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Approaches for Integrated Sediment Flow Management at Dams in the Mimikawa River Basin

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ABSTRACT:
From the point of view of Japan being an energy-resource-poor nation, hydroelectric power generation to ensure a stable supply of energy and as a measure against global warming, is a valuable source of power. In recent years Japan has suffered frequent disasters as a result of increasing large-scale rainfall, and it is important that hydroelectric power generation be continued into the future while adaptation to various environmental changes is carried out. Prompted by the tremendous damage suffered in the Mimikawa River Basin as a result of Typhoon 0514, with Miyazaki Prefecture, the river administrator, playing a central role, through cooperation and participation of those with an interest in the river basin, including residents in the area, integrated sediment flow management is being deployed proactively. This paper reports on approaches for integrated sediment flow management in outline, and on a plan focused on the management of dam-regulating reservoir sediment that will employ sluicing of sediment at a series of three dams in the downstream of the Mimikawa River System, now being progressed by KEPCO (Kyushu Electric Power Company).

Keywords: integrated sediment flow management, sluicing of sediment, modification of dams

1. INTRODUCTION

Mimikawa River in Miyazaki Prefecture, in the southeast of Kyushu, Japan, runs almost due east, flowing into the Sea of Hyuga. With a length of 94.8km and a watershed area of 884.1km^2, the river is one of the largest class B rivers in the prefecture. Making use of an abundant volume of water and large drop, between the 1920's and 1960's 7 dams and hydro power stations were developed as shown in Fig. 1, and currently have a combined generating power of 340MW, and an output of 900 million kWh, making it one of the most important areas in the Kyushu region for hydroelectric power.

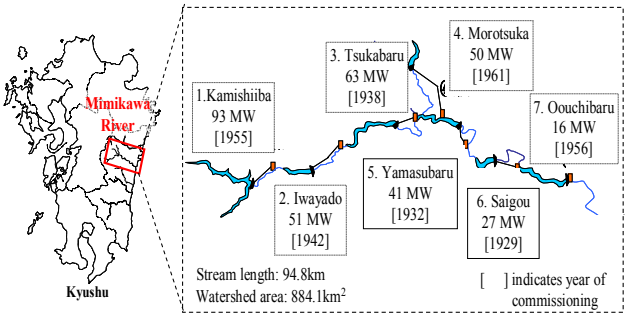

Figure 1. Mimikawa River Basin – Overview

In September 2005, Typhoon 0514 hit Japan, leaving behind large scale damage in various parts nationwide, including Miyazaki Prefecture. For Mimikawa River also, rainfall exceeding the designed dam flood flow was recorded. Flood damage was the worst known, and especially in the central area of Morotsuka located on the upstream edge of the Yamasubaru Dam regulating reservoir, the damage caused by flooding was extensive. Moreover, flood damage was amplified by mountain slope failures in 491 locations, large and small, causing a huge amount of sediment and driftwood flow into the river and dam-regulating reservoirs in the Mimikawa River Basin.

In October 2011, Miyazaki Prefecture, the river administrator, having set out the current status of the complex Mimikawa River sediment problems and approaches to resolving these problems while balancing river safety, water usage and environmental preservation, compiled the "Mimikawa River Basin Integrated Sediment Flow Management Plan".

KEPCO, which is responsible for dam installations, is as part of the Management Plan aiming to restore the original sediment flow, which has been intercepted by dams up until now, and has drawn up a plan for sluicing

of sediment, incorporating Yamasubaru Dam, Saigou Dam, and Oouchibaru Dam.

In this paper we report on how local communities, local government and the private sector (KEPCO) have come together to formulate a plan as part of various approaches being carried out related to integrated sediment flow management, and on a plan for modification of old dams in the Mimikawa River Basin, the first attempt of its kind in Japan.

2. DAMAGE CAUSED BY TYPHOON 0514

Typhoon 0514 was large, and maintained its large-scale and strong power as it moved slowly northwards over the sea to the west of Kyushu. This caused warm moist air to flow for a long period from the typhoon to the eastern side of Kyushu's mountainous areas, bringing record heavy rainfall to mountains in Miyazaki Prefecture that exceeded 1,300mm in total.

