Comprehensive Sediment Management in the Kurobe River

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1. Introduction

The Kurobe River is a class A river that flows through the eastern part of Toyama Prefecture. As one of the most torrential rivers in Japan, it discharges a characteristically large volume of sediment from its upstream area. Due to the accumulation of a substantial quantity of sediment runoff over several thousands of years, a typical alluvial fan has been formed in the lower reaches of the Kurobe River. This beautifully shaped fan jutting into the ocean is recognized as a rare formation in the world. However, there is a danger that such a great quantity of sediment runoff may cause earth-flow disasters. In recent years, as upstream sediment has not been conveyed down to the river mouth due to changes in the flow regime, there has been much erosion along the coast in the area near the river.

For this reason, it is vital that a comprehensive sediment management system be established for the Kurobe River in order to secure a steady discharge of sediment, maintain stable river channels and preserve coastal areas, while at the same time preventing earth-flow disasters. As one of the countermeasures, coordinated sediment flushing has been carried out from the Unazuki Dam, completed in 2001 and managed by the Ministry of Land, Infrastructure and Transport, and the Dashidaira Dam, completed in 1985 and managed by Kansai Electric Power Co., Inc.

Many problems remain to be addressed before a comprehensive sediment management system can be established. This paper introduces some of the problems to be faced in formulating the system and outlines the coordinated sediment flushing operation and its achievements.

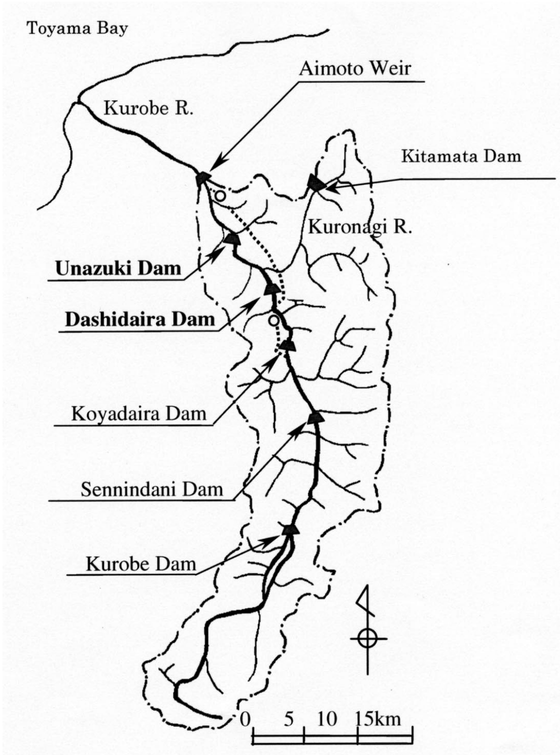

Figure 1 Kurobe River Basin

2. Comprehensive sediment management for the Kurobe River

(1) Profile of the Kurobe River

Figure 1 shows the Kurobe River basin. The Kurobe River, 85 km in length, is one of the most torrential rivers in Japan. It flows from Japan's highest 3,000 m level alpine mountains right down to the Sea of Japan and has an average riverbed slope of about 1/30.

The rainfall in the basin is also conspicuous in Japan. The annual rainfall in the upstream area reaches 4,000 mm, more than double the national average. Hydroelectric power generation has been utilized to take advantage of the abundant volume of water and torrential flow.

The Kurobe River has, since ancient times, meandered wildly across its alluvial fan, causing problems for people living in the area. This was particularly so when a flood levee failed and devastating damage was inflicted in an all-time record flood in August 1969. This huge flood was a turning point, and a project was formed under ministerial jurisdiction, to construct the Unazuki Dam mainly for the purpose of flood control.

(2) Landslide and sediment runoff in the basin

The upstream area of the Kurobe River is known as the unexplored Kurobe Canyon. It is formed basically of granite and is susceptible to weathering. Because the area is relatively new in terms of geochronology, landslide scars of various sizes can be observed at as many as 7,000 locations. These landscape scars occupy nearly 5% of the total area.

A large quantity of sediment runs off along with the rainfall and freshet from these sites. The total volume of sediment runoff in the basin is estimated at about 1.4 million m^3 per year.

Many times, severe damage has been caused by this large volume of sediment runoff. The most recent instance was an extensive landslide that occurred in July 1995 in the upstream area as a result of heavy

Photo 1 Damage inflicted on the Nekomata Station of the Kurobe Gorge Railway in July 1995

rains, causing massive quantities of sediment and timber to flow into the Dashidaira Dam and nearly 6 million m^3 of sediment to accumulate in the middle course of the Kurobe River. Substantial damage was caused, not only to transport facilities such as the Kurobe Gorge Railway as shown in Photo 1, but also to power generation facilities and local tourist spots.

(3) The need for a sediment supply downstream

The Kurobe River carries a large quantity of sediment runoff, and so, it is natural that this will flow into the downstream area. For this reason, if this sediment supply mechanism is obstructed, various problems can be expected to occur.

1) Effect on the downstream course

A large quantity of sediment movement is conspicuous around the middle to lower course of the Kurobe River, and this causes the river channel to be unstable. In recent years, the degradation of the riverbed has become so bad that revetment bases have been constructed in many areas. Accordingly, if the volume of sediment supplied from the upstream course is further reduced, there will be a further degradation of the riverbed and the downstream river channel will become even more unstable.

2) Effects on the coastal area

Wave overtopping and coastal erosion have been observed since ancient times in the coastal area around the Kurobe River mouth. It is estimated that the coastal line has receded some 200 m over the past 100 years. Thus, measures are being taken to prevent further coastal erosion by installing coastal protection facilities. At the same time, it is also necessary to maintain a continuous supply of sediment from the river.

However, if the spontaneous sediment runoff is left to take its own course with no human intervention, such earth-flow disasters as mentioned above are likely to occur again and again. As far as the Kurobe River is concerned, a well-balanced comprehensive sediment management system is vital to realize as great a natural sediment runoff as possible and to prevent earth-flow disasters.

