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Sediment management on the Arase Dam Removal Project

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ABSTRACT: Sediment management during and after dam removal involves extremely important flood control and environmental challenges, including the outflow of reservoir sediment and its effects downstream. The Arase Dam is the first dam to be completely removed in Japan. To assist in sediment disposal planning and to predict both upstream and downstream changes after dam removal, riverbed change simulations and environmental monitoring have been employed. Herein items to consider in sediment control for dam removal are discussed.

1 INTRODUCTION

Dam removal is one of important options for future reservoir management. In such case, suitable management of accumulated sediment in the reservoir is a crucial topic for effective and environmental friendly operation from the viewpoints of river bed geomorphology, water quality and ecosystem in and downstream of the reservoir. Basic understandings are explained by Morris and Fan (1997), and Erosion and Sedimentation manual by USBR (2006). Geomorphologic aspects focusing on channel adjustment in the former reservoir area is explained by Doyle, Stanley and Harbor (2003). Complex ecological aspects are discussed by Stanley and Doyle (2003). Cannatelli and Curran (2012) is reporting importance of hydrology on channel evolution following dam removal.

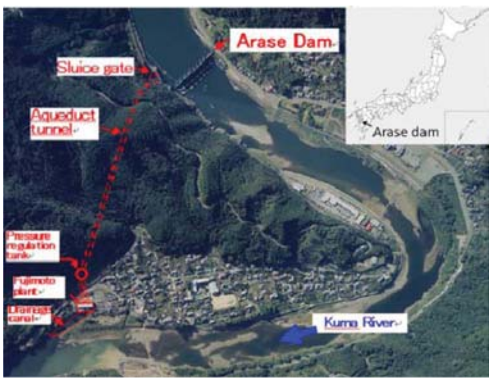

Figure 1. Dam facilities location.

The Arase Dam is the first dam to be completely removed in Japan which is located approximately 20 km upstream from the mouth of the Kumagawa River (Fig. 1). The dam is dedicated to hydropower generation, and has been contributing to the economic development in the Kumamoto Prefecture for over 50 years. However, plans are underway to remove the Arase Dam over the next six years. Because this is the first complete dam removal project in Japan, the removal policies of the Arase Dam must not only consider flood management and the environmental impact, but also an economic removal method and the natural recovery of the river environment in medium and long terms. Based on this background, a committee and working group were created to study the removal method, evaluate the environmental impact, and provide a detailed review.

2 ARASE DAM REMOVAL COMMITTEES AND WORKING GROUPS

The Arase Dam Countermeasures Review Committee and Dam Removal Methods Working Group were established in June 2003 to remove the Arase Dam with considerations to flood control and the river environment. In January 2006, a dam removal policy was developed, and a detailed review of the removal method and other aspects were completed by March 2008. However, the dam removal initiative was put on hold.

Since then the dam removal initiative has been revived. The Arase Dam Removal Technical Research Committee was established in April 2010 to reconfirm and verify the impact of dam removal as well as to provide guidance and advice to the prefectural government. This committee's work led to the Arase Dam Removal Plan (Provisional) for the actual removal work, which was to commence in FY 2012, and included the latest findings and changes in the environment since the first removal decision related to the dam. Below a summary of the discussions within the Committee and Working Group.

- Arase Dam Countermeasures Review Committee
  Based on the reports from the Dam Removal Methods Working Group, the Arase Dam Countermeasures Review Committee provided a direction to the prefectural government from the specialists' viewpoints for dam management, environment, dam removal method, and other areas.
  - The 29-member committee held 9 meetings.
  - Items reviewed:
    - Dam removal methods
    - Sediment removal and disposal method from reservoir area
    - Environmental investigations for dam removal
    - Dam management
    - Current environmental countermeasures and verification of their effectiveness:
    - Sediment removal from the dam reservoir
    - Repair of the embankment along national and prefectural roads
    - Countermeasures against red tide
    - Sediment supply downstream
    - Surveys on water quality, etc.
- Dam Removal Methods Working Group
  This working group was established as a working group for the Arase Dam Countermeasures Review Committee.
  - The 9-member group held 12 meetings.
  - Items reviewed:
    - Dam removal methods
    - Sediment removal and management
    - Environmental investigations
    - Challenges related to dam removal
- Arase Dam Removal Technical Research Committee
  This committee confirmed and verified the review findings of the committees and other bodies as well as provided guidance and advice to the prefectural government towards establishing a removal plan (prefecture's plan).
  - The 14 members and 3 advisors met three times.

