 and (c) 1998-2006, it is found out that turbidities in the period (c) after the operation of the bypass system are similar to those in the period (a) prior to the occurrence of the large landslide. As for turbidities monitored at the upstream flow gauging station, turbidities in the period (c) (average turbidity: 1.84 ppm) are larger than those in the period (a) (average turbidity: 1.30 ppm). On the contrary, as for turbidities monitored at the downstream flow gauging station, turbidities in the period (c) (average turbidity: 2.20 ppm) are smaller than those in the period (a) average turbidity: 2.59 ppm). From this point of view, it is found out that the bypass system is effective for reduction of turbidities at the downstream river from the long-term viewpoints.

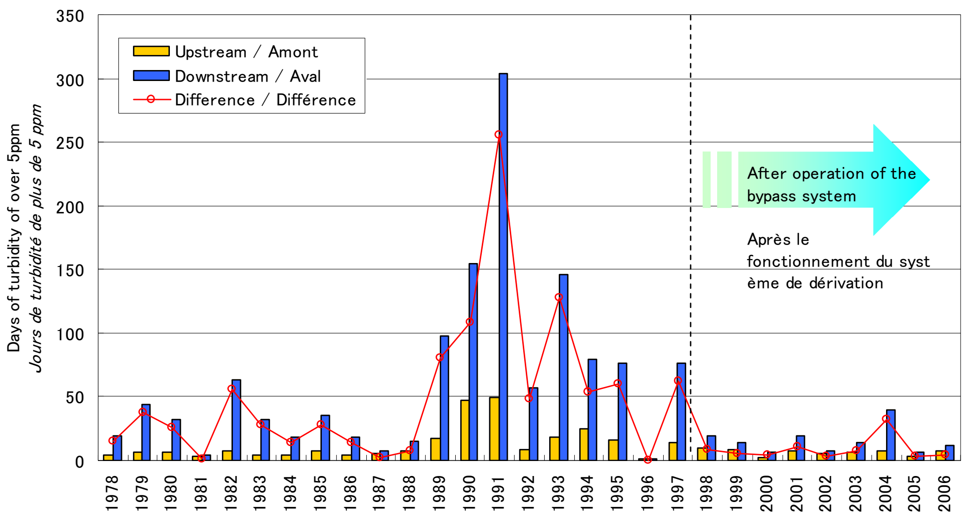



Fig. 6

Number of Days when Turbidity of more than 5 ppm was monitored at Downstream and Upstream Areas of Reservoir

*Nombre de jours de turbidité de plus de 5 ppm constatée dans les biefs aval et amont du réservoir*

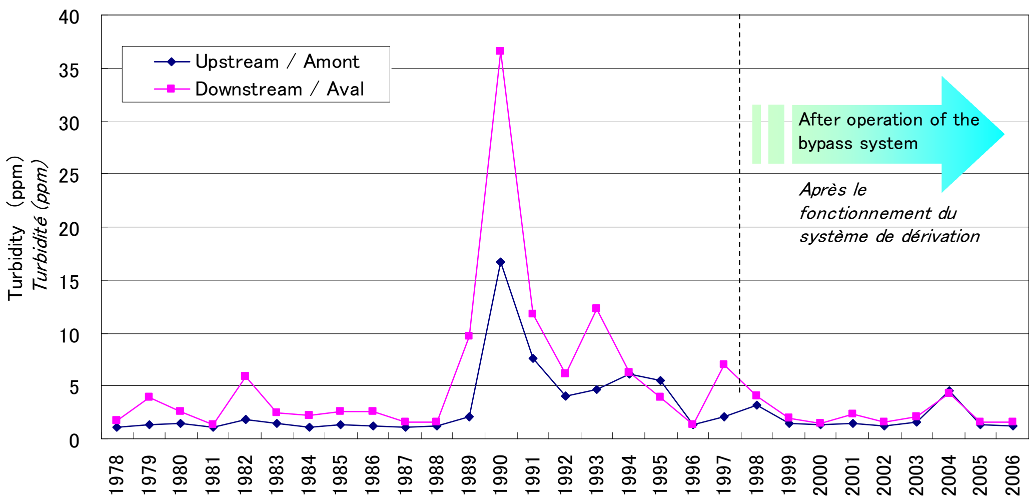



Fig. 7

Changes in Annual Average Turbidity monitored at Downstream and Upstream Areas of Reservoir