(4) Challenges in the comprehensive sediment management system

1) Strategies for sediment management

The comprehensive sediment management operations performed in the Kurobe River are only at their beginning stages. Figure 2 gives a conceptual diagram

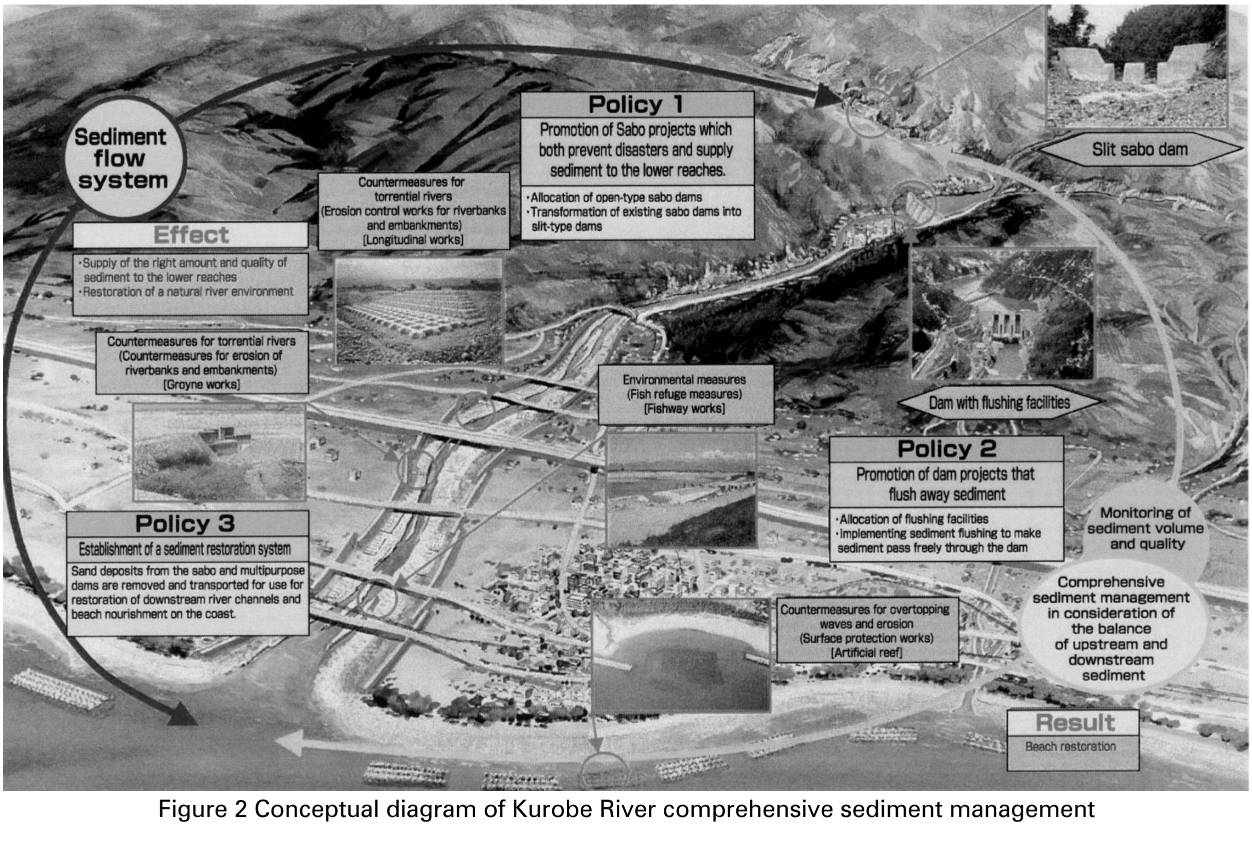

Figure 2 Conceptual diagram of Kurobe River comprehensive sediment management

Photo 2 Establishment of slit-type sabo dam (Kokurobedani sabo-dam No.1)

Photo 3 Establishment of offshore breakwaters (Yoshiwara District in Nyuzen Town)

of the overall basin management and some strategies currently underway are discussed in this section.

a) Installation of slit sabo dams

With the aim of preventing earth-flow disasters, a sabo dam is built on a mountain stream where there is a large outflow of sediment so that the quantity of sediment runoff can be controlled. However, to avoid the excessive capture of soil at times of normal flow, slit sabo dams such as that shown in Photo 2 have come into use. Slit sabo dams effectively check large quantities of sediment discharge at times of flooding, while supplying sediment downwards from between the slits at normal times.

b) Dam sediment flushing

It is usual that, when a dam is newly constructed, much of the upstream inflow sediment accumulates in the reservoir, reducing the amount of sediment supplied downwards from the dam. In the Kurobe River, which is characterized by a large amount of sediment runoff, the checking of sediment transport by the dam is most likely to have a large effect on the lower river course and coastal area. At the same time, voluminous sedimentation in the reservoir can decrease the capacity for both flood control and water supply, resulting in dam malfunction. Therefore, a sediment flushing gate was installed in both the Dashidaira Dam and the Unazuki Dam to flush soil downwards.

c) Apt gravel quarrying plan

The riverbed and riverbank from the middle to lower course of the Kurobe River consist mainly of gravel and small stones. Quarrying has been carried out extensively in the area, as the quality of the gravel is very high. The Kurobe River used to be a raised bed river, and so gravel quarrying was an effective measure for flood control. In recent years, however, with the degradation of the riverbed, there has been a restriction on these activities. However, an appropriate plan for gravel quarrying is to be closely examined in the future.

d) Improvement of coastal protection facilities to prevent beach drifting

Because the sea-bottom slope offshore from the Kurobe River mouth is steep, it is assumed that much of sediment during discharged times of flooding is transported deep under the sea and beach sediment contributes little to maintaining the coastal area. Thus, as Photo 3 indicates, coastal protection facilities such as offshore breakwaters and artificial reefs have been constructed to prevent coastal erosion and beach drifting.

e) Beach nourishment and sand bypassing

Although coastal protection facilities have been installed to prevent coastal erosion and beach drifting, the coastal area has not yet recovered fully, due to an insufficient volume of beach sediment. Therefore, the beaches are being nourished to rehabilitate the coast. Furthermore, sand bypassing is being performed to transport the sand and gravel accumulating at the river mouth for use as beach nourishment materials.

2) Survey on the sediment movement

In conducting sediment management, it is vital that the movement of sediment be grasped as basic information. Unlike water, however, it is quite difficult to establish the quality and quantity of discharged sediment. In the Kurobe River and its coastal environment, various attempts have been made to understand sediment movement. Photo 4 and Figure 3 illustrate a real-time suspended sediment densitometer and its schematic diagram.