As shown in Fig. 2, for 5 of the 7 dams flow exceeded designed dam flood flows, and for all 7 dams flow exceeded previous recorded maximum flows. In addition, power plants at Kamishiiba, Tsukabaru, Yamasubaru and Saigou were flooded rendering power generation impossible, while Tsukabaru, Yamasubaru and Saigou dams were overtopped and their dam control facilities flooded.

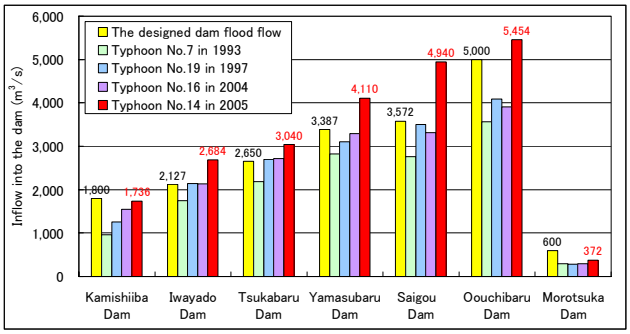

Figure 2. Dam Flow Volumes Resulting from Typhoon 0514

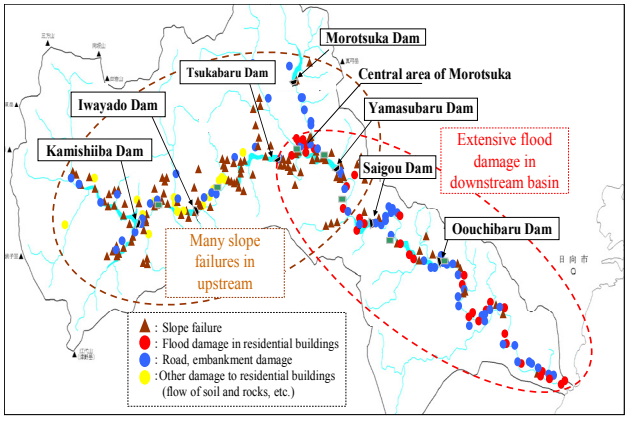

Figure 3. Damage in the Mimikawa River Watershed Area Resulting from Typhoon 0514

Fig. 3 shows mountain slope failures and flood damage caused over the entire Mimikawa River watershed. Within the watershed area mountain slope failures occurred in 491 locations, and 424 residential buildings were flooded. The cost of damage sustained over the whole of Miyazaki Prefecture amounted to 130 billion yen, the greatest amount of damage ever recorded for the prefecture.

As shown in Fig. 4, a total of 10.6 million m^3 of sediment flowed into rivers as a result of mountain slope failures, with approximately half of this amount (5.2 million m^3) being deposited in dam-regulating reservoirs. There is concern about an additional 26.4 million m^3 of sediment which is also in danger of flowing into rivers.

In addition, as shown in Fig. 5, in the central area of Morotsuka located on the upstream edge of the Yamasubaru Dam regulating reservoir, damage caused by flooding was extensive with 70 buildings being flooded, the largest number ever recorded. Over and above the record rainfall, the large quantities of sediment flowing into the Yamasubaru Dam regulating reservoir, which caused rapid aggregation in the vicinity, contributed to further damage.

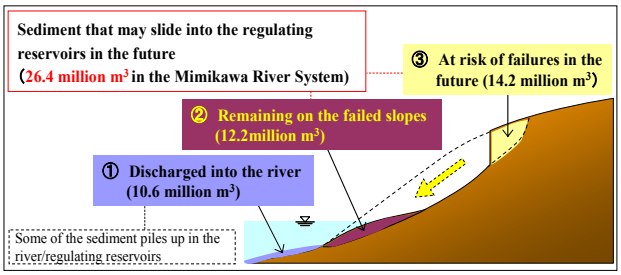

Figure 4. Quantity of Sediment due to Mountain Slope Failures

Figure 5. Flooding in Central Area of Morotsuka

3. APPROACHES FOR MIMIKAWA RIVER BASIN INTEGRATED SEDIMENT FLOW MANAGEMENT

Having proper understanding of these various sediment-related problems in the entire river system from the point of view of river safety, water usage and environmental preservation, rather than focusing on each problem separately, Miyazaki Prefecture, the river administrator, actively promoted integrated sediment flow management in the entire river system, which originates in a mountainous area and flows into reservoirs, rivers and finally to the coast.