3 OVERVIEW OF THE DAM REMOVAL PLAN

Two major dam removal methods were considered: slit removal and slice removal. Eventually slit removal was selected. The dam is situated in a curve of the river. When the dam was constructed, there was a developed sandbar on the left bank, and the center of the water flow was near the right bank. To recover this river channel geomorphology as soon as possible, the plan was to remove the dam from the right bank side.

The dam removal work is scheduled to occur in six phases from 2012 through 2017 during the non-flood seasons (Fig. 2).

- 1st phase (2012)
  Install a water level—lowering facility to lower the reservoir water level and remove the gate on the right bank.
- 2nd phase (2013)
  Remove the gate, pillars, and utility bridge from the right bank.
- 3rd phase (2014)
  Remove the remaining gates and the water channel of the main dam body on the right bank.
- 4th phase (2015)
  Remove the remaining parts of the water channel on the right bank.

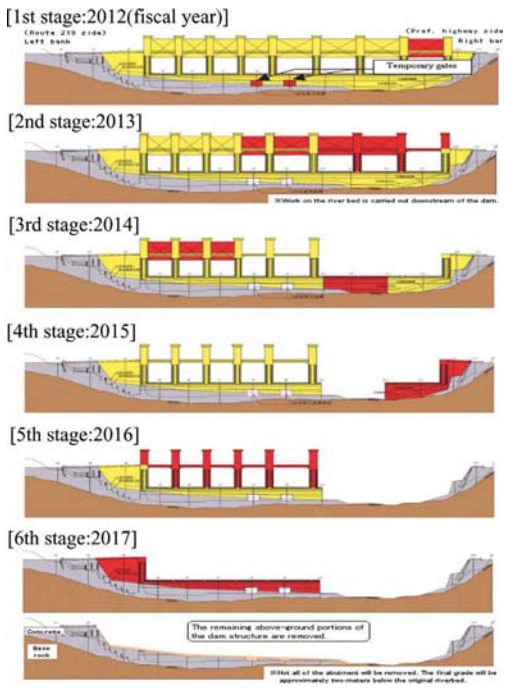

Figure 2. Removal plan.

- 5th phase (2016)
  Remove all remaining pillars and utility bridges.
- 6th phase (2017)
  Remove the main dam body.

4 SEDIMENT DISPOSAL PLAN

The Arase Dam was constructed more than 50 years ago. Its reservoir contains a lot of sediment, including silt, sand, and gravel. Consequently, dam removal may impact flood control and the environment if a large quantity of sediment is allowed to flow downstream during a heavy runoff. To prevent this runoff, the Sediment Disposal Plan removes sediment from the reservoir prior to dam removal.

The current sedimentation was surveyed to devise a plan that is appropriate for each type of sediment. Downstream riverbed changes associated with dam removal were simulated to establish the amount of sediment to be removed for minimizing the impact.

4.1 *Silt disposal*

If silt is allowed to flow naturally from the reservoir without disposal as part of the dam removal project, various environmental impacts are likely to occur downstream. Specifically, if a large quantity and high concentration of sediment flows during a heavy runoff and settles downstream, the riverbed would change, which may negatively impact the spawning fields of the Ayu fish.

To avert these issues, the Silt Disposal Plan removed approximately 100,000 m^3 of silt from the reservoir mainly from upstream of Arase dam and Kudaragi river which is the first tributary in the left bank prior the first phase of dam removal (Fig. 3). To minimize the amount of turbid water generated, the silt removal method was basically dry excavation during the non-flood season.

