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ENVIRONMENTAL IMPROVEMENT EFFECT IN DOWNSTREAM CHANNEL BY SEDIMENT SUPPLY TEST

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1. INTRODUCTION

The Shimokubo Dam has been managed for 40 years since January 1969. The sediment speed exceeds an estimate, showing explicitly degradation and granulation of bed material with landscape change in the dam downstream. Thus, improvement of the river environment raises the issue to manage flushing discharge by sedimentation supply to the dam downstream under the test of flexibility dam operation. This report describes the sediment supply test, which has been performed since 2003, and the result of monitoring survey.

2. OUTLINE OF APPROACH IN SEDIMENT SUPPLY TEST

In the dam downstream, Sanbaseki Gorge, designated as a scenic spot and a natural monument, is famous for its stones. The gorge had resulted in a non flow area due to discharge into the downstream area through pipelines for power generation and had caused deterioration of the river landscape and environment after the start of dam management. Then, 0.323 m^3/s of flow has been maintained to upgrade its scenery and environment under the aquatic improvement project since 2001.

However, sediment interception by dam prevented from restoring the previous scenery. Thus, some trials have been made by transporting sediments from the reservoir upstream to just below the dam and flowing the sediment in case of flood (sediment supply) since 2003.

Consequently, sediment supply at flood time caused flow mingling with sand and produced cleansing (corrasion) effects to separate algae from stones. Local residents valued the restoration of previous landscape. From 2005, the scope and scale of the test have been expanded to evolve into approaches including conservation and enhancement of the river environment in the Kanna River of downstream Sanbaseki Gorge. Furthermore, aiming to hear the views of the test from a wide range of organizations and local residents involved with the Kanna River, a conference on sediment supply in the Kanna River was established in 2005. This conference was to get ideas of the test and serve improvement of the river environment over five years.

In the test evaluation, monitoring survey on the following items has been conducted to grasp quantitatively the effect of sediment supply.

1) Safety in flood control by aggradation
   (Cross-sectional shape)
2) Displacement of sand bar
   (Planar shape, landscape, and grain distribution)
3) Changes in river vegetation
   (Area and dominant species)
4) Study of aquatic insects
5) Study of fishes, etc.

Moreover, from 2007, for the purpose of increase in sediment supply, flexible use of storage capacity (Flexibility Dam Operation) has been implemented through flushing discharge after temporal storage of flood control capacity in order to upgrade the downstream river environment. This discharge has been conducted in three years of experimental period, from 2007 to 2009. For example, the discharge as of July 2008 proved effective in the river environment of Sanbaseki Gorge. The following describes the approaches.

3. SEDIMENT SUPPLY TEST

3.1. IMPROVEMENT TARGET OF SEDIMENT SUPPLY TEST

The target of the test was specified in two sections, shown as in Fig. 1 and Table 1.

[Section 1] Shimokubo Dam to Shinsui Dam
(including Sanbaseki Gorge)
[Section 2] Shinsui Dam to Kanna River headworks
(12 km of the Shimokubo Dam downstream)

Section 1 belongs to Sanbaseki Gorge with scenic views of striped Sanba stones of green quarts schist where some local people could make money as tourist guide. In this section, the thematic target was ‘landscape restoration in Sanbaseki Gorge and recovery of affinity toward the river.’

Section 2, once flourished with hot springs and resort villas in the river bank, was crowded with visitors. In addition, this area was well known for big ayu, Hagoita ayu (about 30 cm long). The thematic target of the section was ‘improvement of river environment within the channel and recovery of affinity toward the river in order to contribute to abundant interaction between humans and the river and conservation of fauna and flora.’ In addition, the downstream area of the Kanna River headworks was not included in these target sections because of the assumed limited effects of sediment supply due to sharply broadened river width.

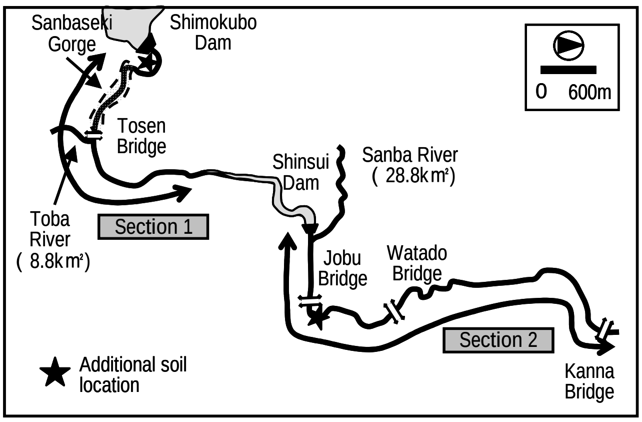


Fig. 1
Location of soil setting

Table 1

Target of environment improvement

Section		Environment Improvement Items
Section 1	Just below the dam-Shinsui Dam	Riverbed recovery by sediment supply
		Riparian vegetation recovery by healthy disturbance
		Sanbasaki Gorge cleaning by cleansing effect
		Recovery of gravel band by sediment supply
		Periodical renewal of attached algae by healthy disturbance
Section 2	Shinsui Dam – Kanna River headworks	Resolution of backwater, regeneration of gravel band
		Suppression of overgrowth submerged plant and bank vegetation by increasing disturbance
		Improvement of being coarse-grain and recovery of fish spawning bed
		Increasing renewal chance of attached algae and recovery of dietary environment of ayu
		Native habitat recovery of organisms utilizing sand gravel

3.2. SOIL SETTING AND FLOW

Sediment to supply to the downstream channel for the test was collected from the check dam installed in the upstream toe of dam and was set in the downstream area. The site for sediment was fixed just below the dam and in the Jobu Bridge downstream to improve the environment in the above Section 1 and 2. (See Fig. 1) Table 2 shows annual soil setting and flow until 2008. Sediment setting, 11,900 m^3 just below the dam and 20,300 m^3 in the Jobu Bridge downstream, was conducted.

Flow of sediment just below the dam varied according to annual flow regime and that in the Jobu Bridge downstream occurred only in flood which arose from the ninth typhoon in 2007. Annual maximum discharge from the Shimokubo Dam, from the management start to 2008, is shown in Fig. 2. In 2007, the ninth typhoon induced the largest class of flood since management start (417 mm of total rainfall depth over the river basin and 1,480 m^3/s of maximum inflow) to discharge 800 m^3/s of maximum design discharge flow. At Wakaizumi site (2.9 km from the Jobu Bridge downstream), 1,023 m^3/s of maximum flow was confirmed.