Especially, since there are many other parties with relationships to the mountainous areas, dams, rivers, estuaries and coastal areas, issues arose concerning how to share sediment-related problems of the basin and approaches to resolving these problems, formulation of directions that must be taken over the whole basin, and division of roles for the realization of directions that must be taken.

In July 2009, Miyazaki Prefecture established the Mimikawa River Basin Integrated Sediment Flow Management Technical Committee, made up of the members shown in Fig. 6, as a framework to formulate an integrated sediment flow management plan for the Mimikawa River Basin, and to continuously evaluate and improve the plan, and started discussions with concerned parties. Also, in October 2011, in the first such case in Japan, communities, local government and the private sector (KEPCO) in the river basin worked in cooperation to compile the Mimikawa River Basin Integrated Sediment Flow Management Plan.

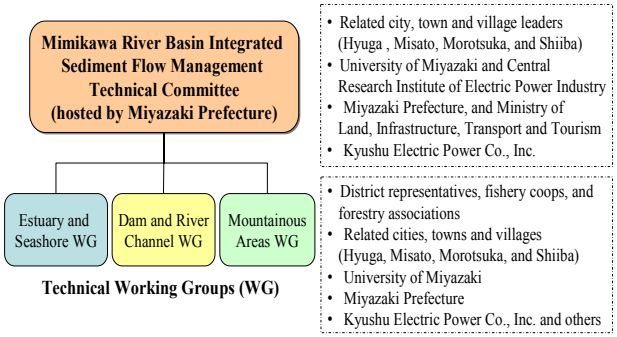

Figure 6. Framework for Integrated Sediment Flow Management Technical Committee

3.1. Adoption of Working Group Format

Established under the Technical Committee, whose participants include city, town and village leaders, academic specialists, the state, Miyazaki Prefecture and KEPCO, are a system of participative working groups made up principally of local representatives formed to cover the following 3 areas: (1) estuary and sea shore, (2) dams and river channels, and (3) mountainous areas.

The Technical Committee has met 5 times, working groups 9 times, and local meetings, held for the exchange of opinion in order that a wide range of opinion from local residents could be reflected in plans, 5 times. In this way, discussions have been progressed through an integrated approach with participation and cooperation from large numbers of people with an interest in the river basin.

3.2. Clarification of "Basic Policies" and "Action Plan"

After specifying the current status of Mimikawa River's sediment problems and approaches to resolving these problems by area, both "Basic Policies" that set out directions that must be taken for each area, and an "Action Plan" that clearly lays down the division of roles for the realization of objectives, were established.

Specifically, the following has been set up as an objective that is shared among the concerned parties in the river basin: "The betterment of the Mimikawa River —connecting forests, dams, the river and sea—." Also, as a basic principle, the following has been adopted: "People with an interest in the Mimikawa River acting together to regenerate the river so that they can live in harmony with a rich variety of other living things, and to ensure safety and peace of mind in the district", to show directions that must be taken for each area as shown in Fig. 7. And in addition, by connecting the problems in each area with the work to be performed by each participating body in a plain way, "Basic Policies" and the "Action Plan" clearly lay down the division of roles.