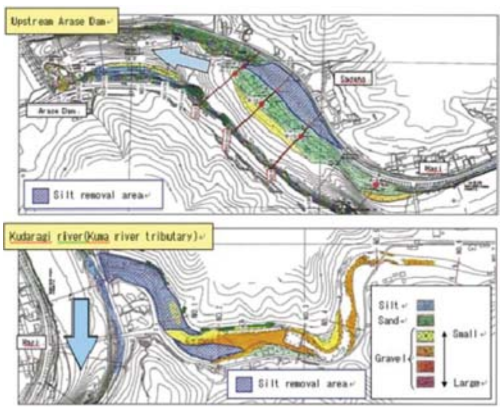

Figure 3. Silt distribution.

4.2 *Sand and gravel disposal*

Besides silt, approximately 700,000 m^3 of sediment remains in the reservoir. The plan is to allow most of the sand and gravel to flow naturally. However, to minimize the impact on downstream flood control due to sand and gravel settlement associated with dam removal, the plan partially removed sand and gravel before the dam removal. The amount to be removed was decided using a riverbed change simulation.

4.2.1 *Riverbed change simulation*

The riverbed change simulation for sand and gravel disposal was performed upstream and downstream of the Arase Dam. A one-dimensional model enabled the large temporal and geographical span to be calculated. The simulation period was fifty years after the start of dam removal with actual flow data repeatedly supplied.

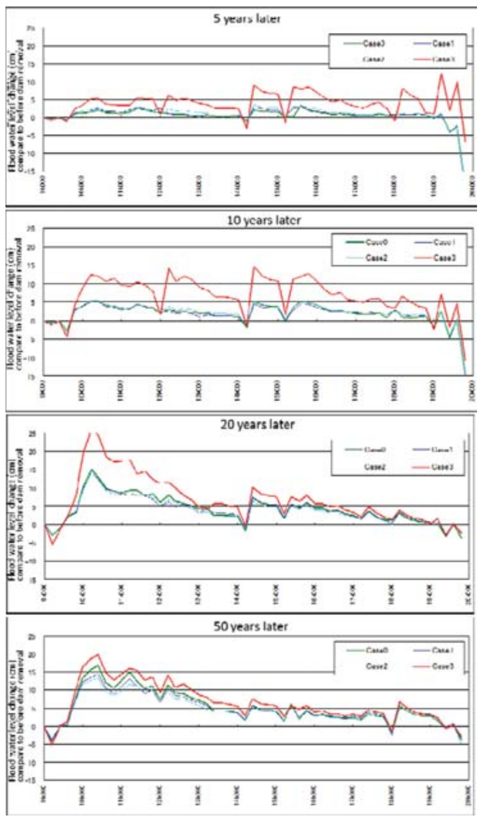

Figure 4. Flood water level change after dam removal.

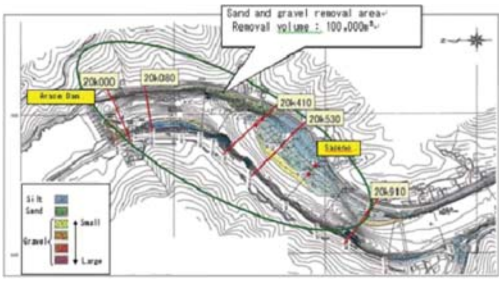

Figure 5. Sand and gravel removal area.

To determine the impact downstream, the simulation used different combinations of dam removal processes and the amount of sand and gravel removed. The results indicated that a phased removal of sand and gravel in the area immediately upstream of the reservoir can reduce the rise in the flood water level in the medium and long terms (Fig. 4).