Table 2
Soil setting and flow

year	Just below the dam downstream (m^3)		Jobu Bridge downstream (m^3)		Flood Cause
	Add Soil Amount	Flow-Down Amount	Add Soil Amount	Flow-Down Amount	
2003	2,000	1,000	-	-	Rain front
2004	2,000	1,000	-	-	Typhoon
2005	2,200	2,000	5,400	-	Typhoon, etc
2006	-	1,500	-	-	Rain front, low pressure
2007	1,800	2,500	10,600	9,500	Typhoon
2008	3,900	1,300	4,300	-	Rain front, Elastic Management Test
Total	11,900	2,300	20,300	9,500	

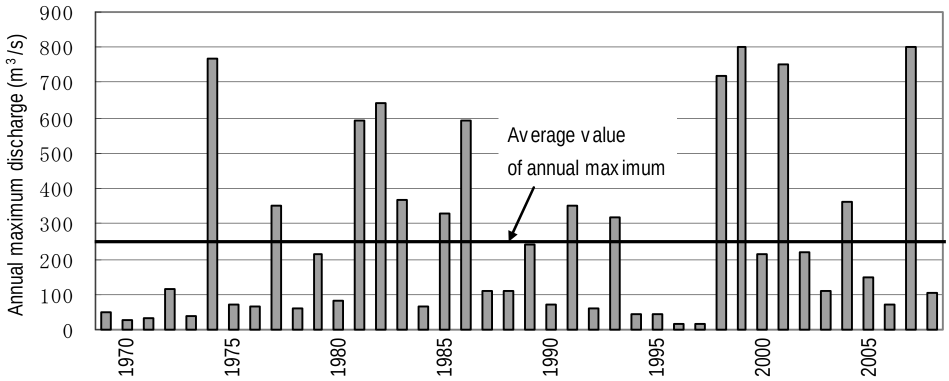


Fig. 2
Annual Maximum discharge in the Shimokubo Dam

3.3. SEDIMENT SUPPLY BY FLEXIBILITY DAM OPERATION TEST

3.3.1. Purpose of test

The test was implemented by 1,100,000 m^3 of temporal storage 0.45 m above the flood season control level for increase of sediment supply, which was prompted by flushing discharge to the downstream area to improve the downstream river environment. The test was designed to be carried out in three years, 2007 to 2009.

3.3.2. Implementation of test

A maximum 90 m^3/s of discharge was planned in the test. The first test was performed in July 18 2008 when high inflow occurred. In the test, as in Fig. 3, 1.5 hour of 90 m^3/s discharge (around 800,000 m^3 of total discharge) transported about 70% of soil setting just below the dam (13,000 m^3 out of

18,000 m^3). However, traction of sediment was rarely found in the Jobu Bridge downstream.

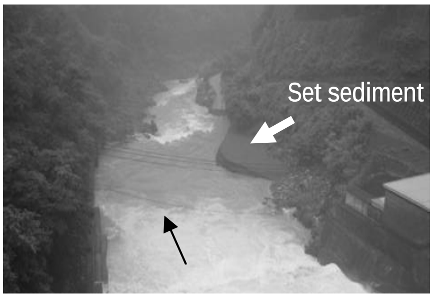


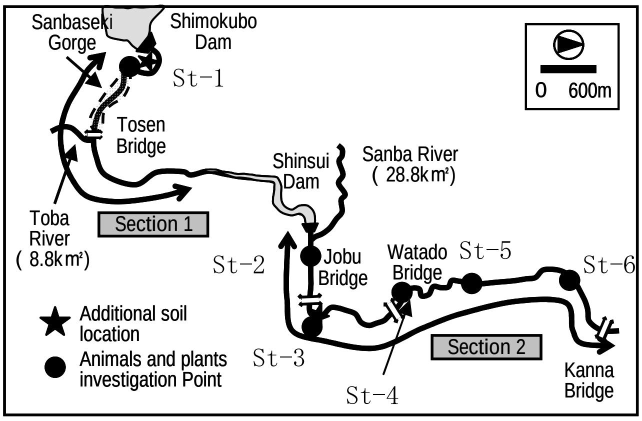
Fig. 3
Soil setting under flushing discharge (Flow at 90 m^3/s)

4. MONITORING SURVEY OF SEDIMENT SUPPLY TEST

The purposes of this survey were to grasp decrease in flow area of channel by silting up in the river bed, formation of sand bar, cleansing effects in Sanba stones, changes in bed material, and effects on flora and fauna.

Table 3
Monitoring survey by sediment supply test

Target	Contents	Purpose	Method
River Shape/landscape	Cross-sectional shape	Figure out sediment deposition status	Transverse shape survey
	Riffle, pooldistribution/sand bar forming	Figure out situation of riffle, pool distribution/sand bar forming	Making out air photograph, exploration
			Fixed point shot shooting
	Cleansing effect	Figure out cleansing effect on Sanbaseki	Exploration, air hotograph shooting
Sediment flow down status	Flow down status	Figure out flow down status of sediment supply	Tracer investigation
	River bed construction material distribution	Figure out variation of river bed construction material at typical point	Quadrate investigation
Riparian vegetation	Vegetation distribution	Figure out influence on riparian vegetation	Making out air photograph, exploration
	Vegetation transverse shape		Classification by dominant species
Aquatic insect class	Aquatic insect class fauna	Figure out influence on aquatic life	Light trap method
Fish class	Fish fauna		Catch investigation



St-1 : Sanbaseki Gorge
St-2 : KATARAI Place
St-3 : Jobu Bridge
St-4 : Waterfront Park
St-5 : Wakaizumi
St-6 : Kannagawa dam

Fig. 4
Test sites of sediment supply test

4.1. SHAPE OF RIVER (CROSS-SECTIONAL SHAPE/PLANAR SHAPE)

4.1.1. Cross-sectional shape of river

Survey of sedimental status in the river bed was conducted in order to recognize the prospect of decreased discharge capacity of channel by sediment supply and the environmental changes in the river bed. Cross-sectional shape of the river was surveyed in 17 sites from the Shimokubo Dam to the Kanna River headworks. The results are described in chronological order by sections investigated (Section 1 in the Sanbaseki Gorge and Section 2 from the Shinsui Dam to the Kanna River headworks). This variation demonstrates annual elevation of the central part of channel surveyed in 2007.