Survey of hillside failure: filming and interpretation of aerial photos, field reconnaissance and morphometry by helicopter

Survey of sedimentation: CCTV monitoring and continuous fixed-point photography

Survey of riverbed deformation: profile and cross-leveling, granulometric analysis and installation of a riverbed degradation sensor

Survey of coastal deformation: aerial photography, sounding, granulometric analysis and follow-up checks using colored sand

Survey of water quality: turbidity and SS measure

Survey of bed load: direct sampling of sediment discharge using a backhoe

Survey of suspended sand: measurement using a real-time suspended sediment densitometer

Photo 4 Real-time suspended sediment densitometer

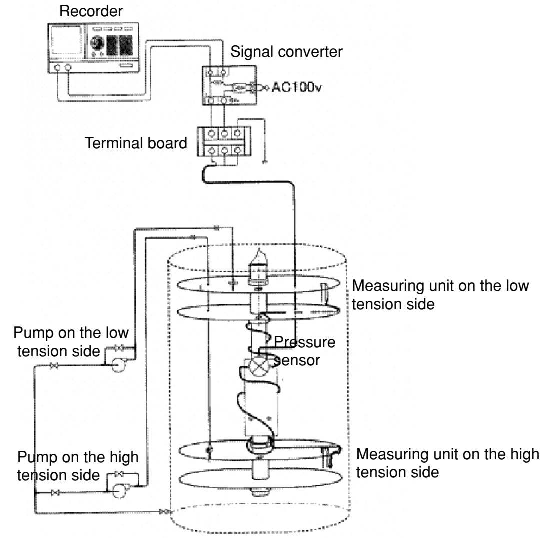

Figure 3 Schematic diagram of a real-time suspended sediment densitometer

and direct sampling of sediment discharge using a backhoe

3. Sediment flushing at dams on the Kurobe River

(1) Necessity of conducting coordinated sediment flushing in the Kurobe River

From the viewpoint of comprehensive sediment management, a downstream supply of sediment is necessary for the Kurobe River. It is also quite difficult to provide a dam with a large storage capacity for sedimentation. Accordingly, both the Unazuki and the Dashidaira Dams are equipped with sediment flushing facilities so that they may jointly conduct sediment supply to the downstream area end of a flood period in as natural a manner as possible.

(2) History of sediment flushing in the Dashidaira Dam

The Dashidaira Dam was completed 7 km upstream from the Unazuki Dam in September 1985, by Kansai Electric Power, exclusively for the purpose of power generation. The dam was equipped with sediment flushing facilities and its first operation was carried out in early December, 1991.

However, the first sediment flushing operation created problems for local residents as it adversely affected the lower reaches of the river and the coastal area. In this light, the Kurobe River Dashidaira Dam Flushing Evaluation Committee was formed. This consists of experienced scholars, administrative organs and relevant interested groups. In April 1995, the committee issued a report that published the results of their examinations and their proposals. The report concludes with the following statement, "A sediment flushing operation was initiated six years after the impoundment of the Dashidaira Dam. Meanwhile, the flow of organic material, including trees, leaves and humus had continued and accumulated in the dam together with a considerable quantity of sediment. The degradation of this material through anaerobic decom-

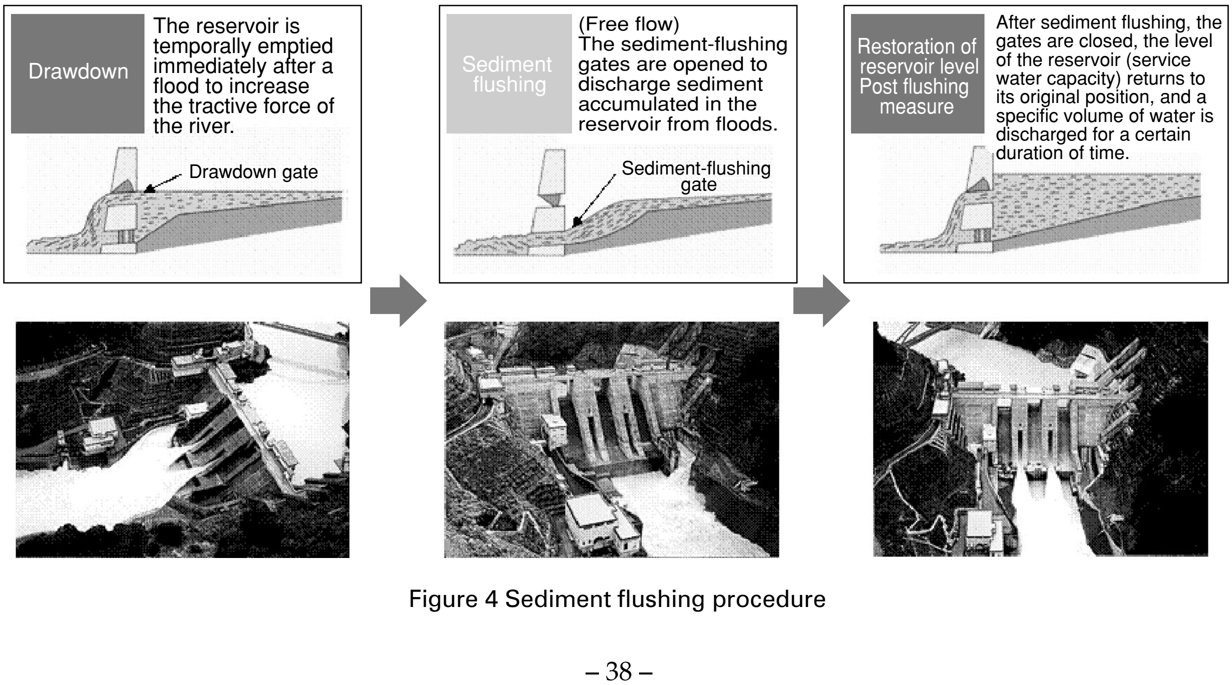

Figure 4 Sediment flushing procedure

position and the resultant impact on the basin had not been anticipated at all."

The report suggested that dam sediment flushing be conducted annually during times of river overflow and flooding, and that environmental surveys should be continued, giving priority to the alleviation of impact on the basin as far as possible.

(3) Outline of coordinated sediment flushing by the Unazuki Dam and the Dashidaira Dam

On the basis of the proposals outlined above, the committee members examined the method used for sediment flushing to reduce its impact on the basin as much as possible. As a result, the following method was judged to be the most appropriate.

Sediment flushing operations should be carried out during times of river overflow and flood between June and August to maintain the riverbed shape as far as possible without allowing an excess of sediment to accumulate in the dam reservoir. In the final stage following a flood peak, a drawdown gate would be opened to lower the dam water level. Next, sediment flushing gates should be opened to restore the natural pre-impoundment condition of the river inside the dam reservoir and to make use of the tractive force of the inflow to discharge the sediment. This state is called "free flow." Following this, the reservoir would be replenished, and a specific amount of water would be discharged from the dam as a post-flushing measure to wash down any sediment still remaining in the downstream channel.

They also suggested that there should be closer liaison between the Unazuki and the Dashidaira Dams in coordinated sediment flushing operations.

Every factor was taken into consideration, including the frequency of flooding, in consultations with interested groups engaged in inland water fishery, sea fishery and agriculture, and, as a result, it was determined that coordinated sediment flushing operations would be carried out between June and August.