Examined cases of sediment removal

- Case 0: All in time of 100,000 m^3
- Case 1: Before dam removal 80,000 m^3, After dam removal 20,000 m^3
- Case 2: Before dam removal 50,000 m^3, After dam removal 50,000 m^3
- Case 3: No sediment removal

4.2.2 *Sand and gravel disposal plan*

Based on the riverbed change simulation results, a Sand and Gravel Disposal Plan was created to remove approximately 100,000 m^3 (Case 2: 50,000 m^3 before and another 50,000 m^3 during dam removal) of the approximately 700,000 m^3 of sand and gravel in the area immediately upstream of the reservoir (Fig. 5). In addition to restoring the Kumagawa River basin and the Yatsushiro Sea Area, the removed sand and gravel will be used for other purposes such as public works.

5 RIVERBED CHANGES ASSOCIATED WITH DAM REMOVAL

Based on the one-dimensional model, the Sediment Disposal Plan specifies the amount of sediment to be removed during each phase of dam removal. Although the one-dimensional model provides a macroscopic view of sediment movement in the medium to long term, it does not provide yield changes in the planar distribution of shallow parts, deep parts, and sandbars during a high level of water flow.

To resolve this shortcoming, a two-dimensional riverbed change simulation was performed in the surrounding areas of the Arase Dam assuming that the dam is removed over six years and 100,000 m^3 of sand and gravel is removed. This simulation confirmed the appropriateness of the dam removal project from a flood control viewpoint in terms of changes in the state of the river.

5.1 *Calculation conditions*

Each removal phase was assigned a flood hydrographs, which caused the largest floods in the past. Removal phases with similar flow rates were grouped together. Thus, the number of removal phases was reduced from six to four (Fig. 6). The one-dimensional simulation results were used as the boundary conditions for the two-dimensional model (incoming flow rate, inflowing sediment materials, and water level downstream) to maintain continuity with the one-dimensional model.

5.2 *Calculation results of the simulations*

Figure 7 shows the simulated temporal changes of the riverbed height and its planar distribution. As dam removal progresses, sediment accumulates from the center of the water flow to the left bank in areas immediately downstream. Over time, a sandbar is formed, and it eventually connects with the upstream left bank. In contrast, the upstream riverbed is removed by the water flow on the outer bank of the curved part of the right bank.

River flow patterns in the vicinity of the dam at high levels of water flow during and after dam removal indicate that the main part of the flow is near the right bank (outer bank) (Fig. 8). After the dam removal project is complete, the river flows smoothly and a sandbar forms from the center of the river to the downstream left bank, restoring this portion of the river to its original path before the dam was constructed.

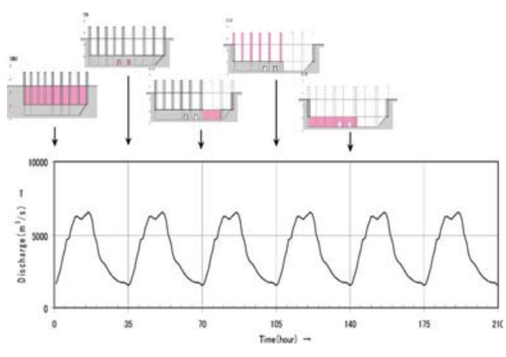

Figure 6. Calculation condition. (Step of removal and hydrograph of flood dischage).

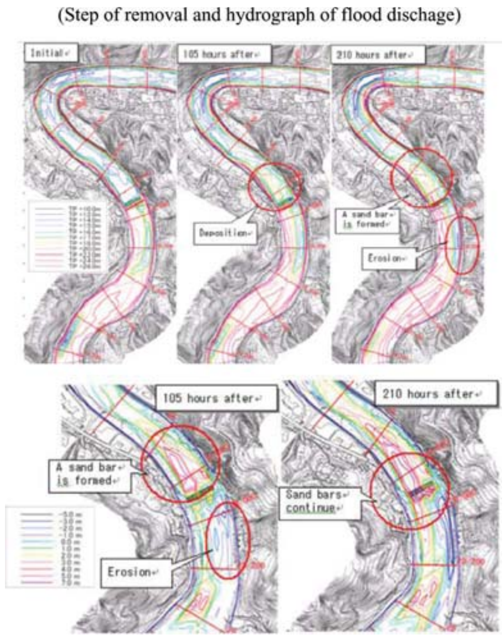

Figure 7. Contour of bed level and bed deformation. (Simulation).