Fig. 5 displays elevation change in the central part of channel in the Sanbaseki Gorge area (Section 1). (Site① is 0.1 km downstream from soil setting just below the dam, and Site is 1.8 km downstream; the larger the number of site is, the more downstream it is.) This implies that the sections changed are mainly parts of pools where repetitive phenomena of sediment deposit by traction and sweep by flood have occurred. In Site , located in shallows, soil setting and much sediment supply appear to cause temporal increase in siltation. On the whole, apparently, the tendency of sedimentation does not become a problem in terms of discharge capacity of channel.

Similar changes in Section 2 are shown in Fig. 5. Sedimentation was confirmed mainly in the part of pools, meaning that sediment discharge caused temporal deposition in the area. St-3 in riffles exhibited tendency of about 75 cm higher sedimentation in 2007 and 2008, compared with those in 2004. This also appears to be caused by soil setting and much sediment supply. The section generally showed the sedimentation tendency but did not present a problem in terms of discharge capacity of channel.

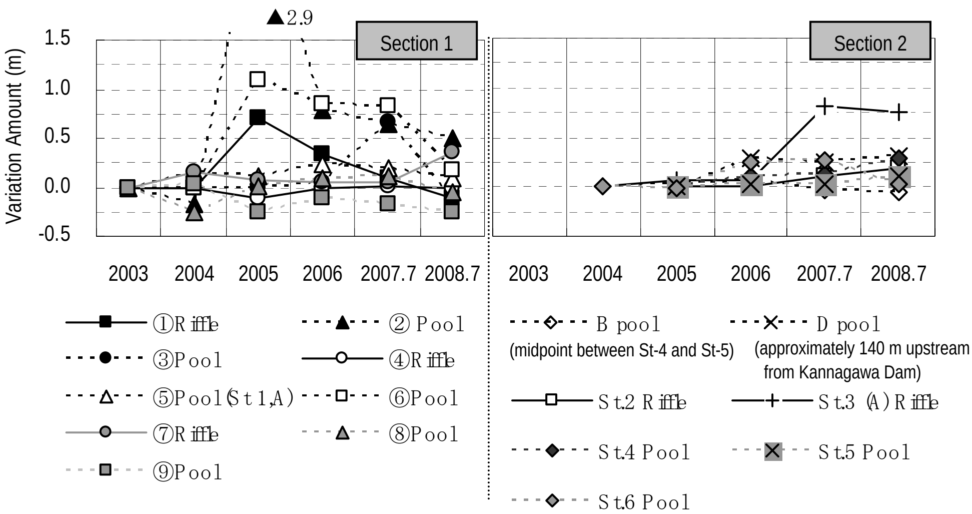


Fig. 5
Changes in cross-sectional shape at Section 1 (Sanbaseki Gorge) and Section 2 (Jobu Bridge-Kanna River headworks)

4.1.2. Planar shape

Changes of planar shape in the river were verified by aerial photographs. Fig. 6 displays secular variation of landforms in the upstream river of Sanbaseki Gorge just below the dam, showing repetitive deposition and erosion of sediment. With no tributaries in this area, sediment just below the dam is deposited by smaller discharge and transported by larger discharge to disappear repeatedly.

In November 2007, immediately after the large typhoon as of September 2007, sediment was virtually washed out to the downstream area. In this typhoon, discharge from the Shimokubo Dam at 800 m^3/s resulted in about 4 m/s of flow velocity in the river of Sanbaseki Gorge. If we followed Iwagaki's formula[1),],almost soil set just below the dam with about 5 cm of maximum grain size would be swept away. This suggested the importance of sediment supply after the large discharge from the aspect of river environment.

Fig. 7 shows changes across ages in the downstream area of Jobu Bridge. There are significant signs of vegetation runoff after the severe flood in this area. Little disappearance of sand bar seems to result from sediment supply from tributary of the Sanba River even after the flood.