*Évolution de la turbidité annuelle moyenne mesurée dans les biefs aval et amont du réservoir*

### *3.2.2. Short-term effect*

As an example showing reduction effect on flood-related turbidity by the bypass system, comparisons of change in turbidities monitored at the upstream and downstream flow gauging stations in a flood between June 20, 2001 (maximum river inflow into the reservoir: 288 $m^3/s$) after the operation of the bypass system and July 13, 1986 (maximum river inflow into the reservoir: 271 $m^3/s$) prior to the operation of the bypass system are shown in Fig. 8 and 9 respectively. Maximum river inflow of the flood on June 20, 2001 is almost same as that on July 13, 1986.

Seeing turbidities monitored at the downstream gauging station in 7 days after the maximum turbidity was observed, prior to the operation of the bypass system, average measured turbidity was approximately 20 ppm, however, after its operation it was reduced to 5 ppm or less. The bypass system is confirmed to also contribute to reduction of turbidities in the reservoir from the short-term viewpoints.

Change in turbidities in the flood in 2004, which was the greatest flood after the installation of the bypass system could not be measured, therefore they could not be summarized in the same manner as Fig. 8 and 9. Judging from Fig. 6 and 7, however, the bypass system is estimated to have alleviated long-term turbidity in the reservoir significantly.

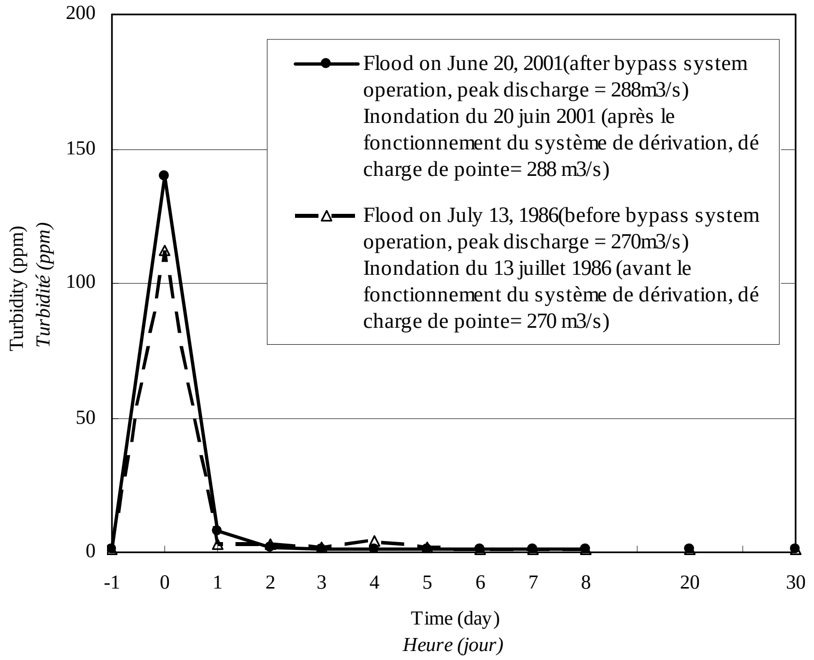



Fig. 8

Variation of Turbidities in Flood (4.3 km upstream from Asahi Dam)