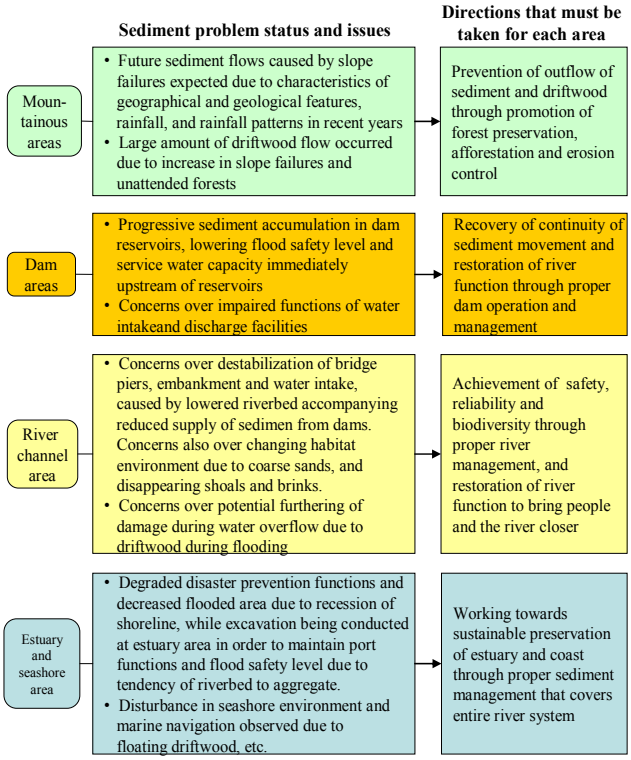

Figure 7. Directions that must be Taken for Each Area

4. APPROACHES TO INTEGRATED SEDIMENT FLOW MANAGEMENT IN DAM AREAS

KEPCO has been having repeated discussions with Miyazaki Prefecture, national and academic institutions as well as many people who have an interest in the basin, to draw up an action plan regarding dam sediment problems which are becoming increasingly serious.

As a result, KEPCO has formulated an action plan focusing on sluicing of sediment, incorporating Yamasubaru Dam, Saigou Dam, and Oouchibaru Dam,

with the aim of restoring the original sediment flow, which has been intercepted by dams up until now while balancing river safety, water usage and environmental preservation.

As shown in Fig. 8, the sluicing of sediment will let inflow sediment from the upstream pass dams by pre-drawdown to create a state close to a natural river state when heavy rainfall by typhoon is expected.

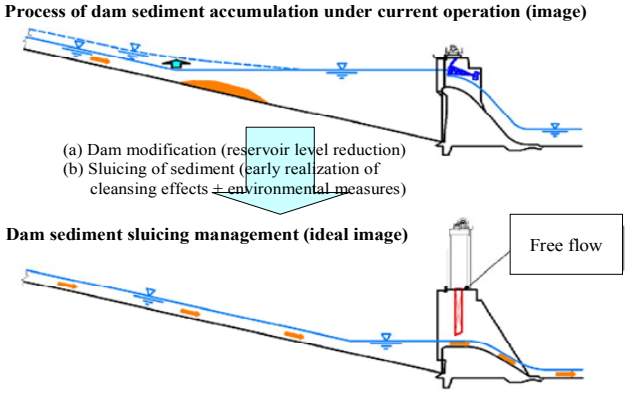

Figure 8. Sluicing of Sediment – Image

Under this action plan the aim is to commence sluicing of sediment in 2016 and carry out the measures and monitoring as described below.

4.1. Sediment Dynamics Forecasting

In order to forecast the effects of sluicing of sediment, under the conditions shown in Table 1, analysis of one-dimensional riverbed fluctuation over the approximately 58km between Yamasubaru Dam upstream and the river estuary was conducted. Fig. 9 shows the results of the longitudinal riverbed form analysis of the Yamasubaru dam-regulating reservoir, while Fig. 10 shows the results of the balance between incoming and outgoing sediment from the upstream of Yamasubaru dam-regulating reservoir to the river estuary by sediment particle diameter.

Concerning dams where sluicing of sediment will be carried out, this is reflected in modifications to be carried out to Yamasubaru Dam and Saigou Dam mentioned below.