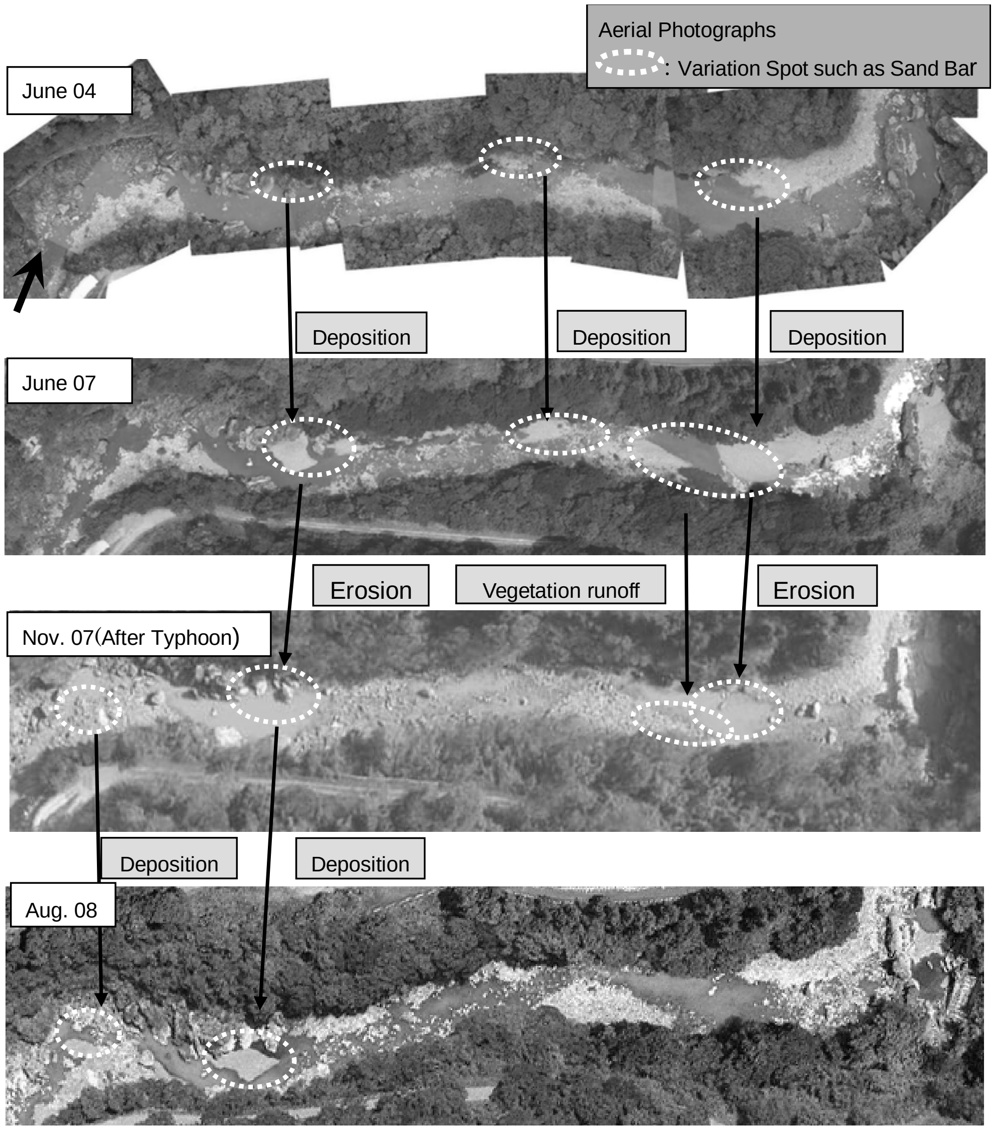
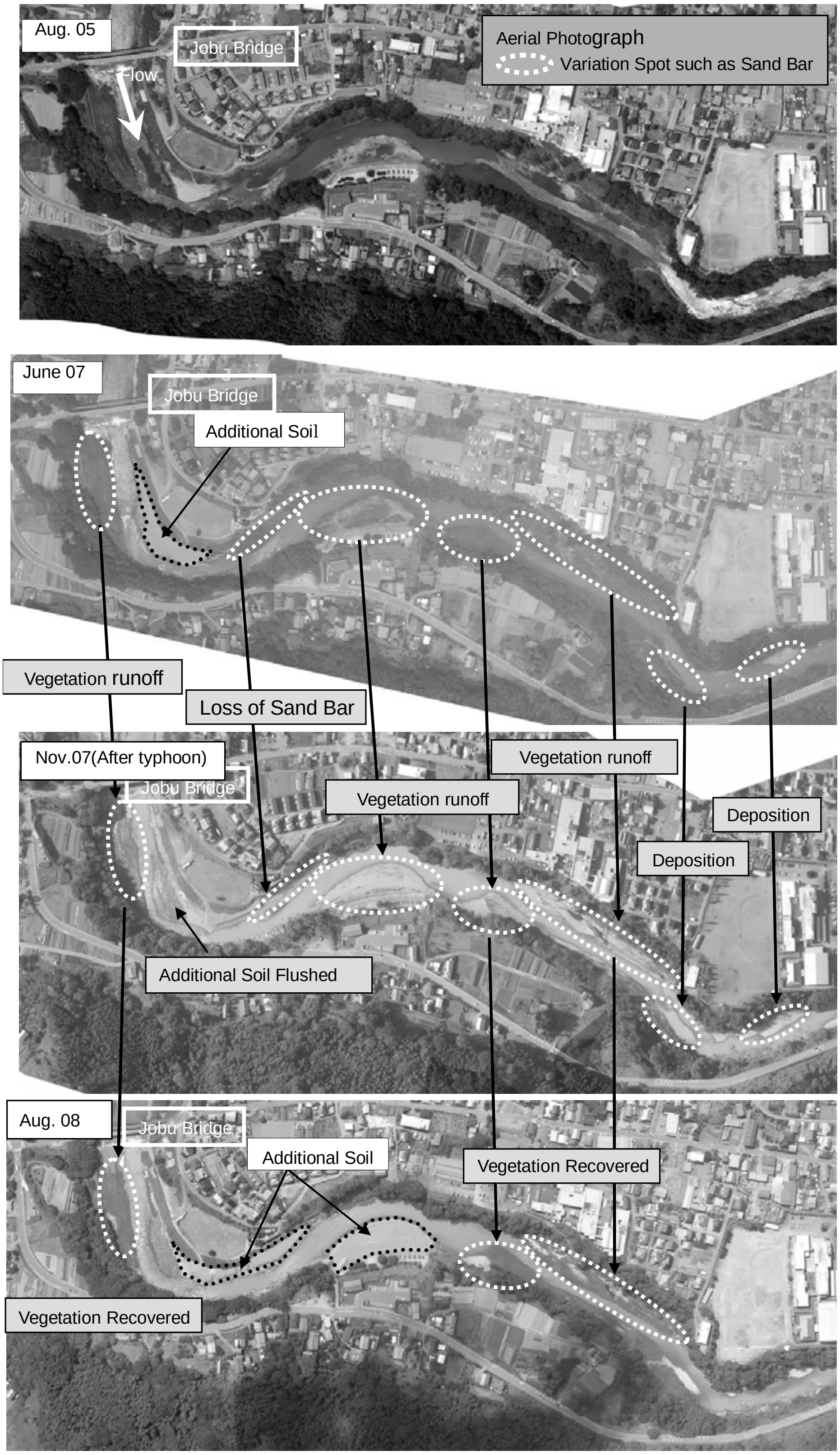


Fig. 6
Changes of planar shape in Section 1 Sanbaseki Gorge



Aug. 05
Jobu Bridge
Flow
Aerial Photograph
Variation Spot such as Sand Bar
June 07
Jobu Bridge
Additional Soil
Vegetation runoff
Loss of Sand Bar
Nov.07(After typhoon)
Jobu Bridge
Vegetation runoff
Vegetation runoff
Deposition
Deposition
Additional Soil Flushed
Aug. 08
Jobu Bridge
Additional Soil
Vegetation Recovered
Vegetation Recovered

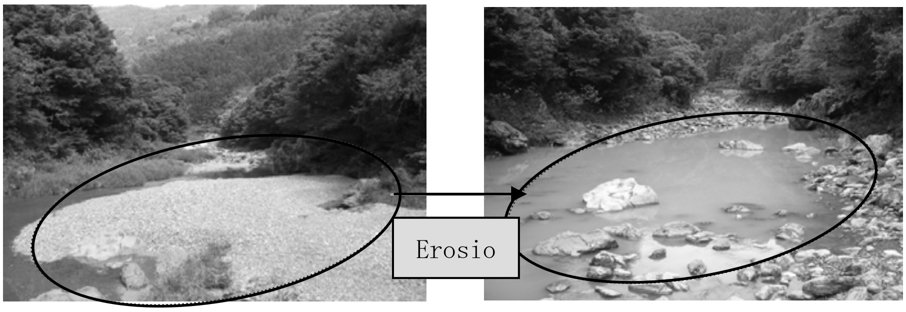
Fig. 7
Changes of planar shape in Section 2 (Jobu Bridge - Kanna River headworks)