There are three major differences between the current sediment flushing method and the initial method performed by the Dashidaira Dam in 1991:

(1) In the initial sediment flushing operation, the sediment discharged from the Dashidaira Dam had degraded over a period of six years. In the current method, sediment flushing operations are carried out on a yearly basis to prevent sediment degradation.

(2) The initial sediment flushing operation in the Dashidaira Dam was carried out during winter when the river was low. In the current method, the operation is synchronized with the occurrence of flooding which is large enough in scale to allow turbid water to flow through under normal conditions.

(3) In current sediment flushing operations, advance explanations and hearings are held to give interested groups, scholars and local residents a better understanding of the procedure. This kind of effort was not made for the initial operation of the Dashidaira Dam.

(4) Coordinated sediment flushing operation plan

As Table 1 indicates, coordinated sediment flushing operations are carried out based on the coordinated sediment flushing operation plan which delineates the amount and timing of sediment flushing, the flow type, its duration, and the measures to be carried out prior to and following the actions of flushing and sluicing.

1) Sediment flushing and sediment sluicing

In the coordinated sediment flushing operation plan, the operations are divided into two phases: sediment flushing and sediment sluicing.

Sediment flushing is carried out first on a flood of a certain magnitude within the sediment flushing period for the purpose of maintaining the shape of the sedimentation in the reservoir as much as possible by discharging the soil that had accumulated before the sediment flushing period.

Sediment sluicing is performed when a certain level of flooding occurs after the sediment flushing operation within the sediment flushing period, defined as the passing inflow flood sediment through.

2) Standard flow rate for sediment flushing operations

To successfully conduct sediment flushing operations on a yearly basis and maintain a flow rate of at least 130m^3/s in the free flow, the standard flow rate for sediment flushing operations has been set at 300m^3/s or over for the Dashidaira Dam and 400m^3/s or over for the Unazuki Dam (over 250m^3/s for the Dashidaira Dam only during the thawing and rainy season when the flow rate is higher).

The standard flow rate for sediment-sluicing operations depends on the flood discharge of each dam.

3) Quantity of sediment flushing

To maintain the specified level of sedimentation in the reservoir as much as possible, the excessively accumulated soil is regarded as a target volume and is therefore flushed annually.

Specifically in the case of the Dashidaira Dam, the amount of sediment accumulating after the last sediment flushing (or sediment sluicing) operation until May of the following year is assigned as the target volume. The target volume for the dam for 2005 is estimated as 540 thousand m^3. Meanwhile, the target volume for the Unazuki Dam is 0 m^3, as it is considered that the current height of the riverbed is still below that of the estimated stable riverbed in the Unazuki Dam Reservoir. Figures 5 and 6 demonstrate the shape of sedimentation in the Dashidaira Dam and the Unazuki Dam.

4) Duration of free flow

By using hydro data and hydro models derived from past floods that reached the standard flow rate, a simulation was run on the shape of the sedimentation and the grain size of the sediment as analytical factors to clarify the length of time taken for the target volume of sediment to flow down in a flood on a scale of 250-1,000 m^3/s, the figure the most likely to attain the standard flow rate. Based on this result, the duration of free flow for 2005 was determined as greater than 12 hours.

Table 1 Coordinated sediment-flushing plan

	Sediment flushing		Sediment sluicing	
	Dashidaira dam	Unazuki dam	Dashidaira dam	Unazuki dam
(1) Timing	・From June through August, flushing can be implemented in the first flood when either discharge into Dashidaira or Unazuki become larger than 300 or 400m³/s respectively. ・Only in high discharges by snow melting or rainy season, flushing can be implemented in the first flood when discharge into Dashidaira becomes larger than 250m³/s. Flushing must be stopped when discharge becomes smaller than 130m³/s.		・From June through August, sluicing can be implemented in every flood when either discharge into Dashidaira or Unazuki become larger than 480 or 650m³/s respectively.	
(2) Quantity of sediment flushing	・Sediment exceeded the regular volume will be flushed out to maintain the regular sedimentation profile in a reservoir as much as possible.		・Natural floods with sediments will be passed through sediment flushing gate each time.	
(3) Flow type	・Draw-down and open channel flow		・the same as the left	
(4) Duration	・Period that is necessary to flush out sediment exceeded the regular volume to maintain the regular sedimentation profile in a reservoir as much as possible.		・Within the draw-down and open channel flow of Unazuki dam	・12 hours for draw-down and open channel flow
(5) Pre flushing / sluicing measure	・Opening a sediment flushing gate from the beginning of a flood, e.g. high water level.	・Drawing down from the latter stage of a flood control, e.g. high water level.	・the same as the left	
(6) Post flushing / sluicing measure	・In principle, stopping hydropower intake in 24 hours after the flushing and outflowing discharge as the same as inflow.	・In 24 hours after the flushing, outflowing discharge as the same as inflow from the dam and Unazuki power station.	・In 12 hours after the sluicing, outflowing discharge as the same as inflow from the dam and a downstream power station.	

5) Post flushing measure

With the aim of preventing local sedimentation along the downstream channel, the inflow in both the Dashidaira and the Unazuki Dams is continually discharged for 24 hours following the sediment flushing operations. In the Unazuki Dam, however, from 2005, an attempt will be made to promote the prevention of local sedimentation to a higher degree, with a small-scale flood of less turbid water entering the downstream channel through the effective use of dam capacity.

(5) Consensus building for the coordinated sediment flushing activity

Before performing coordinated sediment flushing operations, as Figure 7 illustrates, advance explanations and hearings are arranged for relevant parties including those from fishery and agricultural industries and administrative organs. Following this, discussions are held overseen by the third party "Kurobe River Dam Sediment Flushing Evaluation Committee," consisting of specialists in the fields of the environment, biology and fishery, and the "Kurobe River Sediment Management Council," made up of relevant municipalities and representatives of the Toyama prefectural government. At the same time, extensive use is made of public relations to disseminate information about the coordinated sediment flushing operations and to enable the local residents to gain a better understanding before the operation is begun.

(6) Environmental survey on the coordinated sediment flushing operation

The results of the coordinated sediment flushing operation are grasped and monitored through periodical investigations performed not only while the operation is in progress, but also before and after the operation (at ordinary times before and after the sediment flushing/sediment sluicing period). In addition, an extensive environmental survey is carried out during the sediment flushing/sediment sluicing operation. The findings are promptly made public and scientifically and objectively discussed and evaluated by the "Kurobe River Dam Sediment Flushing Evaluation Committee," which reports the results to the "Kurobe River Sediment Management Council." The relevant sediment flushing surveys are listed in Table 2, and Figure 8 illustrates points of observation in the environmental research.

