Examples of Measures being taken for the Preservation of the Sediment Transport Systems in Rivers Downstream of Dams

Akira Kubota
Water Resources Engineering Department, Japan Water Agency, Japan

Kentaro Kido
Water Resources Engineering Department, Japan Water Agency, Japan

1. Introduction

In general, the following points are indicated as the effects of dam construction to sediment transport system:

- Increase in the danger of floods due to the riverbed aggradations in the upstream of the dam.
- Progress of the riverbed degradations in the downstream reach of the dam due to the interruption of sediment transport.
- Prolonged period of turbid water in the reservoir.
- Functional deteriorations of river structures due to the riverbed degradations or riverbed aggradations.
- Coarsened riverbed material in the downstream reach of the dam and the effects of the fixed flow course to river environment.

Because of the above-mentioned reasons, it would be necessary to consider the sediment problems in reservoirs not only from the viewpoint of the maintenance of the reservoirs' storage functions but also from the viewpoint of the sediment management that aims at the preservation and restoration of the river, including the ecosystem. As measures against the sediment problems, the management of the sediment qualities and quantities in the reservoirs and the method that properly supplies sediment material in the downstream reaches of dams are being conducted.[1)]

This paper delineates the examples of experimental measures for the preservation of the sediment transport system in the downstream of those dams that are managed by Japan Water Agency and the examples of studies and analyses being conducted for the preservation of future sediment transport system in the downstream of a dam being constructed. This study intends to clarify and examine the themes for the evaluation of concrete measures for the preservation of the sediment transport system in the future by analyzing these examples.

2. Studied Dams

Concerned dams in this paper are those that were constructed and are being managed by Japan Water Agency and those for that sediment nourishment and preservation measures are being taken in the downstream reaches of them. The locations of those dams are shown in Fig. 1.

The conditions of the sediment in the downstream of dams are strongly affected by area factors in general. This tendency is conspicuous in areas along a large geological tectonic line, such as the Itoigawa-Shizuoka tectonic line and the Median Tectonic Line. When looking into the total sediment rate in a dam reservoir (a ratio of the amount of the sediment in a reservoir to the total reservoir capacity; see Fig 2[2)] in each river system, it is especially large in the Tenryu River and Ooi River systems and the second largest is in the Kiso River and Kurobe River systems.

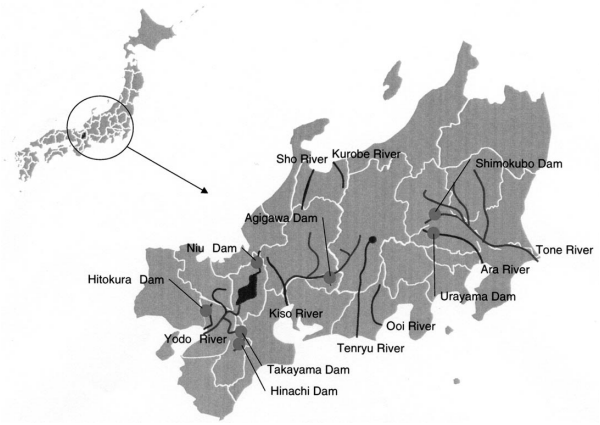

Fig. 1 Locations of Dams and Rivers Examined by this Study

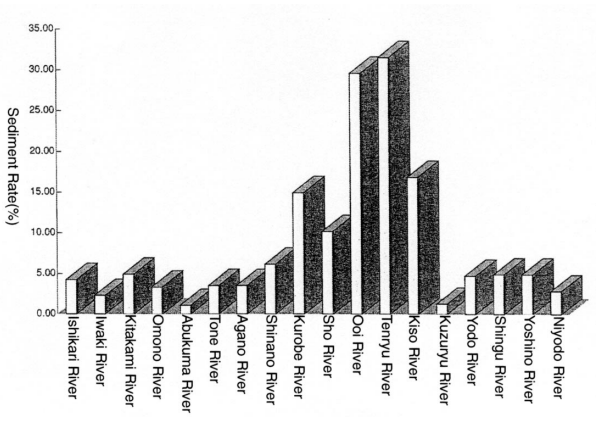

Fig. 2 Sediment Rate in Each River System[2)]