Table 1. Investigation Conditions

Investigation conditions			Yamasubaru Dam upstream	Saigou Dam upstream	Oouchibaru Dam upstream	Oouchibaru Dam downstream river
Initial riverbed conditions			Riverbed survey after Typhoon 0514			
River flow rate conditions			Actual flow rates at each dam 1994-2004			
Post-calculation conditions			Calculation until dam-regulating reservoir riverbed stabilization confirmed			
Sediment inflow conditions	First 10 years (m^3/km^2/year)		1,092	1,056	791	791
	From year 11 (m^3/km^2/year)		606	742	521	521
Water level conditions	Case1	Existing operation case	Reflects dam operation results			
	Case2	Sluicing of sediment case	Using actual flow rates, while flow rate at each dam exceeds 200m^3/s, calculate water level during sluicing of sediment (all gates free flow)			

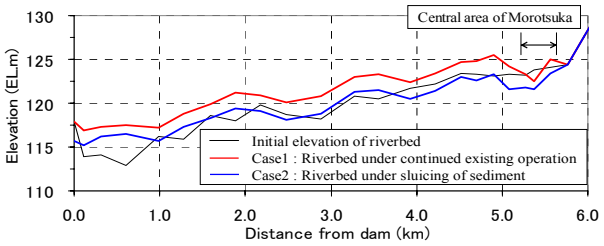

Figure 9. Results of Riverbed Fluctuation Analysis

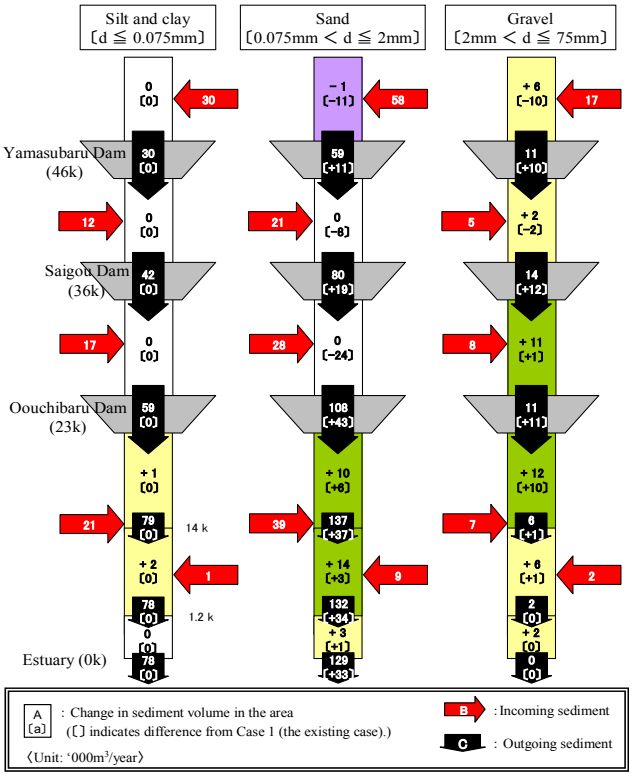

Figure 10. Results of Calculation for Incoming and Outgoing Sediment in Case 2

As a result of the above, concerning the future form of dam-regulating reservoirs, it has been confirmed that if current operations are continued, sediment will continue to be deposited in the reservoirs and aggregation will occur, whereas if dam sediment sluicing is carried out, sediment upstream of regulating reservoirs will be drawn downstream, which will cause the riverbed form of regulating reservoirs' upstream to stabilize at lower than existing levels. In particular, it was confirmed that there would be improvement in the feeding of sand and gravel downstream of dams, which have up until now accumulated at dams.

Therefore, it is expected that this will lead to mitigation of the flood risks associated with rapid aggregation of dam-regulating reservoirs in the dam upstream region during flooding. Also, it could contribute to creating a healthy water environment including the ecosystem by controlling degradation and beach erosion in the dam downstream and in littoral areas, as well as by promoting cleansing effects of the river.

4.2. Dam Modification Plan

For Yamasubaru and Saigou Dams, with the existing structure it is not possible to do the necessary drawdown in order to carry out sluicing of sediment. For this reason sluicing functions will be added to these dams by partially cutting down their overflow sections without causing structural damage.

For Oouchibaru Dam, which is the furthest downstream, dam height is low, and by changing dam operation, sluicing of sediment will be possible with the existing structure, so dam structure will not be modified.