4. Operational results of coordinated sediment flushing

(1) Achievements of coordinated sediment flushing

1) History of coordinated sediment flushing

As Table 3 shows, the first sediment flushing operation was performed in the Dashidaira Dam in 1991. From 1994 to 1995, test sediment flushing was carried out to collect data with the aim of further enhancing the accuracy and reproducibility of simulation models for contaminated substances and environmental loads in the river mouth and its surrounding coastal area, matters that were on the agenda of the Kurobe River Dashidaira Dam Flushing Evaluation Committee.

On the occasion of the July 1995 flood, nearly 3.4 million m³ of sediment had accumulated around the

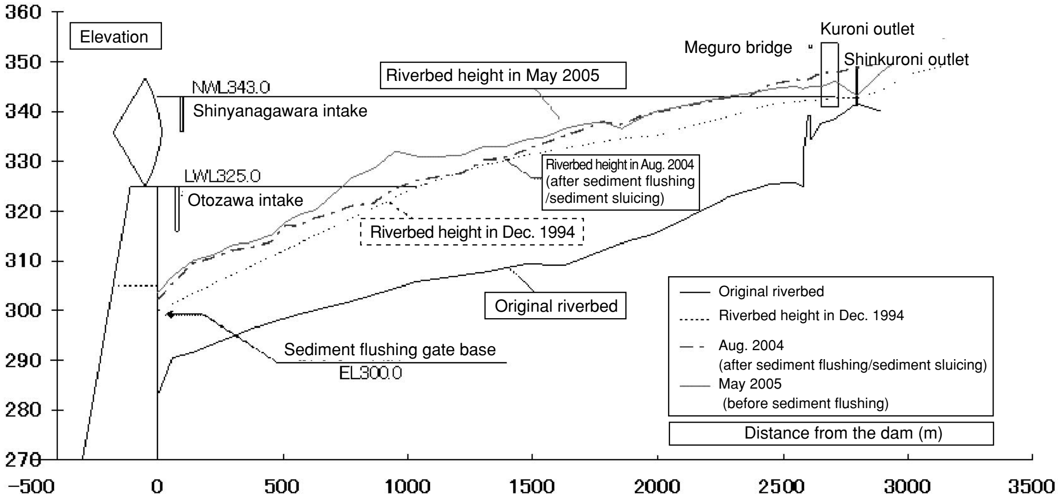

Figure 5 Sediment profile of the Dashidaira Dam (May 2005)

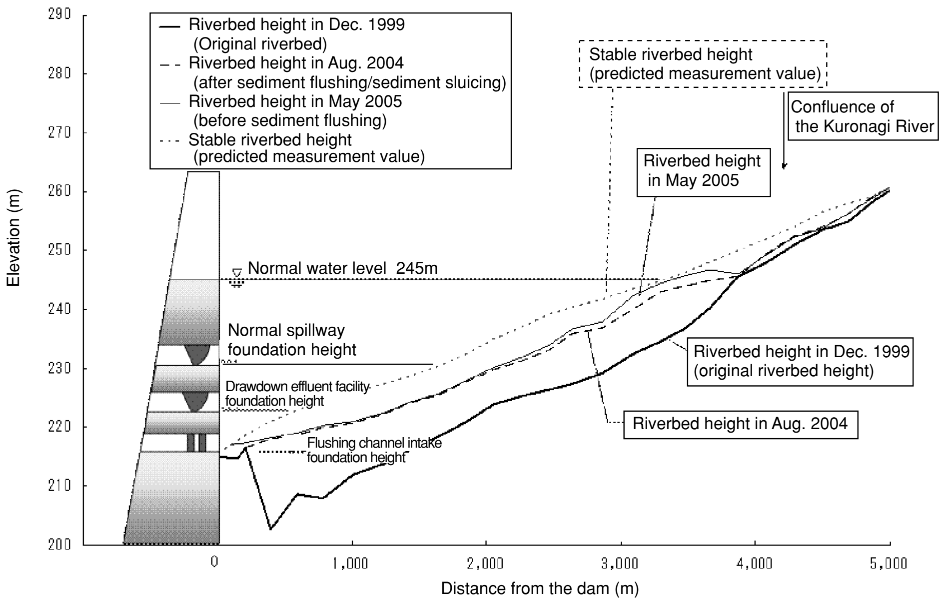

Figure 6 Sediment profile of the Unazuki Dam (May 2005)

Dashidaira Dam reservoir and about 6 million m^3 in the middle course of the main part of the Kurobe River. Particularly in the Nekomata district upstream from the Dashidaira Dam, the riverbed had risen nearly 10 m, inflicting devastating damage on the Kurobe Gorge Railway and the Kansai Electric Kurobe River Power Plant No.2. Consequently, the "Coordinating Council for Kurobe River Disaster Restoration," was launched to discuss ways to prevent the recurrence of the disaster, to ensure the safety of the Nekomata district and to restore the Dashidaira Dam sediment into the state that had existed prior to the flood. On the basis of this agreement, emergency sediment flushing operations were carried out three times between 1995 and 1997 from the Dashidaira Dam.

Sediment flushing operations were implemented from the Dashidaira Dam alone for two years in 1998 and 1999 before coordinated sediment flushing operations started in 2001 with the completion of the Unazuki Dam.

2) Coordinated Sediment Flushing in 2004

From July 16, 2004, heavy rainfall stimulated by an active seasonal rain front continued over the upstream course of the Kurobe River.

As, by 9:00 PM, the inflow of the Dashidaira Dam had exceeded the standard flow rate for the scouring operation (250 m^3/s in the rainy season), it was determined that coordinated sediment flushing operations would be carried out. Because the dam inflow rapidly increased as the rain intensified again during free flow operation, the coordinated sediment flushing operation was suspended at 12:00 AM on July 18. While flood treatment in the Dashidaira Dam and flood control in the Unazuki Dam were being carried out, it was determined that coordinated sediment sluicing would be