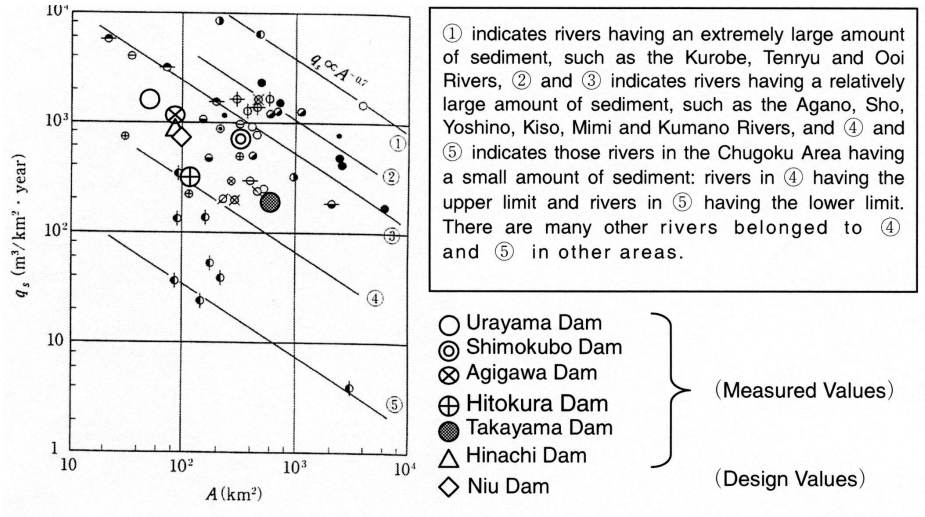

Fig. 3 Relationship between the Size of a Catchment Area and the Amount of the Annual Average Sediment in the Catchment Area[3)]

Fig. 3[3)] shows the relationship between the catchment area of each dam and the amount of annual average sediment produced in the catchment area extracted from the observed sediment data in Japan. Dams discussed in this paper are also included in this figure. In this figure, ① indicates those rivers having the largest amount of sediment, ② and ③ having a large amount of sediment and ④ and ⑤ having a small amount of sediment.

Dam reservoirs having extremely large amount of sediment, such as those in the Tenryu River system and the Kurobe River system, large-scale reservoir sedimentation control measures, such as scour gates and outlets and sediment bypass, are provided.

On the other hand, concerned dams in the paper are built on rivers having a medium amount of sediment transport in Japan. For this reason, the clarification of themes was made not in view of the sedimentation prevention measures in the reservoirs in river systems having an extremely large amount of sediment transport but in view of the sediment transport preservation measures in rivers having a medium amount of sediment.

Japan Water Agency is experimentally applying the following two methods to dams under its management:

① A method to transport and agitate riverbed material by temporarily increasing reservoir discharge amount (hereinafter referred to as flush discharge) without sediment supply in the downstream reaches (Takayama Dam and Hinachi Dam).

② A method to artificially supply riverbed material in the downstream reaches and transport and agitate the sediment by the flush discharge and flood control discharge (Agigawa Dam, Hitokura Dam, Urayama Dam, and Shimokubo Dam).

3. Example of the Effects of Flush Discharge only (Takayama and Hinachi Dams) [4), 5)]

3.1 Outline of these Dams and the Purpose of Flush Discharge

The outline of Takayama Dam and Hinachi Dam is listed in Table 1. The Kizu River, downstream of these dams, is a typical sand river. Area residents and specialists have presented the following opinions regarding the river environment in the downstream of these dams:

- Flow regime in the downstream of these dams became more uniform than before dam construction due to the effects of these dams.
- Algae, that is the main feed of Ayu fish (Japanese sweet fish), is hard to grow fresh.
- Dirt sticks on algae and makes it inappropriate for the feed of Ayu fish.

To respond to the above-mentioned opinions, flush discharge was conducted during the period when the reservoir level was to be lowered to the limit level set for the flood season (hereinafter referred to as a drawdown period).

3.2 Study Method

The study was conducted under the maximum flush discharge of 40 m³/s from Takayama Dam (the flow velocity was in the range of 0.78 to 0.87m/s at the study point) and of 20 m³/s from Hinachi Dam (the flow velocity was in the range of 0.91 to 1.10 m/s at the study point).