4.2. River landscape

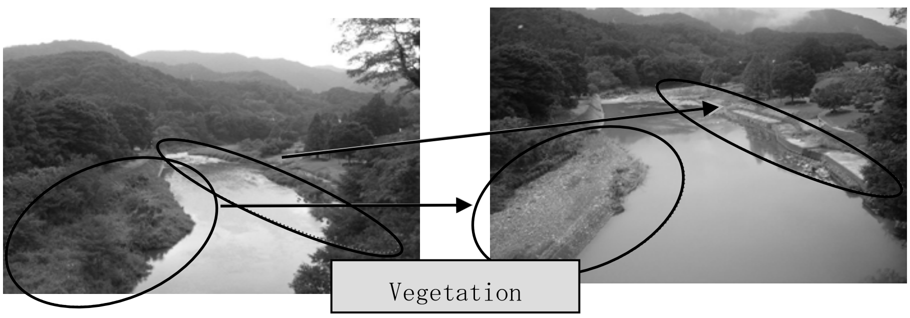
4.2.1. River landscape（Fixed point photography）

Changes of river landscape were surveyed by fixed point photography in 36 sites from the dam to the Kanna River headworks, two sites of which are described. Fig. 8 shows the landscape variation 400 m downstream from the set sediment before and after the typhoon in 2007. The sand bar seen before the typhoon led to granulation by sand fraction flow after it. The mentioned sand bar is thought to contribute to cleansing effects.

On the other hand, Fig. 9 displays the landscape 700 m downstream of the Jobu Bridge from the set sediment before and after the typhoon. As mentioned in the above, the changes in the aerial photograph can be confirmed from the ground. Traction of sediment in Section 1 and vegetation runoff in Section 2 are seen after the severe flood.



September 2007 (before typhoon No. 9)　October 2007 (after typhoon No. 9)
Fig. 8
Landscape change at about 400m downstream from set sediment just below the dam(Section 1)



September 2007　(before typhoon No.9)　October 2007 (after typhoon No.9)
Fig. 9
Landscape change at about 700m downstream from set sediment at Jobu

Bridge downstream(Section 2)

July 7, 2005 October 22, 2008(after typhoon No.9)

Fig. 10

Typical example of cleansing effect at Sanbaseki Gorge (Torage Stone)

4.2.2. Cleansing effects in Sanbaseki Gorge

(1) Effects in Sanbaseki Gorge

As in Fig. 10, in Sanbaseki Gorge, flood caused by the typhoon produced cleansing effects from traction of sediment below the dam to confirm separation of attached algae, mosses, and vegetation. Such effects are awarded the highest rating in the sediment supply test partly because the local public comments that there have never been changes like this before the test.

(2) Verification of cleansing effects

Verification of level of cleansing effect from mixed sediment in flowing water was conducted. In the soil setting just below the dam, volume of ‘chlorophyll a’ which was attached to fieldstones in St. 0, upstream side, and St. 1, downstream side, was measured over time after the mesoscale flood. Environmental conditions of St. 0 and St. 1, adjacent to each other, could be regarded as the same except for the sites of soil setting. Fig. 11 shows the result. In addition, the reason for selection of ‘chlorophyll a’ as a measurement item was to exclude dead algae.

Attached algae were completely separated both in deep water and shallows at St. 0 while they were not absolutely separated at St. 1. This indicates a slower recovery speed at St. 1. Cleansing effects, resulted from mixed sediment in flowing water due to soil runoff, proved a little more effective in pools than in riffles because of high detachment effects of attached algae.

4.3. SURVEY OF BED MATERIAL

As revealed in Fig. 12, composition ratio of bed material grading was compared at four sites from just below the dam to 8 km downstream site before and after the typhoon and flushing discharge in flexibility dam operation test. At the sites, 50*50 cm of quadrats on six cross-sectional lines at 20-meter intervals were set at 1-meter intervals to determine bed material grading within the quadrats visually.