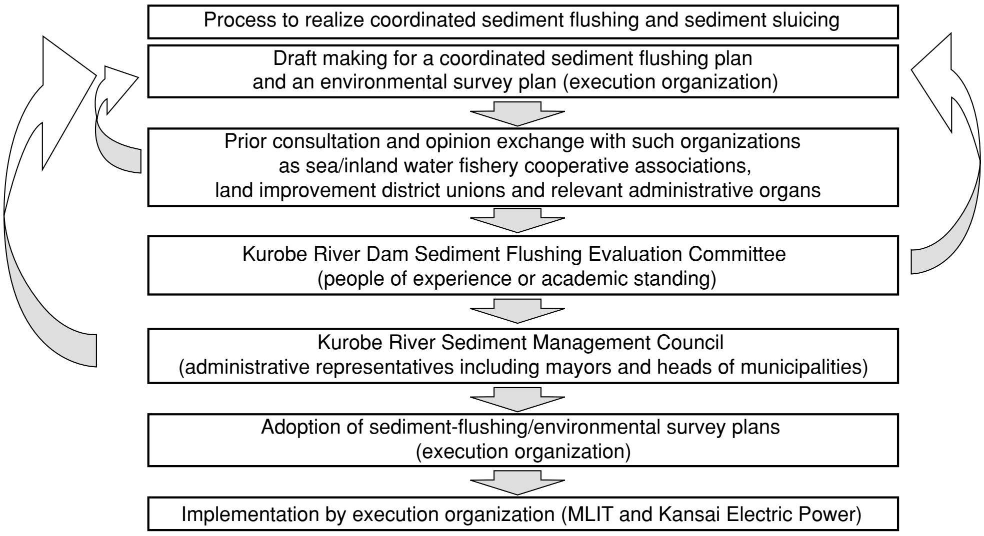

Figure 7 Process to realize coordinated sediment flushing and sediment sluicing

Table 2 List of environmental survey on sediment flushing

Month		4	5	6	7	8	9	10
Entire process			←———	Sediment-flushing/sediment-sluicing operation period			———→	
Research subjects			Regular research	During the sediment flushing operation			Regular research	
Dam lake	Water quality		●	●	One day after the sediment-flushing/sediment sluicing-operation		●	
	Sediment		●	●	One day after the sediment-flushing/sediment sluicing-operation		●	
River	Water quality		●	●	During and one day after the sediment-flushing/sediment-sluicing operation		●	
	Sediment		●				●	
	Aquatic organisms		●				●	
Irrigation channel	Sediment		●				●	
Coastal area	Water quality		●	●	During and one day after the sediment-flushing/sediment-sluicing operation		●	
	Sediment		●	●	One day after the sediment-flushing/sediment-sluicing operation (four major observation points)		●	
	Aquatic organisms		●				●	
Cross-leveling in the reservoir			●		● (implemented immediately after the sediment flushing operation)			

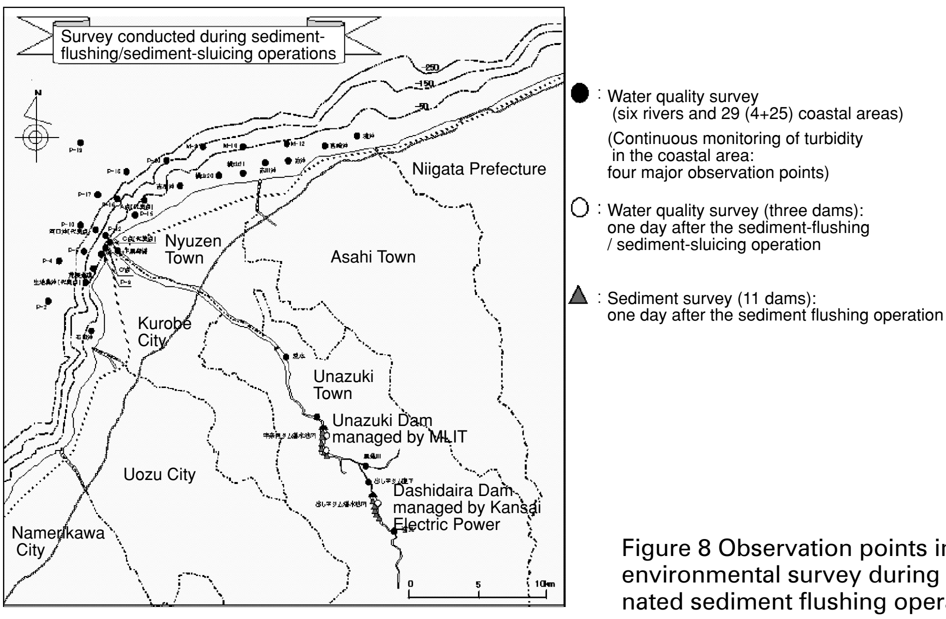

Figure 8 Observation points in the environmental survey during coordinated sediment flushing operations

Table 3 History of coordinated sediment flushing

Year	Quantity of sediment flushing (10,000 m^3)	Classification	Remarks
1991	46	Sediment flushing by the Dashidaira Dam alone	First sediment flushing
1994	8		Test sediment flushing
1995	2		
1995	172		Emergency sediment flushing
1996	80		
1997	46		
1998	34		
1999	70		
2000			No flood reaching the standard flow rate
2001	59	Coordinated sediment flushing	
2002	6		
2003	9		
2004	28		
2005	54		(Target volume)

conducted. The series of operations, from coordinated sediment flushing to coordinated sediment sluicing, lasted for 82 hours and 28 minutes until 10:22 AM on July 20. The volume of sediment discharged in 2004 amounted to 280 thousand m^3. Figure 9 and Photos 5 through 8 show the sediment flushing operations carried out in 2004.

(2) Results of environmental survey

The results of an environmental impact survey associated with the coordinated sediment flushing operation are reported to and evaluated by the Kurobe River Dam Sediment Flushing Evaluation Committee. Regarding coordinated sediment flushing operations up to this point, such comments were given as “no specific problems have been detected,” and “in general, there do not appear to be any problems resulting from environmental impact.”

In all kinds of environmental surveys, such elements as DO and SS are regarded as important indices in examining the impact on the environment. Figures 10 and 11 indicate the transition of SS and DO in the coordinated sediment flushing and sediment-sluicing operations for 2004, and Table 4 shows the maximum observation values in SS and minimum observation values in DO. Although the first sediment flushing operation of the Dashidaira Dam brought about a noticeable impact in that the DO value measured 0 mg/l in the area immediately below the dam, no conspicuous DO decrease was observed in the subsequent sediment flushing and sediment-sluicing operations. The SS values in the downstream course remained low for the incipient 2001 and 2002 coordinated sediment flushing operations, which may be because a great quantity of sediment discharged from the Dashidaira Dam had accumulated in the Unazuki Dam reservoir. As sedimentation in the Unazuki Dam reservoir has continued to accumulate, and the gradient has settled into shape, sediment is allowed to pass through smoothly and the trend of the SS value in the downstream course is to increase. However, the rise in the SS value is a temporary matter and regular follow-up surveys have observed no significant environmental impact.

The observed values for bottom COD and sulfide, the major marine indices, have not so far exceeded ordinary sludge levels in terms of the aquatic water use standard. Figures 12 and 13 demonstrate the survey results of COD and sulfide.