The study purpose was to investigate sediment transport and the conditions of algae grown on rock. The study boundary was an approximately 10km section of the river in the downstream of Takayama Dam and an approximately 5km section (up to the confluence of the Shorenji River) in the downstream of Hinachi Dam.

Table 1 Outline of Takayama Dam and Hinachi Dam

Name of Dam	Takayama Dam	Hinachi Dam
Name of River System and River	Yodo River System, Nabari River, a tributary of Kizu River	
Catchment Area of Nabari River	615km^2	
Operation period since dam completion	35 years	6 years
Dam Location (distance from the confluence with Kizu River)	about 0.5km	about 37km
Dam's Catchment Area	615km^2	75.5km^2
River Conditions at Dam Site:		
River slope	about 1/250	about 1/200
Inflow rate(normal water discharge ,2002)	8.5m^3/s	1.43m^3/s
Discharge rate (normal water discharge,2002)	10.16m^3/s	1.58m^3/s

Photo 1 Takayama Dam

Photo 2 Hinachi Dam

3.3 Study Results

The study results of Takayama Dam were as follows:

- Movement of gravel having a maximum diameter of 26mm was confirmed by the sediment transport investigation.
- No great changes could be seen in the chlorophyll-a survey result and no peeling of algae due to flush discharge was confirmed. However, existed predominant species of algae were taken over by others and change in the river environment could be seen.

The study results of Hinachi Dam were as follows:

- Movement of gravel having a maximum diameter of 10mm was confirmed.
- As the same at Takayama Dam, no great changes could be seen in the chlorophyll-a survey result and no peeling of algae due to flush discharge could be confirmed. However, as shown in Fig. 4, the survey result of the ratio of chlorophyll-a to pheophytin-a before and after flush discharge revealed the increase in the chlorophyll-a content. It is considered that this phenomenon means increased algae activities, because chlorophyll-a changes into pheophytin-a after algae die.

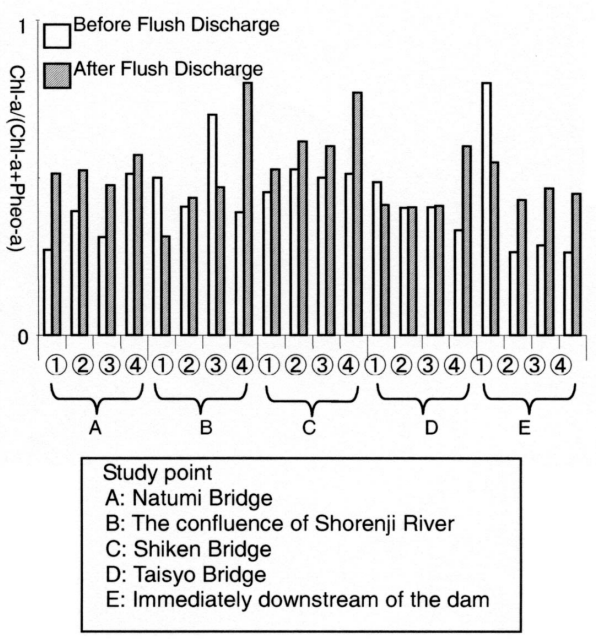

Fig. 4 Change in the Activation of Algae on Rock before and after Flush Discharge (Hinachi Dam)

4. Examples of Sediment Transport Effects (Agigawa Dam, Hitokura Dam, Urayama Dam, and Shimokubo Dam)

4.1 Agigawa Dam[6)]

4.1.1 Outline of Agigawa Dam and the Purpose of Measures Taken

The outline of Agigawa Dam is listed in Table 2. Area residents and specialists have presented the fol-

Table 2 Outline of Agigawa Dam

Name of Dam	Agigawa Dam
Name of River System and River	Kiso River System, Agi River
Catchment Area of Agi River	133km^2
Operation period since dam completion	14 years
Dam Location (distance from the confluence with Kiso River)	8.0km
Dam's Catchment Area	81.8km^2
River Conditions at Dam Site:	
River slope	about 1/80
Inflow rate(normal water discharge ,2002)	1.61m^3/s
Discharge rate (normal water discharge,2002)	1.74m^3/s