*Variations de la turbidité en crue (à 4,3 km en amont du Barrage Asahi)*

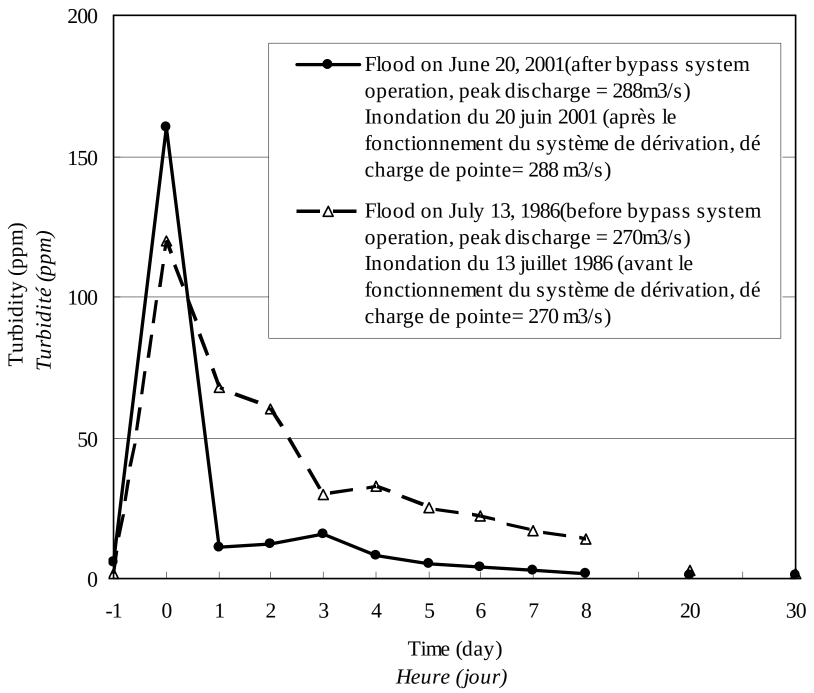



Fig. 9

Variation of Turbidities in Flood (1.6 km downstream from Asahi Dam)

*Variations de la turbidité en crue (à 1,6 km en aval du Barrage Asahi)*

## 3.3. REDUCTION OF SEDIMENT VOLUME IN RESERVOIR

The Change in sediment volume in the reservoir of Asahi Dam is shown in Fig.10. Sediment volumes passing through the bypass tunnel after 1998, when the operation of the bypass started, are based on simulation results using actual inflow data.

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 ($D_{50}$=5cm) and the porosity of the bed loads is assumed to be 0.4. For labor saving, the inflow under 30m$^3$/sec is neglected. The validity of the simulation model was confirmed by the calculation results before the operation of the bypass system.

According to Fig.10, it is found out that about 90% of sediment volume that would have accumulated in the reservoir without the bypass system is estimated to have been led to the downstream river of the dam by the bypass system, resulting in reduction of almost 90% of the possible sediment volume in the reservoir.