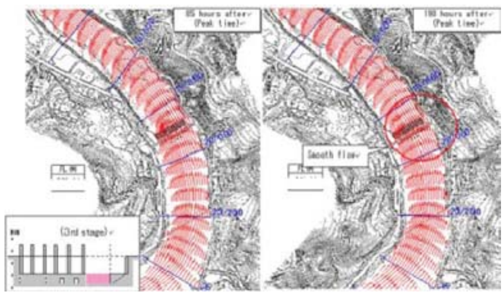

Figure 8. Velocity distribution (Simulation).

6 ENVIRONMENTAL PROTECTION MEASURES AND ENVIRONMENTAL MONITORING

Basic policies for the environmental impact prediction associated with the removal of the Arase Dam were established by the end of FY 2005. These policies are based on a survey of the current status (April 2004 to March 2005) with prediction and evaluation of environmental changes due to dam removal. Furthermore, a detailed study was conducted on the changes in living organisms and their environment due to dam removal. From the basic policies and study results, the Environmental Protection Countermeasures Plan and Environmental Monitoring Survey Plan were established in 2007.

Environmental protection countermeasures and environmental monitoring surveys have been conducted since FY 2008 in accordance with these plans. The flow rate and water quality were studied between FY 2008 and FY 2010. Comprehensive environmental monitoring surveys, including surveys on flora and fauna, commenced in FY 2011.

In April 2011, the Arase Dam Removal Follow-Up Working Group was established to discuss the survey results and assess the environmental impact of dam removal. Environmental monitoring will continue until two years after the dam removal project is complete (FY 2019). Figure 9 shows the review work to date.

6.1 *Environmental protection countermeasures plan*

As the environmental impact prediction is assessed, the plan is to provide "environmental protection measures" for items that have been predicted to impact the environment. The plan also mitigates items forecasted to have a minor environmental impact by providing "measures to reduce further impact". Table 1 shows action items and policies for each countermeasure.

6.2 *Environmental monitoring survey plan*

In addition to the aforementioned environmental protection countermeasures, the plan includes an environmental monitoring survey to observe items with uncertainties in the basic items and prediction methodology. The figure below shows the survey items, while the table lists the environmental monitoring survey items. The survey items cover ecological systems, physical environment, chemical environment, and biological environment as well as items to assess the environmental impact due to the construction machinery during the removal project (atmospheric pollution, noise, and vibrations).

- Physical environment
- Water flow, Sediment property (Grain size), Ecological system, Landscape
  - Chemical environment
    - Water quality (Turbidity, Suspended Solid Concentration),
- Ecological environment
  - Fauna (Bird, Fish, Benthos, Important species)

The surveys and assessments are designed to provide a comprehensive understanding of the overall changes in the ecological system with an emphasis on habitats and reproductive environments of living organisms. Moreover, the plan evaluates the distribution of plants and animals.