(3) Future challenges

In formulating the year-based coordinated sediment flushing plan, as stated earlier, interested groups and relevant organs are invited to give their opinions. Some suggest that the frequency of sediment flushing and sediment sluicing should be increased so that the discharge flow down occurs as naturally as possible. In response, opinions are exchanged and coordinated with the interested groups and relevant organs, while the effective standard flow rate and environmental impact on the downstream course are evaluated under the guidance of the Kurobe River Dam Sediment Flushing Evaluation Committee.

As it is expected that the discharge of sediment in the river channel and coastal area will incur some impact on the environment, and that there will be a temporary degradation of effluent water, including high turbidity as well as biological influence, the discovery of evaluation methods and formulation of mitigation measures require further research and continuous study. In addition to the data introduced in this paper, a substantial volume of monitoring data has been collected, and these have to be examined to analyze the impact on the environment of dam sediment flushing has to be examined.

At the same time, it is also important to evaluate the positive result of sediment flushing. In other words, dam sediment flushing not only realizes sustainable dam reservoir management, but also contributes to the maintenance of a healthy river and marine environment by continuously supplying soil to the downstream course. Quantitative evaluations are required in this regard.

In addition, it is essential to pay attention to the function of sediment to support the circulation of various substances down the river including nutrients, not merely as physical river and marine components in a narrow sense. The examination of impact mitigation measures is also required, and one of the concrete

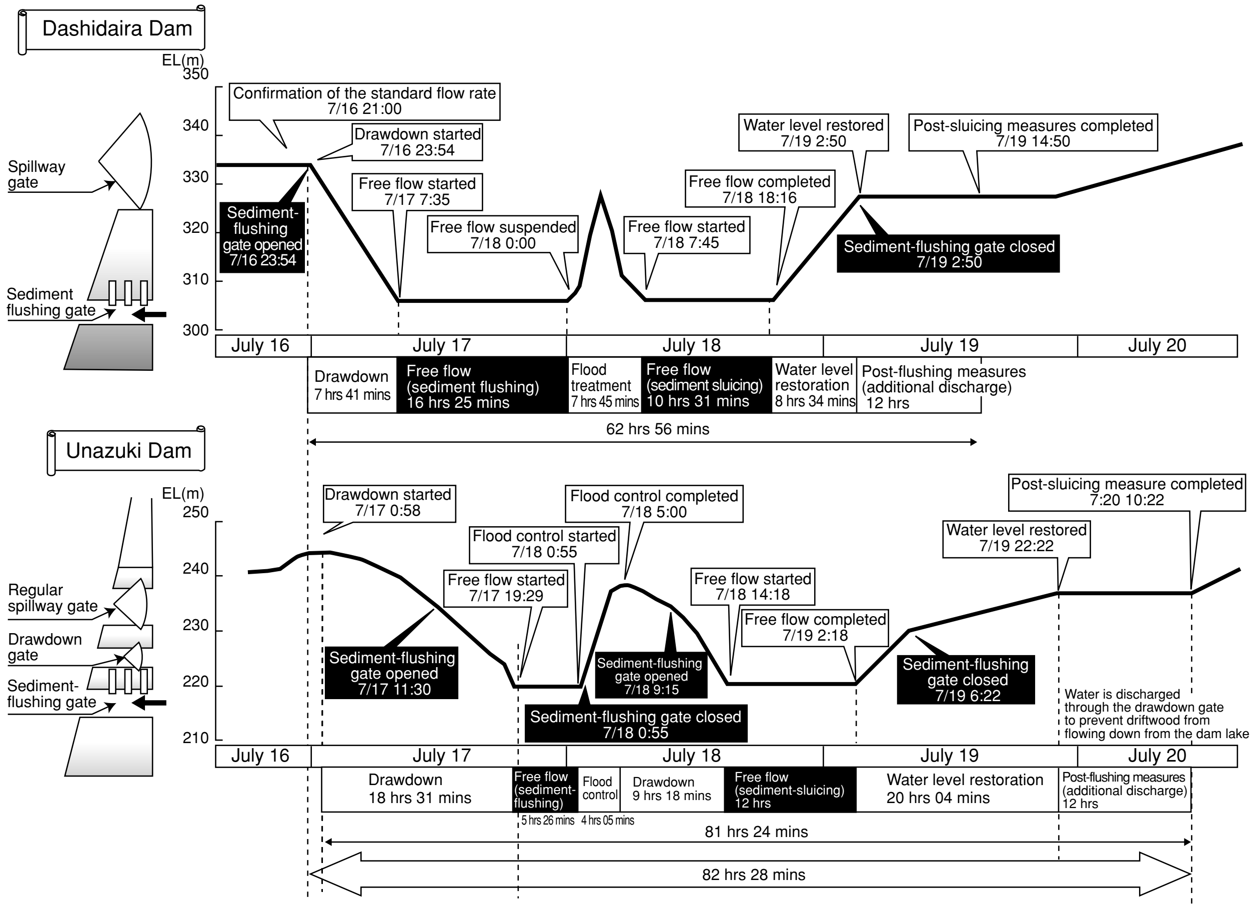

Figure 9 Schematic profile of the dam reservoir level during the 2004 coordinated sediment flushing operation

Photo 5 Dashidaira Dam
(during the free flow operation)

Photo 6 Unazuki Dam
(during the drawdown operation)

Photo 7 Kurobe River mouth during
the drawdown operation

Photo 8 Unazuki Dam reservoir during the
sediment flushing operation

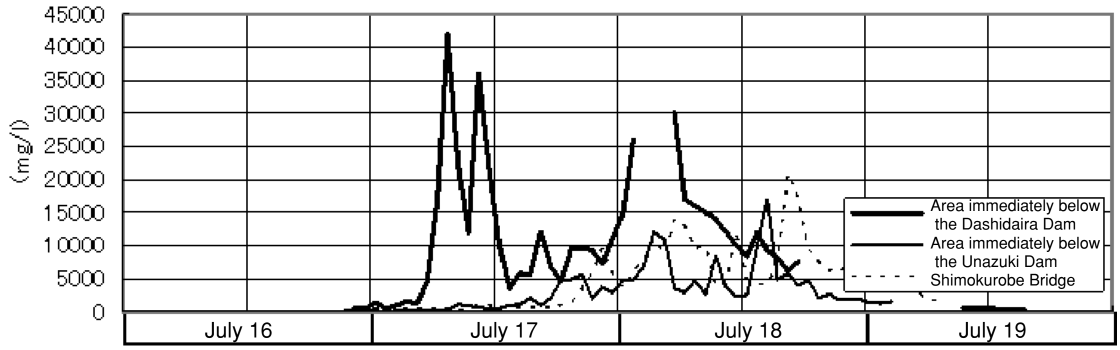

Figure 10 SS in the coordinated sediment-flushing/sediment-sluicing operations for 2004