Photo 3 Agigawa Dam

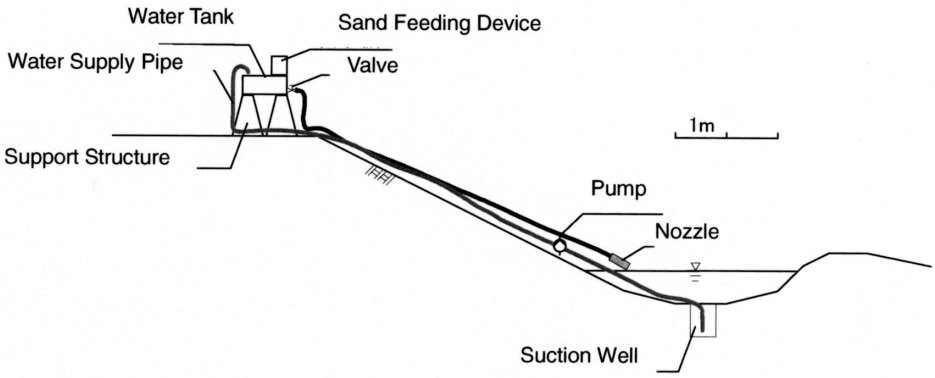

Fig. 5 Equipment Arrangement for Impact and Peeling Test of Algae on Rock

lowing opinions regarding the river environment in the downstream of the dam:

- Riverbed material immediately downstream the dam has become coarser.
- The sand in the river should be flushed so that algae on rock can grow for the feed of Ayu fish.

Based on the above opinions, the sediment material deposited by the check dam (a dam constructed on the upstream of Agigawa Dam Reservoir for water quality preservation purpose) was transported and fed into the downstream reach of the dam in 2004. Before this sediment restoration, the impact and peeling test of algae on rock was conducted as shown in Fig. 5. Gravel mixed water was ejected to algae on rock and the amount of peeled off algae was quantitatively studied.

4.1.2 Impact and Peeling Test of Algae on Rock

Three cases of the test were conducted by changing the amount of gravel in flush water to compare the peel rate of algae on rock with each other. The test results are shown in Fig. 6. The following tendency can be seen from the figure:

① A larger amount of algae is peeled off when gravel-mixed water is ejected onto algae than when water only was ejected (zero gravel concentration).
② When water only is ejected onto algae, the water velocity does not affect to algae peel-off rate.
③ Algae peel-off rate reaches a maximum figure at a certain gravel concentration.

4.2 Hitokura Dam[7)]

4.2.1 Outline of Hitokura Dam and the Purpose of Measures Taken

The outline of Hitokura Dam is listed in Table 3. The Ina River used to be famous as a rare urban river for Ayu fishing. Area residents in the downstream area of the dam have a strong desire to restore the river to the original state so that many Ayu fish will be able to live again as it used to be. For this reason, Japan Water Agency supplies gravel in the downstream of the dam to make spawning grounds, dumps large pieces of rock into the river and repeats flush discharge in order to grow algae on the riverbed. This program is being carried out under the discussions and cooperation with the downstream region's Fishermen's Cooperative Association, NPO groups, community representatives, and related agencies as well as with the participation of area residents.

4.2.2 Study Method

A maximum amount of 20m^3/s flush discharge was made by utilizing a discharge during a reservoir drawdown period. Gravel produced by downstream riverworks was spread uniformly in the river so that the riverbed could be completely submerged when a flush discharge of 20m^3/s was made. The river section studied was an approximately 5km section downstream of the dam (up to the confluence with the Ina River). The main purpose of the study was to investigate the conditions of the algae on the riverbed.