4.2.1. Consideration of dam form modification

The form of dam body cutout is an important determining factor in the result of sluicing. Because of this, the cutout form needs to be assessed comprehensively from the view points of river safety, environmental preservation and effects on power generation. Table 2 shows one case for examination.

Table 2. Investigation Case Relating to Form of Dam Modification

Dam modification	Cases for examination								
	Yamasubaru Dam					Saigou Dam			
	1	2	3	4	5	1	2	3	4
Modification width (No. of existing spillway gates to be modified)	Existing	4	2	1	Dam re-moval	Existing	8	4	Dam re-moval
Depth to cut down dam spillway height (m)		4.65	9.3	18.6			2.15	4.3	

In response to dam overtopping that occurred at Yamasubaru and Saigou Dams in 2005 during heavy rain due to Typhoon 14, the form of the dam body cutout has been designed based on constraint conditions to let the amount equivalent to a 1 in 100 year flow rate (for Yamasubaru 5,190m^3/s and Saigou 5,570 m^3/s, while maximum flow rates during Typhoon 14 in 2005 were equivalent to 1 in 50 year flow rates) flow down safely while maintaining dam safety.

In addition, to comprehensively assess river safety, environmental preservation and effects on power generation, Eq. 1 has been adopted as an indicator to calculate sediment flow management cost.

$$C_m = (C_d+C_s+C_e+C_p)/V \quad (1)$$

Where C_m is sediment flow management cost, C_d is dam measures cost, C_e is environmental measures cost, C_p is power generation reduction cost, and V is amount of sediment flow through dam.

Fig. 11 shows the results of investigation relating to Yamasubaru dam form modification.

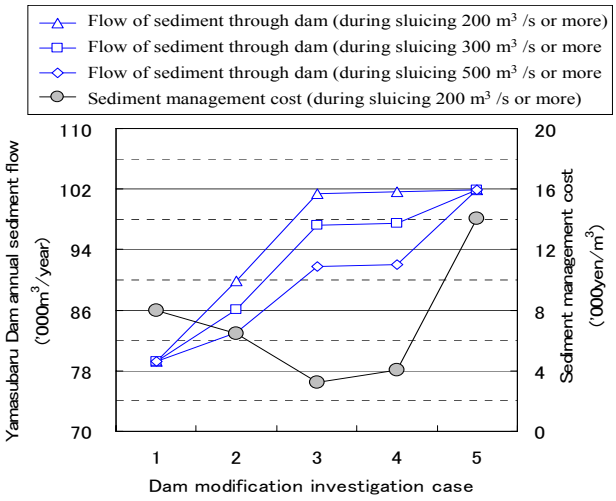

Figure 11. Results of Investigation Relating to Form of Yamasubaru Dam Modification

For Yamasubaru Dam, modification will be carried out by removing the existing two central spillway gates, cutting down spillway crest height by approximately 9.3m, and installing a single large spillway gate.

Concerning the method for sluicing of sediment, when flooding due to a typhoon is forecasted, pre-drawdown operations will be carried out in advance if flooding is expected due to a typhoon. Also, when dam flow rate exceeds 200m^3/s, all gates will continue to be open fully (free flow) so that the amount of sediment flow would be the same as if the dam had been removed, and it was also confirmed that this method was the optimal measure by which sediment flow management cost would be minimised.

For modifications to Saigou Dam, removing the four central spillway gates, and then cutting down spillway crest height by approximately 4.3m has been confirmed to be the optimal measure.

Fig. 12 shows images of the final appearances of Yamasubaru and Saigou Dams after modification.