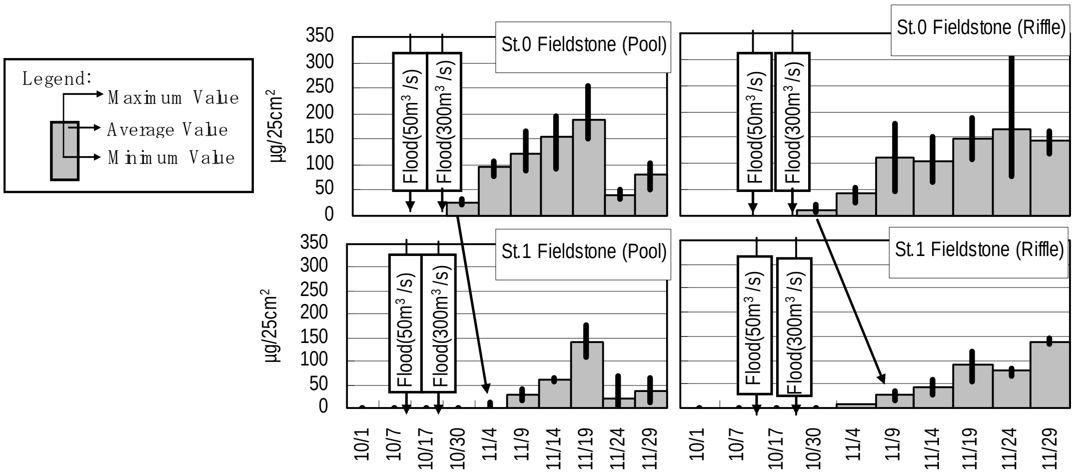
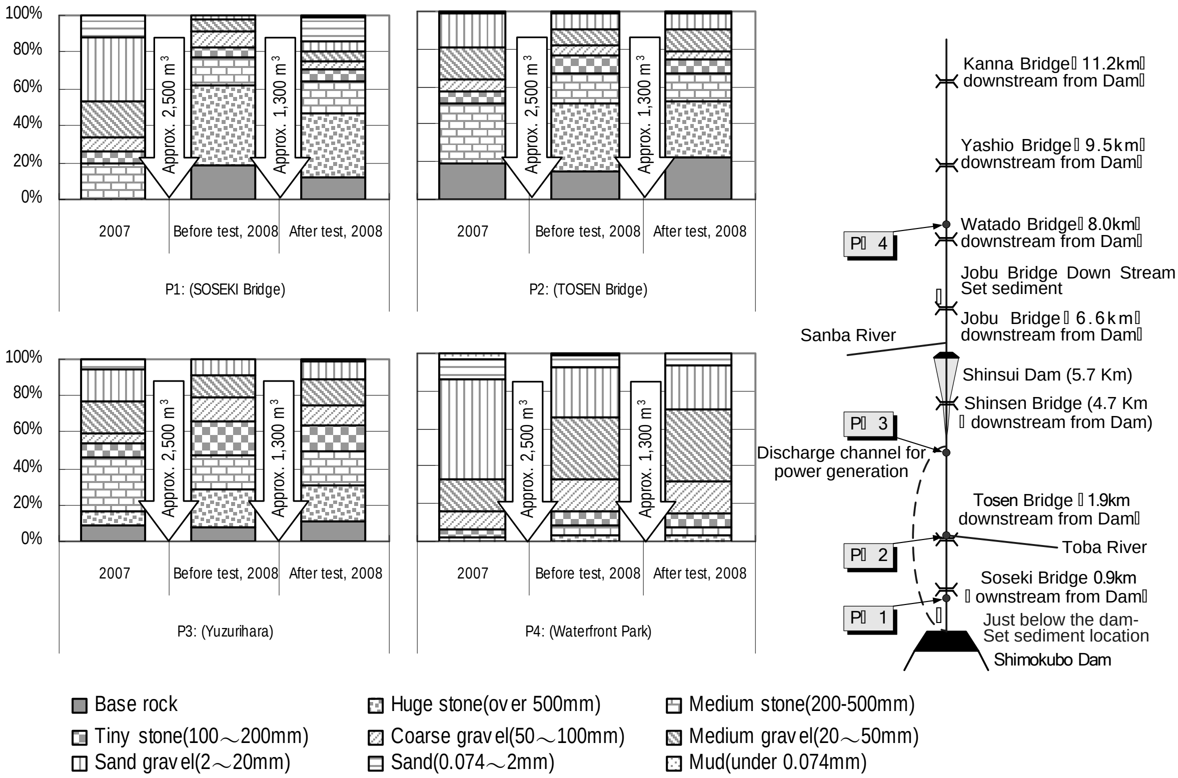


Fig. 11
Volume of "Chlorophyll-a" of attached algae at up/downstream of set sediment



Before test, 2008: before flushing discharge in flexibility dam operation test.
After test, 2008: after flushing discharge in flexibility dam operation test

Fig. 12

Survey results on river bed composition material

In four sites investigated, fine fraction was commonly seen after the ninth typhoon. P-1 and P-2 sites consisted of 50% or more of bedrock and large stones, which indicated the fine fraction was considerably swept away. P4 site, the lowermost part, was at the junction of the Sanba River where less mud, sand, and sand gravel proved that fine fraction was washed away in serious flood though not to the level of Sanbaseki Gorge.

Moreover, before and after the test, P2 site, 1.8 km downstream from the set sediment just below the dam, obserbed increase in fine fraction. Then, discharge at 90 m^3/s flowed sediment from upstream area even at 1.8 km downstream site. At P4 site, downstream area from the Shinsui Dam, there were not any changes in bed material.

4.4. RIPARIAN VEGETATION VARIATION

Riparian vegetation map was created from aerial photographs and reconnaissance, and distribution change of plant community was organized in order to understand the variation of riparian vegetation. Section 1 had a narrower river width with less kinds of vegetation, compared with those in Section 2. For the purpose of clarification, the former was organized by dominant species in the plant community (quantitatively); the latter by a rougher classification, basic plant classification of riparian zone census.

(1) Section 1 (Sanbaseki Gorge)

As shown in Fig. 13, natural bare land increased due to typhoon-induced vegetation runoff in flood, while there were no significant changes in river vegetation from 2005 to 2007.

(2) Section 2 (Jobu bridge to Kanna River heaways)

As shown in Fig. 13, natural bare land decreased due to vegetation overgrowth while there were no considerable changes from 2005 to 2007. Then, 9,500 m^3 of sediment, set downstream the Jobu Bridge, was swept away by the flood to disappear the vegetation like *Phragmites japonica* community, which was displaced by newly formed sandy gravel layer.

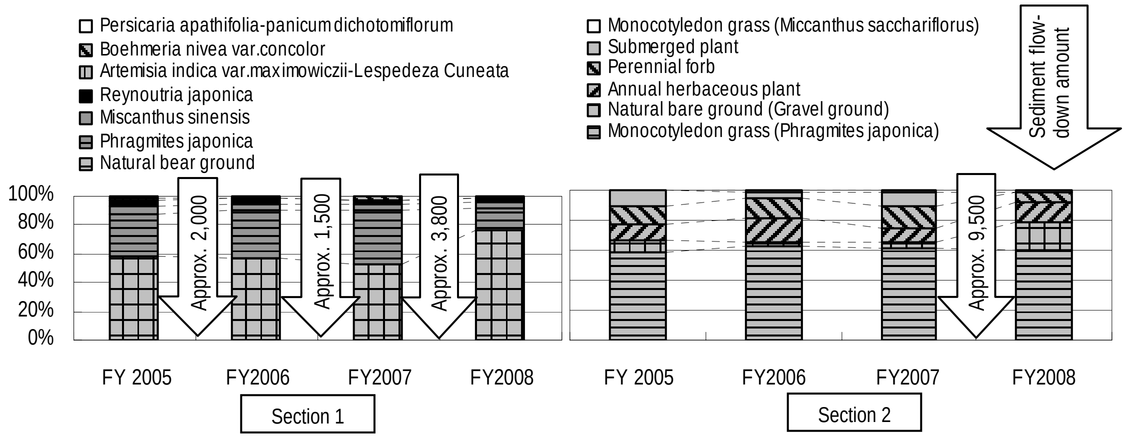


Fig. 13

Secular variation of riparian vegetation at Section 1(Sanbaseki Gorge) and between the Jobu Bridge and Kanna River headworks(Section 2)

4.5. AQUATIC INSECTS

Light trap (box) method was adopted to collect aquatic insects, aiming to get a broader range of species than those in usual surveys for macro understanding of the river environment variation. The survey was conducted three times a month from April to June in the timing of emergence of insects. White fluorescent lamps and black ones were used to attract insects by lightening for one hour (in 2008) to a maximum of three hours (in 2005 to 2007) after sunset. Insects collected were classified according to life types in addition to species in order to demonstrate variation of dominant species involved with changes of river bed material.