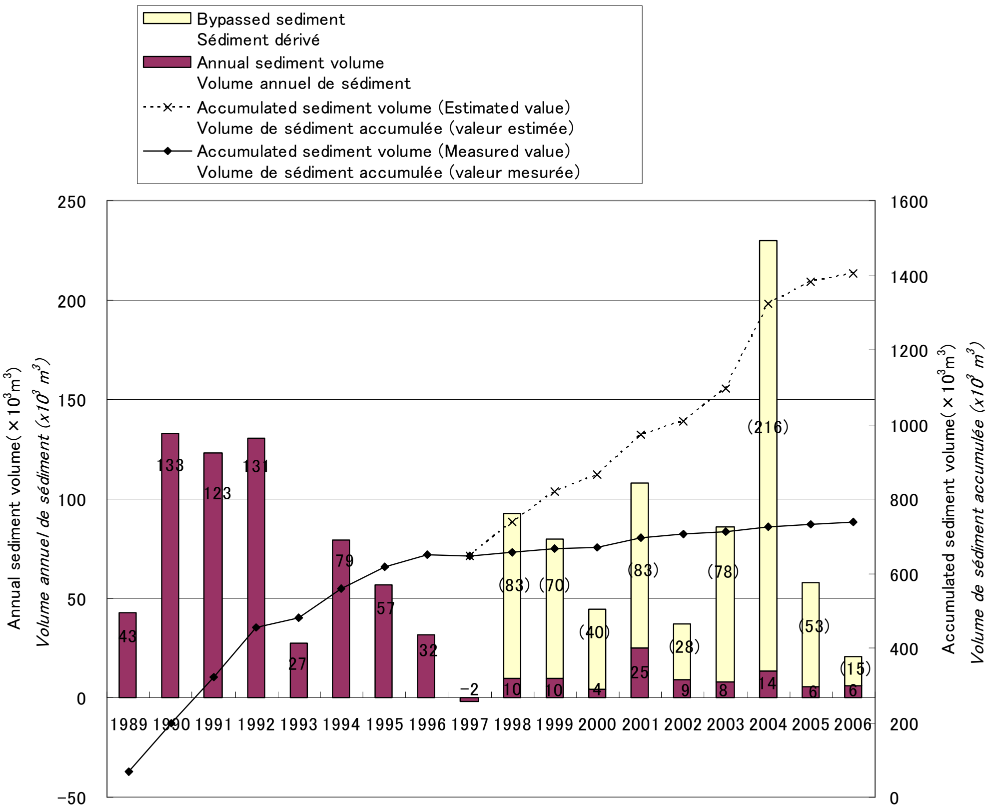



Fig. 10

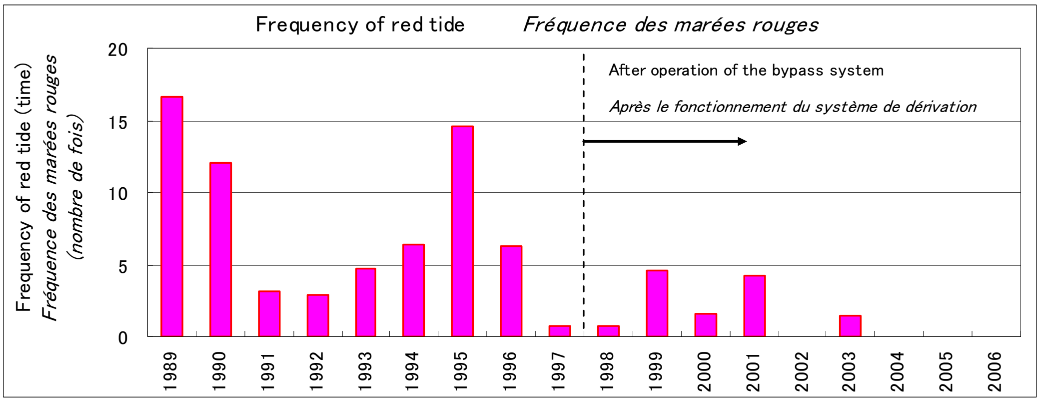
Change in sediment volume in Reservoir of Asahi Dam

*Modification du volume de sédiment dans le réservoir du Barrage Asahi*

## 3.4. WATER QUALITY IN RESERVOIR

By the operation of the bypass system, river inflow that would have flown into the reservoir without the operation of the bypass system is directly led to the downstream river of the dam. For this reason, the exchange ratio of reservoir water (=Annual total discharge/Total capacity) in the reservoir decreases, resulting in concerns over deterioration of water quality in the reservoir. On the other hand, it was expected that the water quality would be improved because river inflow would be directly released to the downstream river and the inflow load into the reservoir would be decreased in floods.

Fig. 11 shows the occurrence frequency of freshwater red tide in the reservoir in each year. After the operation of the bypass system, the occurrence frequency was reduced. No red tide has occurred in the past three years.




※Annual average data *Données moyennes annuelles*

Fig. 11
Variation of Occurrence Frequency of Red Tide in Reservoir
*Variations de la fréquence des marées rouges dans le réservoir*

Generally, the water quality in reservoirs is evaluated with TSIM [Modification of Trophic State Index, Aizaki et al. (1981)] (refer to Eq.[1],Eq.[2],Eq.[3],Eq.[4]). In this study, T-N, T-P, COD and SD are used as items related to the water quality and average monitored values near the upstream end of the reservoir and those on the surface layer near the dam are used.

Evaluation results of the water quality with TSIM are shown in Fig. 12. When the water quality is applied to categories of the environment criteria, the water quality before and after the operation of the bypass system falls under Class III and Class II respectively (refer to Table 2). This indicates that the water quality was improved by the bypass system.