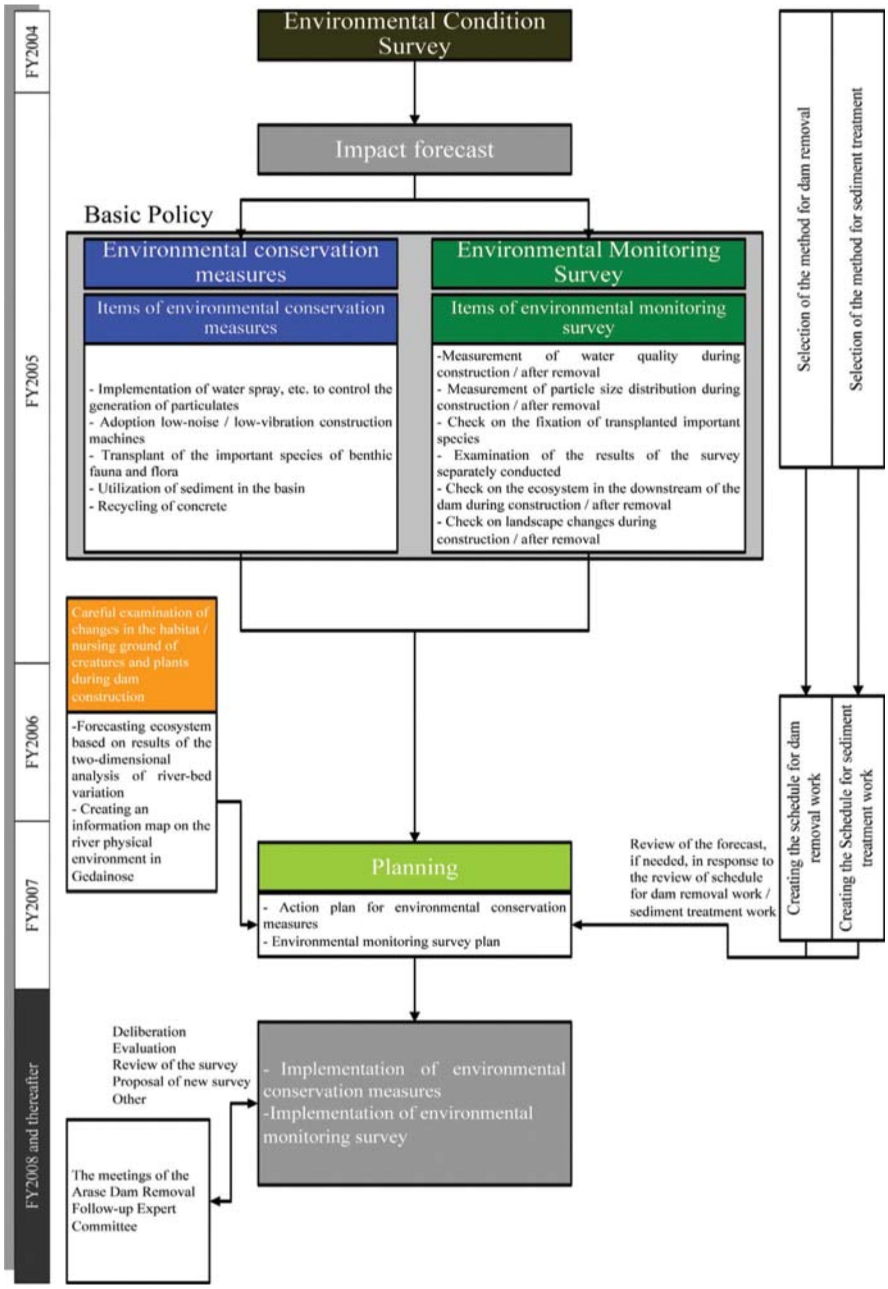

Figure 9. Flow chart of examination.

If the surveys reveal unforeseen issues, the Arase Dam Removal Follow-up Working Group will address them. This working group has the flexibility to add items to the surveys to address specific issues. Below are examples of surveys under consideration or in progress.

1. Belt transect survey on fauna
   Because opening the dam gates will lower water levels in flooded areas and dam removal should revive vegetation in flooded areas, the vegetation in upstream areas should change. To quantitatively assess these changes, five survey lines

Table 1. Implementation items of the environmental conservation measures and policy.

Implementation items	Policy
Animals	
Important species of benthic fauna *Paludinella devilis* Lymnaea	Survey where they may be transplanted and consider measures since drawdown expected during the construction period may affect the river, including temporary loss of their habitat.
Plants	
Important plant species Water speedwell *Salvia plebeia* Siberian motherwort	Consider measures thinking of the condition of growth in the areas along the Kuma River since the part of the land area including sandbar are expected to be submerged due to the water level rising in the recession area during construction and after removal.
Wastes	
Construction by product	Consider how to control and reuse soil and concrete expected to be generated during construction in order to minimize their disposal.