Fig. 14 shows the ratio of life type in Section 1 where Creeping types(mainly *Caenidae*) were dominantly seen for unknown reasons in 2006. Fig. 14 displays life type proportion in Section 2. In 2005, Swimming types (several types of *Baetidae*) were dominant without explained reasons. Year of 2008 witnessed an increase in burrowing types (mainly *Tipulidae* and *Chironomidae*) which could result from traction and replacement of sediment by the typhoon, given the species' tendency to thrive in sand zone. However, traction and replacement of sediment are affected by combined effects including set sediment downstream the Jobu Bridge and inflow sediment from a tributary of the Sanba River. The mentioned effects are difficult to distinguish from each other. In addition, increase of net-spinning types (mainly *Trichoptera*) in 2008 appeared to be caused by stable river bed without large-scale flood.

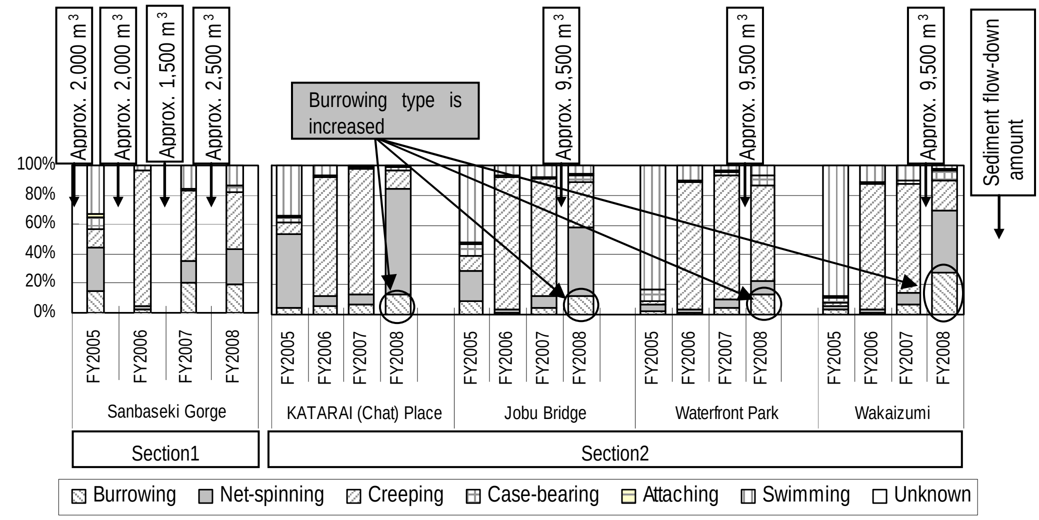


Fig. 14
Life type classification of aquatic insects at Section 1 (Sanbaseki Gorge)and Section 2 (Jobu Bridge – Kanna River headworks)

4.6. FISHES

(1) Section 1 (Sanbaseki Gorge)

According to Fig. 15, *Tridentiger brevispinis* and *Rhinogobius sp*. OR of Family *Gobiidae* decreased only in 2007 during 2005 to 2008. The typhoon seems to carry away fishes in the river bed (benthonic fishes) at the time of survey, which was performed about 20 days after the typhoon. There were no significant changes otherwise.

(2) Section 2 (Jobu Bridge to Kanna River headworks)

Fig. 15 does not demonstrate such substantial changes in fishes even immediately after the typhoon as in Sanbaseki Gorge in 2007. In 2008, however, less *Triborodon hakonensis* and *Zacco platypus* of Cyprinidae Family and more *Rhinogobius* were seen. Apparently, the result of 2007 suggested less frequency of downstream inflow due to larger width of the river, which allowed fishes to evacuate within the river, and the result of 2008 demonstrated that replacement of bed material by the typhoon affected the habitat of fishes to reflect into the outcome of survey one year later. But, further survey is needed to specify the causes.

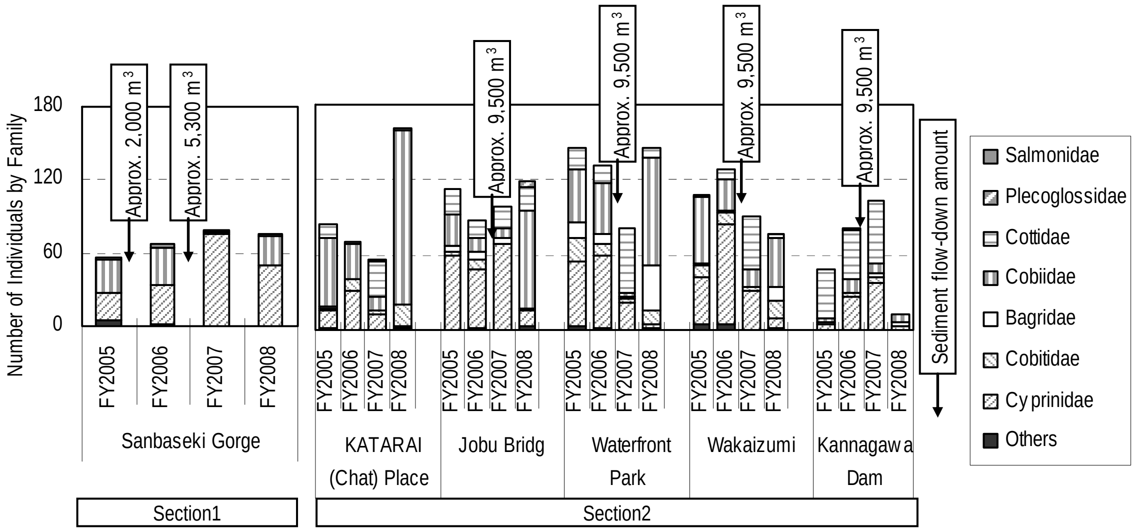


Fig. 15
Fish species at Section 1 (Sanbaseki Gorge) and Section 2 (Shinsui Dam – Kanna-River headworks)

5. EFFECTS OF FLEXIBILITY DAM OPERATION TEST

As shown in Fig. 16 and 17, partial effects such as sedimentation in pools water and separation of attached algae by cleansing effects were confirmed in the process of flushing discharge under the test in downstream Sanba Gorge. However, effects in the Shinsui Dam downstream have never been verified without traction of sediment. Thus, maximum discharge 90 m^3/s proved effective only in Sanbaseki Gorge.