Based on these results, it is indicated that the water quality in the reservoir became better by the bypass system in comparison with the water quality in 1989 to 1997 prior to its operation.

$$TSI_M[COD] = 10 \times \left[ 2.46 + \frac{1.50 + 1.36 \times \mathrm{LN}(COD)}{LN2.5} \right] \quad [1]$$

$$TSI_M[SD] = 10 \times \left[ 2.46 + \frac{3.69 + 1.53 \times \mathrm{LN}(SD)}{LN2.5} \right] \quad [2]$$

$$TSI_M[TP] = 10 \times \left[ 2.46 + \frac{6.71 + 1.15 \times \mathrm{LN}(TP)}{LN2.5} \right] \quad [3]$$

$$TSI_M[TN] = 10 \times \left[ 2.46 + \frac{3.93 + 1.35 \times \mathrm{LN}(TN)}{LN2.5} \right] \quad [4]$$

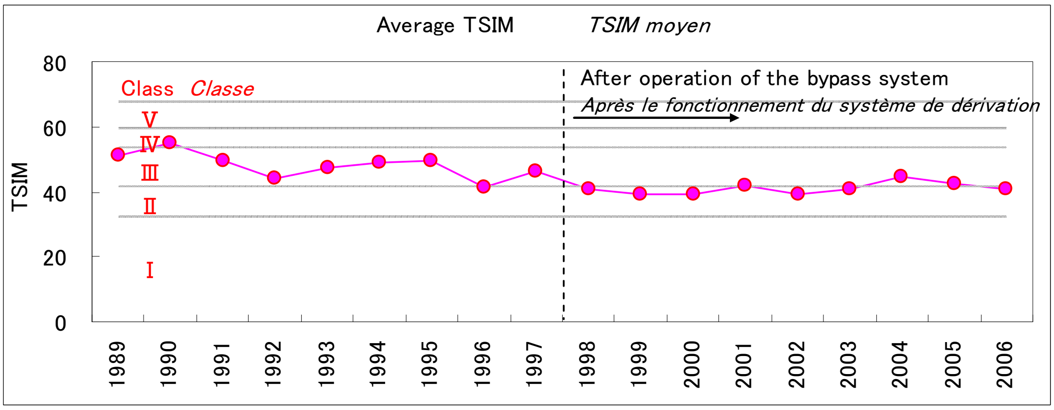



Fig. 12

Change in Overall Indicator on Eutrophication (Average TSIM) and Environment Criteria (Class)

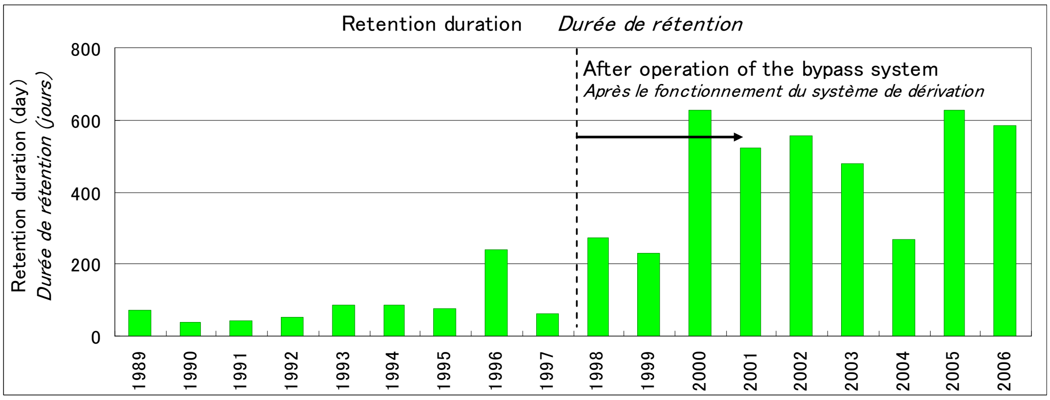
*Modification de l'indicateur global d'eutrophisation (TSIM moyen) et critère de l'environnement (classe)*

Table 2
Relation of TSIM and environmental standards in Japan

| Items / Classes | TSIM | Environmental standards | |
|---|---|---|---|
| | | T-N | T-P |
| Ⅰ | 32.4 or under | 0.1 mg/L or under | 0.005 mg/L or under |
| Ⅱ | 41.9 or under | 0.2 mg/L or under | 0.01 mg/L or under |
| Ⅲ | 53.9 or under | 0.4 mg/L or under | 0.03 mg/L or under |
| Ⅳ | 60.1 or under | 0.6 mg/L or under | 0.05 mg/L or under |
| Ⅴ | 68.2 or under | 1 mg/L or under | 0.1 mg/L or under |

*[*]Relation entre TSIM et les normes de l'environnement du Japon*

Figure 13 shows retention duration of water in the reservoir. The retention duration of water is increased by about 5 times after the operation of the bypass, which generally means the water quality in the reservoir tends to become deteriorated. However, actually, it is observed that the water quality was improved after the operation of the bypass system. This demonstrates that cutoff of nutrient salts by the bypass system was very effective in improving the water quality in the reservoir.