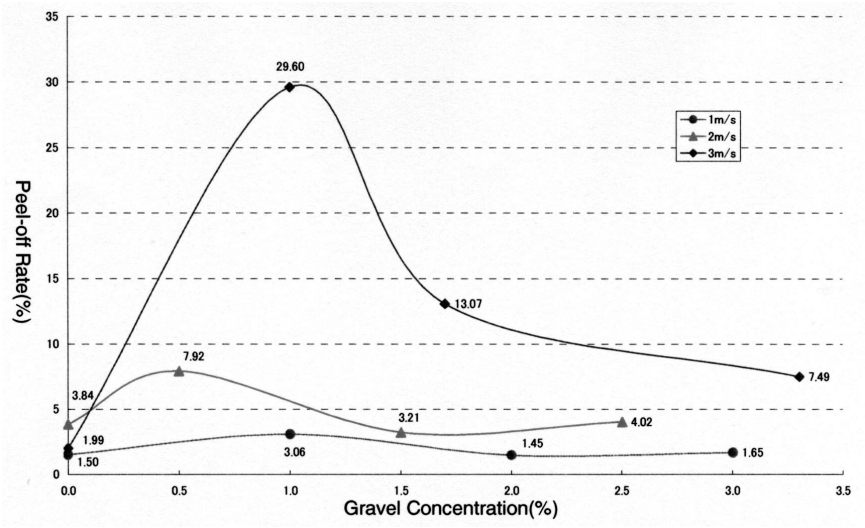

Fig. 6 Peel-off Rate of Chlorophyll-a in the Impact and Peeling Test of Algae on Rock

Table 3 Outline of Hitokura Dam

Name of Dam	Hitokura Dam
Name of River System and River	Yodo River System, Hitokura Ooroji River, a tributary of Ina River
Catchment Area of Hitokura Ooroji River	132.3km^2
Operation period since dam completion	22 years
Dam Location (distance from the confluence with Ina River)	5.0km
Dam's Catchment Area	115.1km^2
River Conditions at Dam Site:	
River slope	about 1/200
Inflow rate(normal water discharge ,2002)	0.95m^3/s
Discharge rate (normal water discharge,2002)	1.43m^3/s

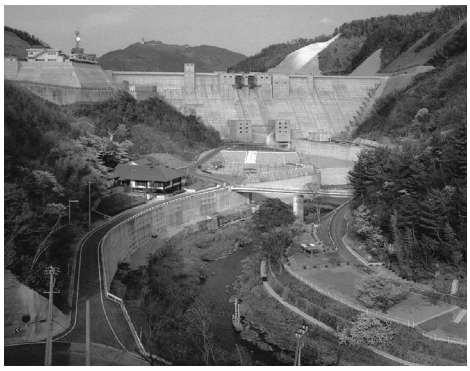

Photo 4 Hitokura Dam

4.2.3 Study Results

Flush discharge was effective to peel off algae from the rock in the downstream of the dam (see Photo 5).

4.3 Urayama Dam[8), 9)]

4.3.1 Outline of Urayama Dam and the Purpose of Measures Taken

The outline of Urayama Dam is listed in Table 4. Ugui fish (dace) live in the Urayama River downstream the dam. The fish is popular for fishing in the campsites along the river. Ugui fish like to spawn on clean riverbed gravel having a 2 to 4mm diameter. For this reason, gravel deposited on the upper part of the reservoir was moved into the downstream reach of the dam in order to prevent the coarsening of riverbed material and the deterioration of fish habitat.

4.3.2 Study Method

A tracer study was conducted to learn if the artificially transported riverbed material was used as a spawning ground. The study was made in an approximately 2.3km river section downstream of the dam (up to the confluence with the Ara River).

4.3.3 Study Results

Spawning of Ugui fish (dace) was confirmed on the artificially relocated gravel-mixed riverbed (see Photo 7). It is considered that the relocating gravel would be effective to maintain the good spawning ground.

4.4 Shimokubo Dam[10)]

4.4.1 Outline of Shimokubo Dam and the Purpose of Measures Taken

Shimokubo Dam is outlined in Table 5. The approximately 1.5km river section downstream of the dam is designated as a national scenic spot and natural monument called as "Sanba Seki Kyo (gorge)." Due to the lowering of the water level and the interruption of sediment supply, the riverbed in this section has been lowered and the landscape has been deteriorated. For this reason, river maintenance discharge begun in 2001 and experimental gravel nourishing has been carried out since 2003. The purpose of this measure is to restore the riverbed and the landscape of "Sanba Seki Kyo" by the cleansing effect. The activities are carried out under discussions with area residents and administrative organs and by taking into consideration the directions and advice of specialists.