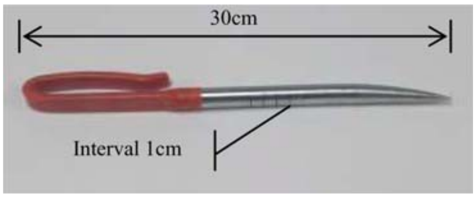

Figure 10. Shino.

Figure 11. Monitoring point.

have been selected, including group scale, cover scale, and tree height.

2. Ayu fish apawning field survey at Gedainose
   Ayu fish symbolize the clarity of Kumagawa River water, and many people enjoy Ayu fishing from early summer to fall. For these reasons, many local residents are concerned about the Ayu fish and their habitat. Thus, the survey aims to assess the impact of sediment due to dam removal on the downstream spawning fields of the Ayu fish as well as obtain comparison data for the Ayu fish spawning fields that are expected to appear upstream of the dam. In particular, there is an artificial spawning field for the Ayu fish at Gedainose where a survey is to be conducted. Ayu fish spawn their eggs on riverbeds where suitable size of gravels are softly placed and flows underneath them. Instead of counting the number of spawning fish, the survey uses a simpler method; a survey worker places a steel construction tool called a "Shino" (Fig. 10) into the riverbed with his/her own body weight, and its measured penetration is an indicator of how the riverbed is packed.
3. Physical environment survey
   To directly assess the impact of sediment outflow due to the removal of the Arase Dam (caused by the methodology and equipment such as employing a water level–lowering facility) on the downstream physical environment during normal and heavy runoff, the cross-sectional profile, water level, flow rate, and the size of sediments on the riverbed will be measured on two survey lines immediately downstream the dam using the linear lattice and planar methods.

6.3 *Interim report on the environmental monitoring survey*

Major changes have not occurred downstream of the dam. However, opening of the gates in April 2010 lowered the water level of the reservoir, and water has returned to a flowing state in some upstream sections (Fig. 11).

Water flow is particularly noticeable in the Kudaragigawa River, which is a tributary on the left bank upstream of the dam, and in Nishikamase, which is located near the upstream end of the dam reservoir. In addition to plants returning to its banks, the Kudaragigawa River now has streams with deep paths, multiple riffles as well as pools (Fig. 12). Nishikamase now has large sandbars on the bank or in the middle of the river (Fig. 13).

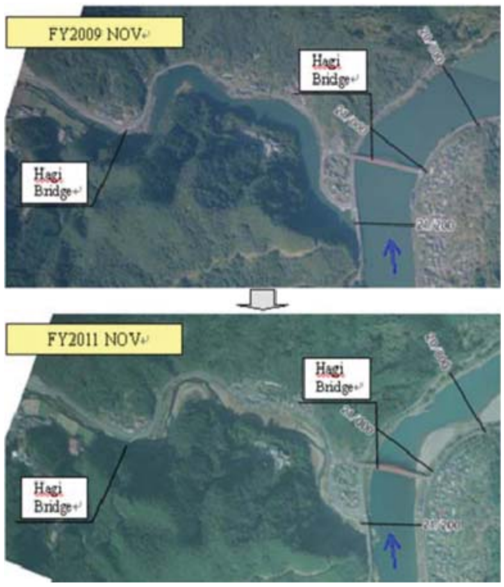

Figure 12. Kudaragi creek.

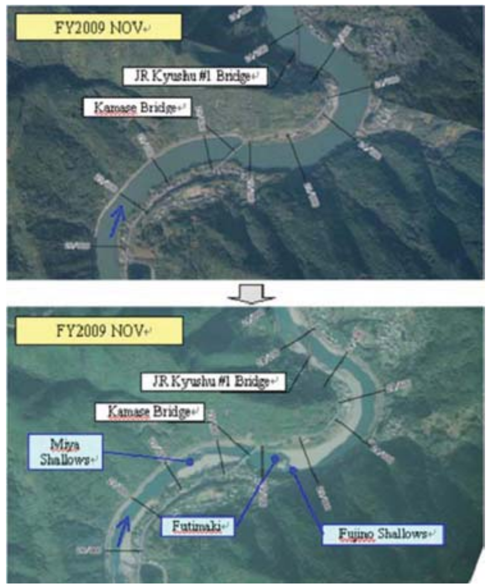

Figure 13. Nishikamase.