※Retention duration=Annual days/Annual inflow to reservoir/Reservoir capacity
*Durée de séjour = jours par année/influx annuel dans le réservoir/volume de retenue*

Fig. 13
Variation of Retention Duration of Water in Reservoir
*Variations de la durée de séjour de l'eau dans le réservoir*

### 3.5. RIVERBED FLUCTUATIONS AT THE DOWNSTREAM RIVER OF DAM

Fig. 14 shows the states of erosion and sedimentation of riverbed calculated from cross-leveling data at the downstream river of Asahi Dam.

By the operation of the bypass tunnel, it was expected that the riverbed level would rise, however, actually approximately 32,000m$^3$ of sediment was eroded from the Asahi River immediately downstream Asahi Dam to its confluence with the main river of Shingu River (about 6km downstream from Asahi Dam) in 2006.

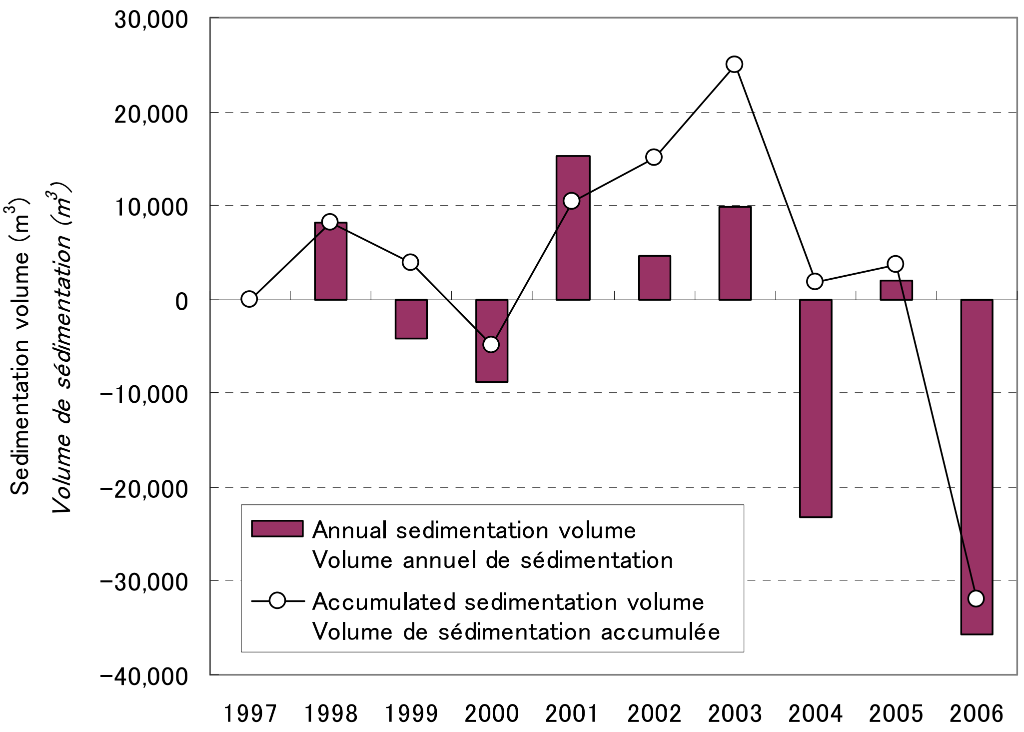



Fig. 14
Variation of Sedimentation in Downstream River of Asahi Dam
*Variations de la sédimentation en aval du Barrage Asahi*

## 3.6. HABITAT CONDITION AT RIVER DOWNSTREAM FROM DAM

In order to survey the environment of the downstream river of Asahi Dam after the operation of the bypass tunnel, a fish survey, a benthic fauna survey, an attached algae survey and other investigations has been conducted so far. Results of the benthic fauna survey, which are considered to have comparatively strong relevance to sediment movements, are shown in Fig. 15.