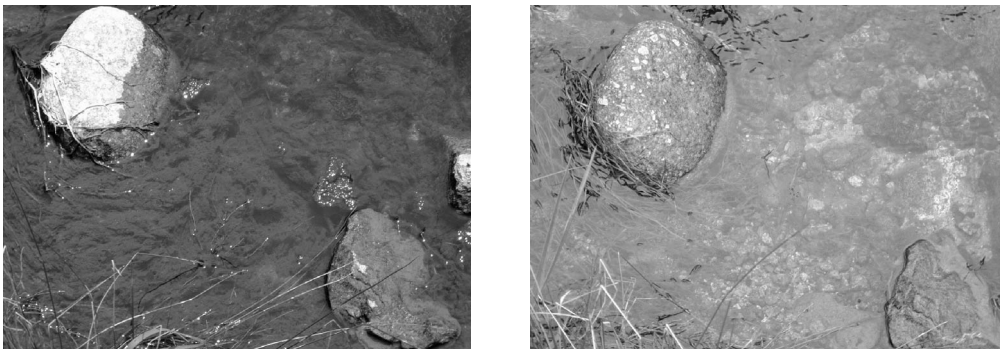

Photo 5 Riverbed Condition Before (left side) and After (right side) a Flush Discharge

Table 4 Outline of Urayama Dam

Name of Dam	Urayama Dam
Name of River System and River	Ara River System, Urayama River
Catchment Area of Urayama River	59.6km^2
Operation period since dam completion	6 years
Dam Location (distance from the confluence with Ara River)	about 2.3km
Dam's Catchment Area	51.6km^2
River Conditions at Dam Site	
River slope	about 1/80
Inflow rate(normal water discharge ,2002)	1.01m^3/s
Discharge rate (normal water discharge,2002)	0.72m^3/s

Photo 6 Urayama Dam

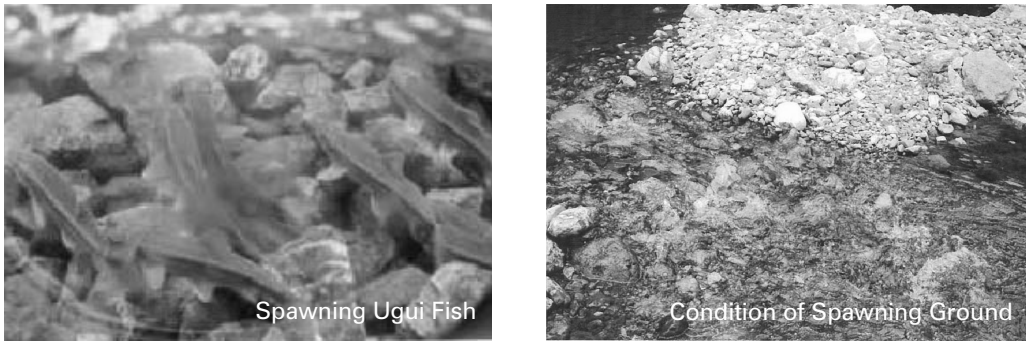

Photo 7 Spawning Ground of Ugui Fish made with Artificially Placed Gravel

Table 5 Outline of Shimokubo Dam

Name of Dam	Shimokubo Dam
Name of River System and River	Tone River System, Kanna River
Catchment Area of Kanna River	407km^2
Operation period since dam completion	36 years
Dam Location(distance from the confluence with Tone River)	about 30km
Dam's Catchment Area	322.82km^2
River conditions at Dam site	
River slope	about 1/130
Inflow rate(normal water discharge ,2002)	3.02m^3/s
Discharge rate (normal water discharge,2002)	3.60m^3/s

Photo 8 Shimokubo Dam

4.4.2 Study Method

Riverbed material was obtained at the sediment trap dam site. The material was transported and placed in the river downstream of the dam in order to make it to flow when reservoir water was discharged. The study included a periodical landscape survey by photographing. The study area was an approximately 3km section of the river downstream of the dam (Tosen Bridge point).

4.4.3 Study Results

A certain landscape improvement was confirmed, such as the restored shininess of Sanba Seki rock by the cleansing effect (see Photo 9). In addition, some riverbed restoration was confirmed.