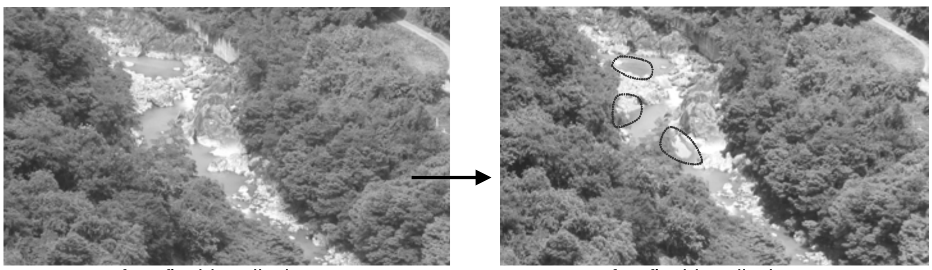
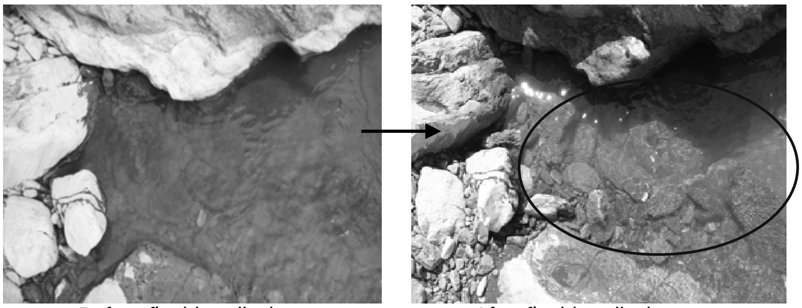


Fig. 16
Sedimentation to pool after flushing discharge



Before flushing discharge After flushing discharge

Fig. 17
Cleansing effect by flushing discharge (Sanbaseki Gorge)

6. CONFERENCE FOR TRACTION OF SEDIMENT IN THE KANNA RIVER

This conference was established in November 2005 to hear a broad range of views about sediment supply and its monitoring survey from agencies and local public involved with the river and contribute to the riparian environment improvement. It consists of persons of learning and experience, river managers, local authorities, fishermen, river users, and so on.

The 2nd conference, November 2008, was held to report the results of the test. Typical comments from the members are as follows:

Many insisted that sediment supply test and flexibility dam operation test be continued.

Below the dam, aquatic insects of ephemeridae which are specific to the area of natural pools were observed for the first time in 2007, considered to be some signs of improvement. However, being hard to distinguish sediment supply from sediment inflow in the Jobu Bridge downstream, effects of such tests are not understood well. This means a longer period of assessment is necessary to figure out the effects.

Changes in physical surroundings do not lead to prompt changes in the habitat.

The conference this year will be organized to gather opinions on effects of the test, etc. in the survey results from 2004 to 2009. Followed by this, the policy for subsequent test will be determined.

7. CONCLUSION

Findings, effects, and evaluation obtained as well as future issues are described as below.

(1) Findings, effects, and evaluation obtained

It was found out that traction of sediment by setting soil below the dam was effective in downstream scenery restoration such as detachment of attached algae and mosses on Sanba stones, which are designated as a place of scenic beauty and a national monument.
In Sanbaseki Gorge, soil setting for the test induced emergence of sand bar in small- and medium-scale flood and granulation by further transported sediment downstream in large-scale flood. This implies the importance of sediment supply following serious flood from the aspect of river environment.
In addition, after such serious floods, granulation in the Jobu Bridge downstream, not so much as in Sanbaseki Gorge, is inclined to result in sediment with larger grain size by flowed mud and fine sand. This section indicates influence of traction and inflow sediment though it is difficult to clarify the difference between the two.
As far as the habitat in Sanbaseki Gorge is concerned, there have been some signs of improvement like appearance of *ephemera strigata* characteristic of natural pools in 2007. However, a longer-term survey is considered necessary in order to confirm definite effects.
Aquatic flora and fauna in the Jobu Bridge downstream shows some changes as increase in aquatic insects that thrive in the sand zone. These changes seem to be caused by traction of sediment and sediment inflow from tributary, but it is difficult to sort out the both effects.
In flushing discharge under flexibility dam operation test, partial effects including sedimentation in pools water and algae detachment in Sanbaseki Gorge were observed.
In the conference, many proposed to continue sediment supply test and flexibility dam operation test. Moreover, some insisted a long-term test be essential for understanding of the habitat variation.

(2) Future issues

① In the Jobu Bridge downstream, in order to find out traction effects from soil setting, it is important to distinguish between sediment supply and sediment inflow from tributary.
② Long period of survey is needed for recognition of the habitat variation.

Regarding traction of sediment, while drastic improvement of landscape and sedimentation in pools are observed, frequency and scale of flood does not reach the satisfactory level. This indicates insufficient examination of effects. In particular, long-term survey for inspection of the habitat variation is thought to be necessary as the conference points out.

REFERENCE

[1] Hydraulic Formula Committees. *Hydraulic Formula Collection (Suiri-Koshiki-Shu)*,1999 pp.158

SUMMARY

This paper reports about sediment supply test that has been implemented in the Shimokubo Dam Operation and Maintenance Office of incorporated administrative agency, Japan Water Agency, for the purpose of river environmental improvement. In the Shimokubo Dam downstream, the landscape of Sanbaseki Gorge, designated as a natural monument, has been spoiled due to changes in flow regime caused by dam establishment. Therefore, sediment supply test has been conducted in order to improve the river environment since 2003, where sediment is supplied to the downstream channel.

The test includes monitoring survey of the river environment, which has been discussed in meetings of academic experts, managers, and users of the river. The results so far show some improvement in scenery because of advantageous effects of physical aspects. On the other hand, any distinguished effects have not been identified in the habitat despite partial signs of improvement. As a result of this, the necessity of further survey has been confirmed.

Key-words: Shimokubo Dam, sedimentation, monitoring, biological properties

MOTS-CLÉS: Shimokubo Barrage, alluvionnement, auscultation, caractéristique biologique