The number of types of benthic fauna and their population tend to increase on the whole after the operation of the bypass system except for 2002. In 2002, the number of types of benthic fauna and their population were extremely small because the benthic fauna survey was conducted immediately after a flood. Consequently, it is judged that the environment at the downstream river of the dam turns in the direction of improving the situation. This is assumed to be because discharge through the bypass tunnel increased sediment transport to the downstream river.

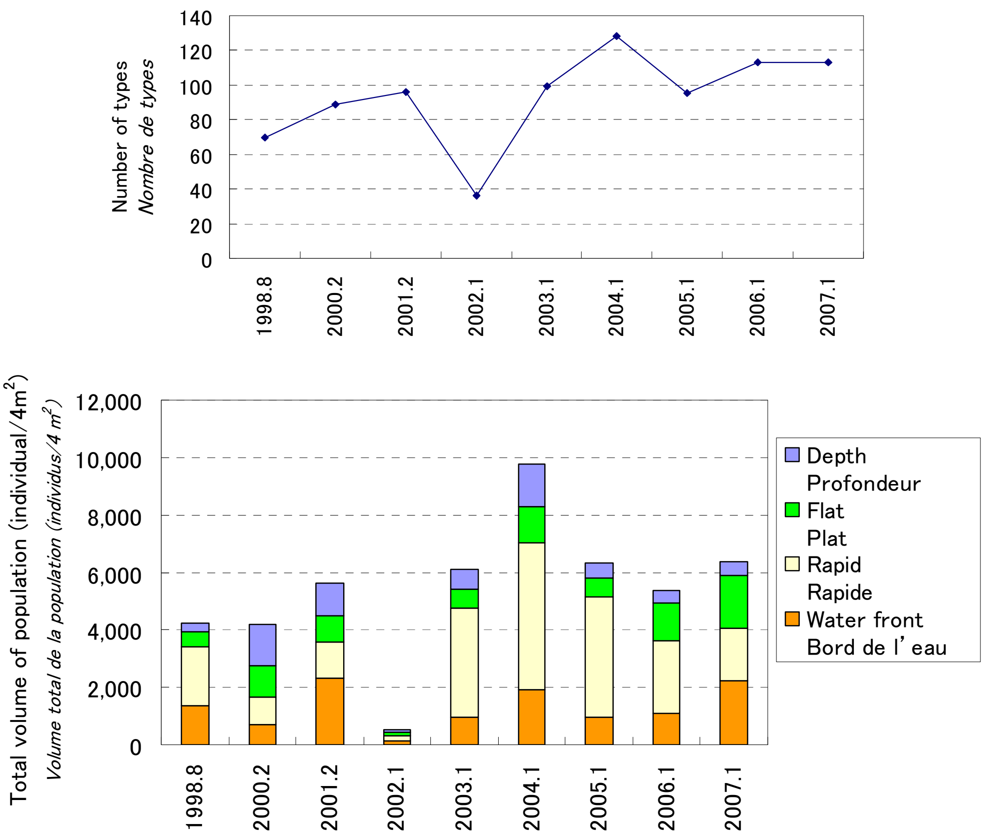



Fig. 15
Variation of analysis results on benthic fauna
*Variations des résultats des analyses de la faune benthique*

## 3.7. EROSION OF CONCRETE LINING IN BYPASS TUNNEL

Fig. 16 shows monitoring results of the bypassed sediment volume and mean eroded concrete volume of the bypass tunnel inverts after the operation of the bypass system (The inside of the bypass tunnel is covered with the reinforced concrete and the invert concrete, total area of which is approximately 9,000 m$^2$). This figure demonstrates that the eroded volume of the invert concrete is depending on the bypassed sediment volumes each year. These eroded concrete volumes are within the range of designed values. Significantly-eroded sections have been repaired using high-strength concrete in consideration of maintenance costs during the non-flood periods.