4.5 Results of Measures Taken at Dams managed by Japan Water Agency

Points to be evaluated in the above-mentioned measures can be clarified as follows:

① When paying attention to the changes in and activation of predominant algae grown on rock at the sites of Takayama Dam and Hinachi Dam, certain effects were achieved by flush discharge. At the sites of Hitokura Dam and Agigawa Dam, peel-off effects of algae on rock by sediment transport were confirmed.

② At the site of Urayama Dam, attention was paid to the maintenance of the fish spawning ground. Sediment supply to the spawning ground by sediment transport was confirmed.

③ At Shimokubo Dam site, special attention was paid to the area's specific tourism resource (scenic spot of natural monument). Sediment transport could accomplish certain effects on restoring the landscape.

④ At Agigawa Dam site, a basic experiment was conducted to learn the relationship between flow velocity, sediment concentration and the peel-off rate of algae on rock prior to the implementation of the sediment transport and important data were obtained.

⑤ At Shimokubo Dam and Hitokura Dam sites, meetings with area residents and specialists were held to exchange opinions and measures to be taken were decided upon and implemented under discussions with them.

5. Examination of the Preservation of Sediment Transport at a Dam under Construction[11), 12)]

The outline of Niu Dam is listed in Table 6. The Niu Dam is being constructed on the Takatoki River of the Yodo River system. The Takatori River is an important spawning ground of various species of fish, including Ayu fish. Thus, the following studies and analysis are being conducted to learn the sediment transport mechanism in the Takatoki River and obtain basic data necessary to take sediment transport preservation measures after completing the dam construction:

Visual observation of the change in the river topography (river channel, water course, sand bars, riverbed, etc.) and vegetation, preparation of the database of river features prior to dam construction, and periodical photograph taking of the conditions in the river section between the dam construction site and the river month before the dam construction are being conducted. Photograph taking is conducted at the intervals of 1 to 2km from existing bridges with a frequency of more than once a week. It is possible to continuously learn the changes in the river flow and riverbed condition through these activities (see Photo 10).

In addition to the above study, possible effects to the sediment, change in riverbed features and the amount and quality of sediment transport in the Takatoki River to be created by Niu Dam after its completion are quantitatively being analyzed by using the sediment transport prediction model that has been developed for the Takatoki River system.

6. Concluding Summary

For Future Measures to be taken to Preserve Sediment Transport System:

Based on the results of the above-mentioned studies, the following five points are considered as important that measures for the preservation of sediment transport system should be taken in the future for those dams that are built on rivers having a medium

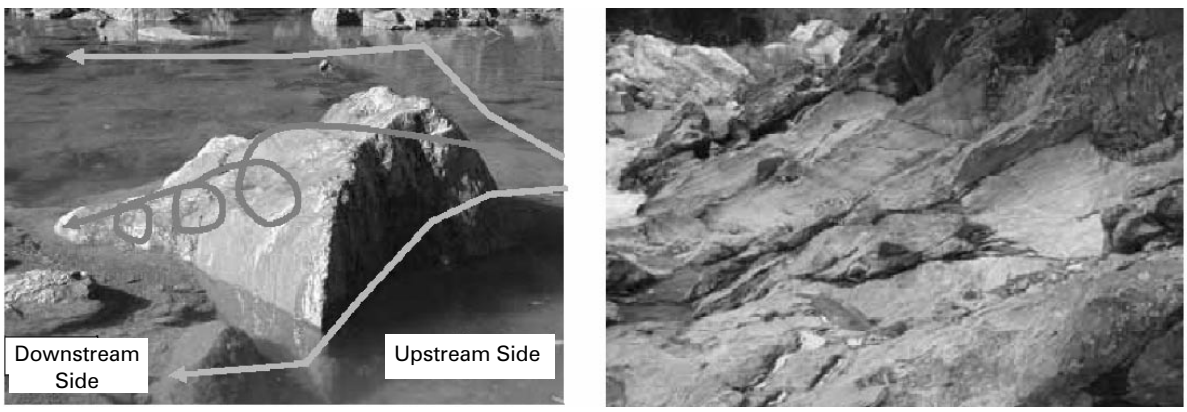

Photo 9 Cleansing Effects and Cleaned Rugged-Rock Surface

Table 6 Outline of Niu Dam

Name of Dam	Niu Dam
Name of River System and River	Yodo River System, Takatoki River, a tributary of Ane River
Catchment Area of Takatoki River	212.0km^2
Dam Location (distance from the river mouth)	about 30km
Dam's Catchment Area	93.1km^2
River Conditions at Dam Site	
River slope	about 1/130
Inflow rate(normal water discharge ,2003)	8.56m^3/s