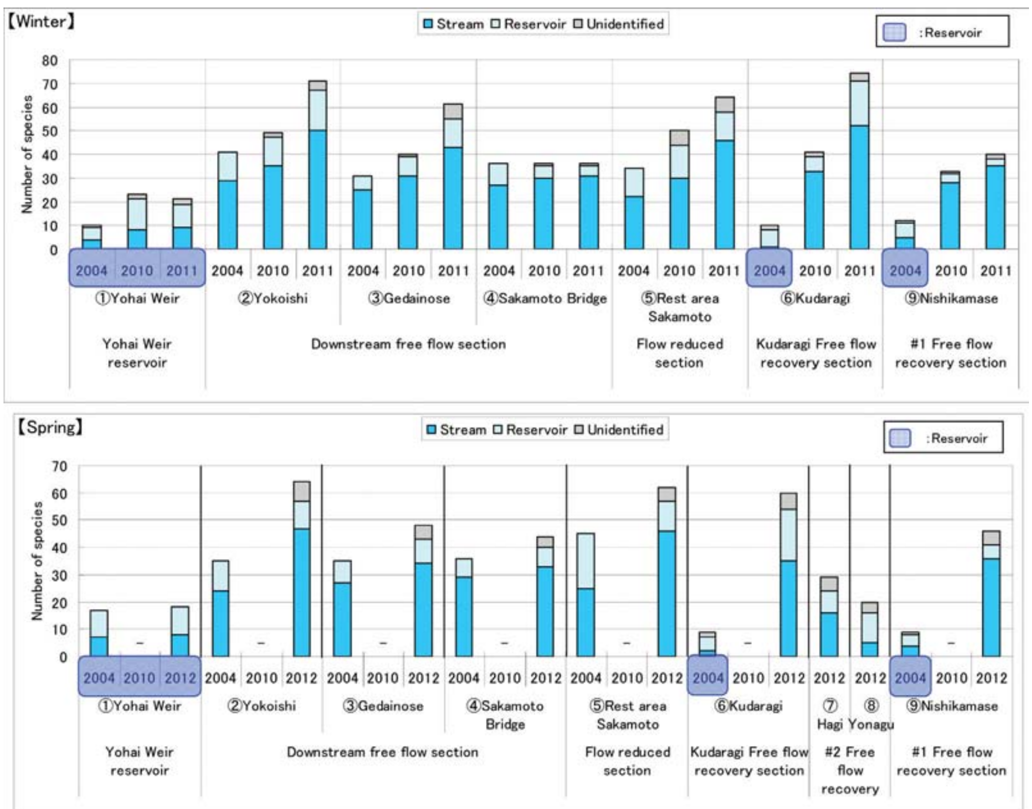

Figure 14. Annual cycles of stream benthos.

Additionally, riffles and pools, which used to have their own names when the river was flowing prior to construction of dam, have reappeared. For example, riffles such as Miyase and Fujinose and pools such as Fuchinomaki exist once again. Furthermore, the numbers of benthos living in running water, including ephemeroptera, plecoptera, and tricoptera, have noticeably increased since 2010 after the Kudaragigawa River and Nishikamase returned to flowing environments (Fig. 14).

7 CONCLUSIONS

The Arase Dam is the first dam in Japan to be completely removed. To assist in sediment management planning and to predict the upstream and downstream changes in the riverbed, simulations and environment monitoring have been employed. Based on the reports from the Asase Dam Removal Technical Research Committee and the Arase Dam Removal Follow-Up Working Group, this paper discusses items to consider in sediment control for dam removal.

To provide a comprehensive assessment of the changes, the physical environment, including the river profile, riverbed composition, the chemical environment in terms of water quality such as turbidity, the biological environment of flora and fauna, and the physical environment of the river will continue to be monitored.

The authors would like to thank committee members and others involved who provided with guidance based on their area of expertise.

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