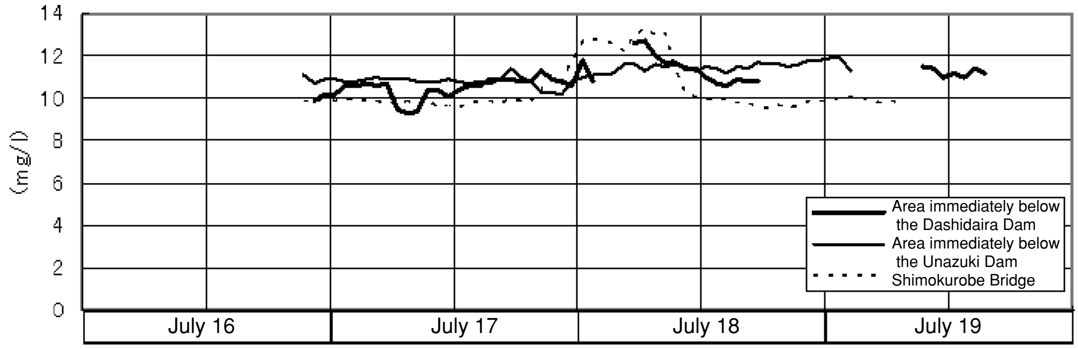

Figure 11 DO in the coordinated sediment-flushing/sediment-sluicing operations for 2004

Table 4 Maximum SS values and minimum DO values observed

Sediment flushing	SS (mg/l) (Maximum values during sediment flushing)			DO (mg/l) (Minimum values during sediment flushing)			Remarks
	Right below the Dashidaira Dam	Right below the Unazuki Dam	Shimokurobe Bridge	Right below the Dashidaira Dam	Right below the Unazuki Dam	Shimokurobe Bridge	
2004.7 Coordinated sediment flushing	16,000	17,000	21,000	10.6	11.2	9.6	
2004.7 Coordinated sediment flushing	42,000	6,800	11,000	9.3	10.2	9.8	
2003.6 Coordinated sediment flushing	69,000	17,000	10,000	11.8	11.3	9.6	
2002.7 Coordinated sediment flushing	22,000	5,400	2,800	9.5	10.5	9.5	
2001.6 Coordinated sediment flushing	29,000	3,700	2,200	11.1	10.6	9.6	First coordinated sediment sluicing
2001.6 Coordinated sediment flushing	90,000	2,500	1,500	7.2	11.4	10.2	First coordinated sediment flushing
1999.6	161,000	52,100	25,700	6.0	5.8	6.5	
1998.6	44,700	9,400	6,750	8.2	7.0	7.3	
1997.7	93,200	28,900	4,330	9.8	9.2	9.3	
1996.6	56,800	9,470	1,520	10.7	10.3	9.8	

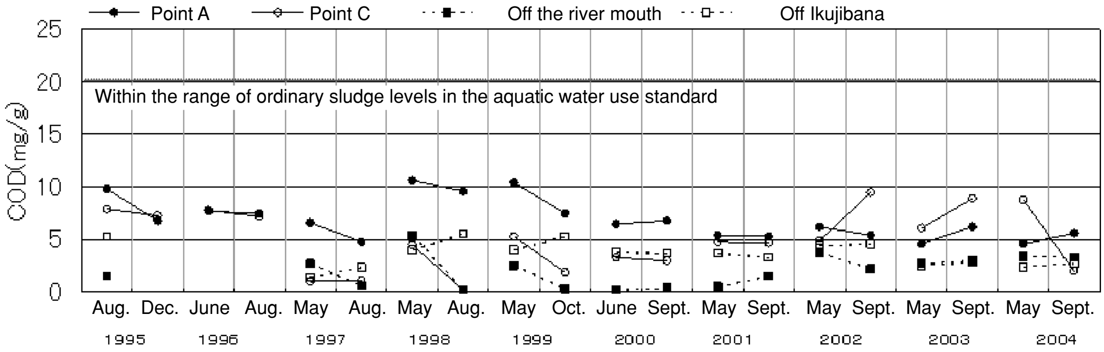

Figure 12 Marine sediment analysis results (COD)

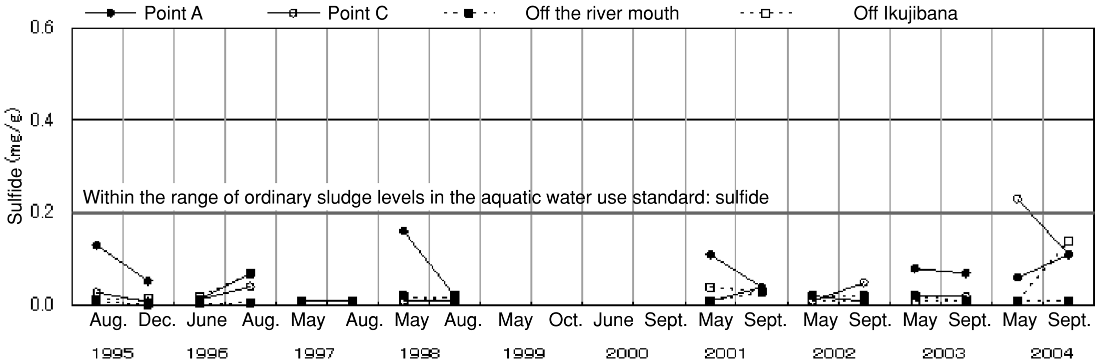

Figure 13 Marine sediment analysis results (sulfide)

Photo 9 Evacuation facility for fish
(resting water channel)

measures up to this point is the installation of an evacuation facility for fish, the (yasuragi suiro or resting water channel) shown in Photo 9. In this system, a foreland stream near the junction of the Kurobe main river and its branch river was improved to secure a freshwater zone into which fish can evacuate as the turbidity of the main river rises. As an evacuation facility for ayu (sweet fish), a positive result has been recognized.

5. Conclusion

The Kurobe River characteristically discharges a large volume of sediment and at the same time is susceptible to flood damage, and so, comprehensive sediment management is required to prevent flood disasters while at the same time maintaining the river's natural gravity flow mechanism. However, it is quite difficult to control sediment movement and a method of grasping soil dynamics as basic information has yet to be fully established. Therefore, at the same time as each sediment control measure is evolved, an attempt is made to elucidate the soil dynamics.

Regarding coordinated sediment flushing operations, environmental assessments and objective evaluations will be carried out to comprehend their impact on the environment. At the same time, sediment flushing methods will be examined and improved to find a method capable of reducing environmental impact to the minimum while the understanding of local residents will be deepened through the disclosure of information and public relations.