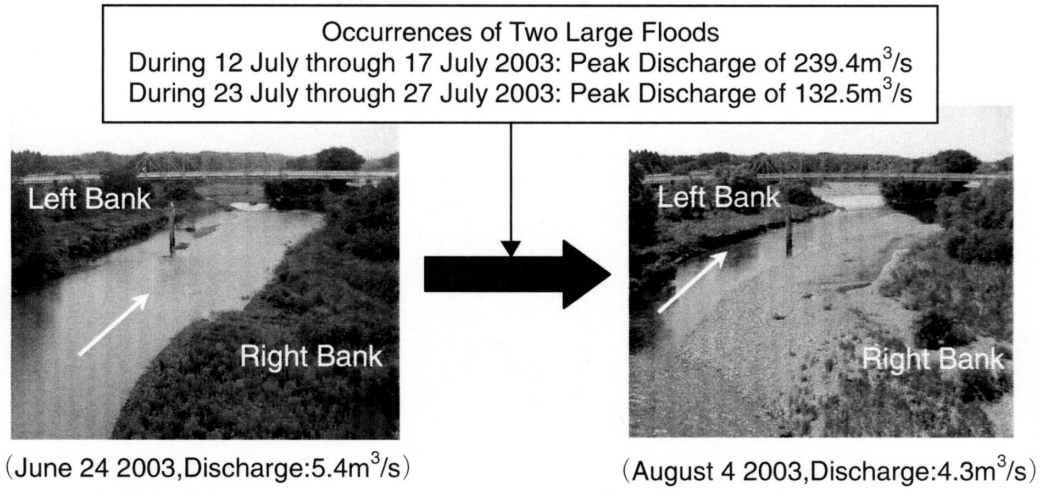

Photo 10 Riverbed Condition Before and After Flood

amount of sediment transport, such as those mentioned above:

(1) Set up of Targets

As targets for sediment transport management, prevention of riverbed degradation, fixed flow course and coarsening of riverbed material, acceleration of the peel-off of algae grown on riverbed rock, and preservation and restoration of landscape are pointed out. Judging from the results of this study, a certain effect to the peel-off of algae was accomplished only by controlling the amount of flush discharge. However, by combining with sediment material supply, flush discharge may result in the improvement of peel-off effect of algae, supply of fine material in river course, and restoration of small sand bars.

(2) Selection of the Method of Sediment Material Supply to Suite the Objective

For the improvement of the river environment in a limited section of the river downstream of a dam, it would be sufficient to conduct sediment material supply in the river immediately downstream of a dam and the drawdown operations of the reservoir. However, when considering a larger scale sediment transport, there would be a limit in the tractive forces to be created by flush discharge from the dam because of the limitation of reservoir discharge equipment and reservoir capacities. Thus, it would be desirable to determine a location to supply sediment material and the amount of it to suite the river course and flow regime.

(3) Careful Monitoring

Discharge from a dam is related to weather condition. Thus, artificial sediment supply and transport should be conducted to suit river conditions that vary from time to time by monitoring the river conditions, preparing a sediment supply plan and modifying the plan from time to time to suit the conditions. To supply a sufficient amount of sediment material, it is important to conduct a continuous monitoring of downstream river environment in detail and prepare the database.

(4) Cooperation and Understanding from Various Aspects

It is important to maintain close communications and cooperation with concerned administrative organs and river water users, fishermen and tourism industries and area residents.

(5) Development of more economical and effective method

As mentioned above, it is considered that the further economical and effective method for sediment material management may be developed by accumulating scientific knowledge related to the effects of sediment transport given to river environment.

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