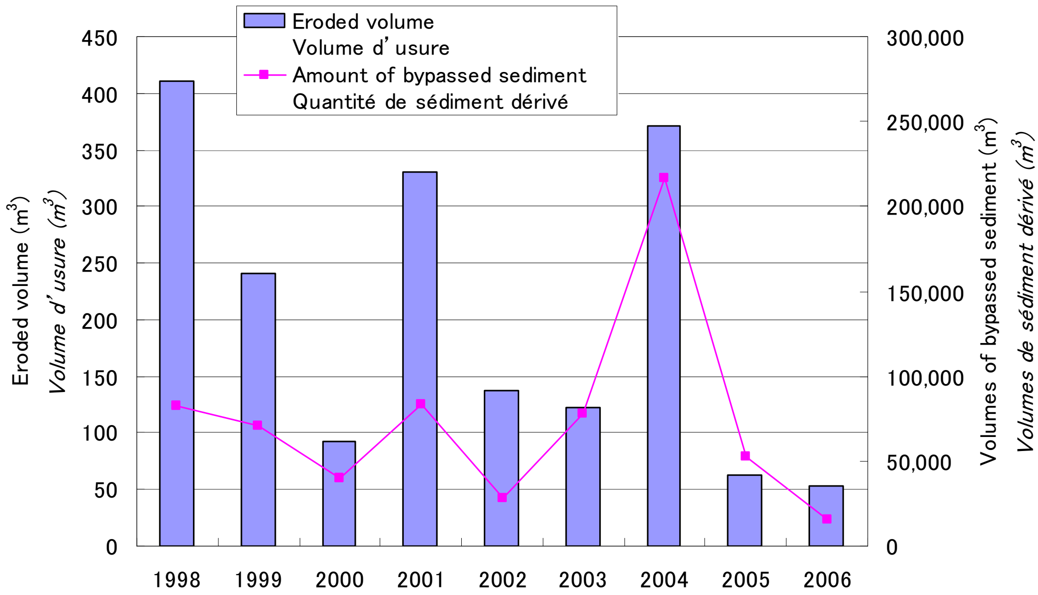



Fig. 16
Annual Eroded Concrete Volume of Bypass Tunnel Invert
*Volume annuel de béton érodé du radier du tunnel de dérivation*

## CONCLUSION

Based on the various surveys on the reservoir of Asahi Dam and the basin of Asahi River, it was confirmed that sediment-related problems, such as long-term turbidity and sedimentation in the reservoir resulting from construction of dam, were alleviated under the operation of the bypass system. In addition, the water quality in the reservoir was improved, and the environment at the downstream river of the dam was found to turn in the direction of improving the situation.

Consequently, it is judged not only that the bypass system in Asahi Dam aimed at solving long-term turbidity and sedimentation in the reservoir accomplished its intended purposes but also that it reduced eutrophication in the reservoir and improved the environment of the downstream river.

We will continue to monitor the reservoir and river in order to review the positive and negative effects of the bypass system.

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## SUMMARY

Kansai Electric Power Company (“KANSAI”)’s Asahi Dam forms the lower regulating reservoir of Okuyoshino Hydropower Station, a pure pumped storage power plant. Since 1998, the plant has been operated with a sediment bypass system to protect against long-term turbidity and rapid progress of sedimentation in the reservoir as a result of a hill-side landslide induced by a great flood in 1990.

Based on the various surveys on the reservoir of Asahi Dam and the basin of Asahi River, it was confirmed that sediment-related problems, such as long-term turbidity and sedimentation in the reservoir resulting from construction of dam, were alleviated under the operation of the bypass system.

We will continue to monitor the reservoir and river in order to review the positive and negative effects of the bypass system.

## RÉSUMÉ

Le Barrage Asahi de Kansai Electric Power Company (« KANSAI ») forme le réservoir régulateur inférieur de l’usine hydroélectrique d’Okuyoshino, une usine de barrage de pompage pur. Depuis 1998, l’usine fonctionne avec un système de dérivation de sédiment comme protection contre la turbidité à long terme et l’avance rapide de la sédimentation dans le réservoir, résultat de l’éboulement d’un flanc de coteau à la suite des inondations de 1990.

Diverses études du Barrage Asahi et du bassin de la Rivière Asahi ont confirmé que les problèmes liés aux sédiments, tels que la turbidité à long terme et la sédimentation du réservoir résultant de la construction du barrage ont été allégés grâce au fonctionnement du système de dérivation.

Nous poursuivrons la surveillance du réservoir et de la rivière afin de suivre de près les effets négatifs et positifs du système de dérivation.