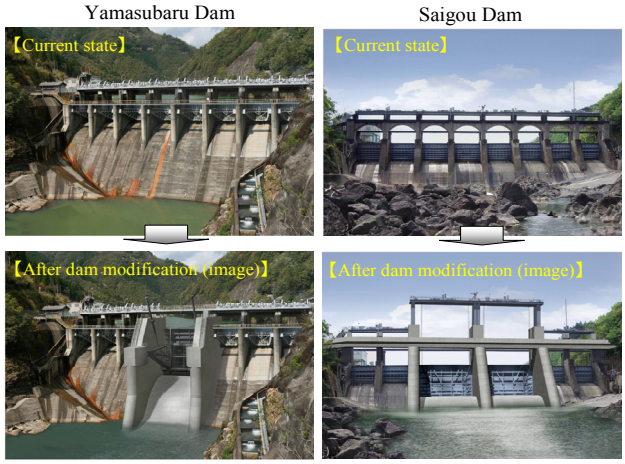

Figure 12. Dam Modification – Image

4.2.2. Modification work plan

Dam modification work on Yamasubaru and Saigou Dams was commenced in November 2011, and is planned to continue for approximately 5 years until December 2016. The work will in principle be carried out between November and May, non flood season.

While work is carried out, a temporary cofferdam will be installed upstream of each dam, and the river diverted through a headrace to allow power generation to continue. In addition, there is the issue that while modification work is in progress, it is necessary to discharge water from dams safely during flooding, in the same way as for existing dams. As shown in Fig. 13, to resolve this, a 4m high steel-rubber gate is to be installed in the upper part of the temporary cofferdam.

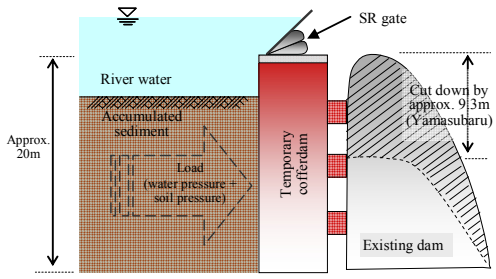

Figure 13. Temporary Cofferdams to be Installed Upstream during Dam Modification Work – Overview

4.3. Plan for Movement of Dam-regulating Reservoir Sediment

In the transition to dam sediment flow operation, after completion of dam modification work, proper consideration must be given to river safety and sudden changes to the river environment. As a measure to deal with this, after appropriately assessing riverbed form and riverbed material particle size within dam-regulating reservoirs in the future, through model tests and numerical simulations, the movement of existing accumulated sediment in dams will be carried out as shown in Fig. 14, in parallel with dam modification work.

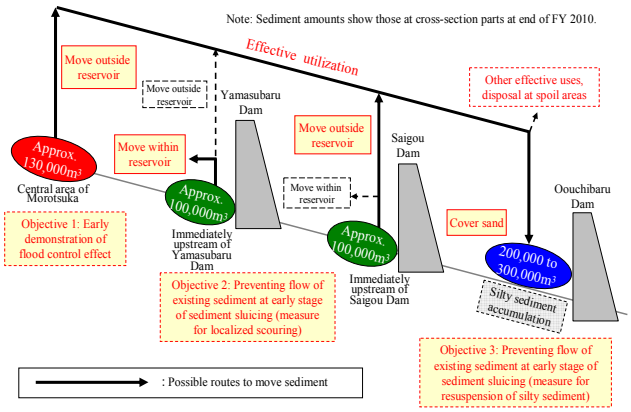

Figure 14. Dam-regulating Reservoir Sediment Movement Plan – Measure Objectives

4.4. Environmental Monitoring

After above-mentioned measures are taken, sand and gravel that has up until now not flown in the river well, will flow in a close-to-natural state, and to understand this environmental change at regular intervals, environmental monitoring on water quality, bottom sediments, fish, and attached algae will be carried out in cooperation with Miyazaki Prefecture.

Working in cooperation with Miyazaki Prefecture and fishing cooperatives, since November 2007, surveys have been carried out, and the current condition of the river environment is now being understood and assessed.

Environmental monitoring will be continued into the future, and is reflected adaptively in plans for sluicing of sediment and moving dam-regulating reservoir sediment.

5. CONCLUSION

Concerning the resolution of the many problems caused by sediment from the mountain areas, through the river, dams and up until the estuary and seashore of the river system, with the aim of achieving the “betterment of the Mimikawa River”, as a result of progressing cooperative approaches through the promotion of consensus between related parties including local communities, local government and KEPCO, it was possible to formulate an integrated sediment flow management plan centred on the secured continuity of sediment flow based on a balance between river safety, environmental preservation and water usage. The social system in a river basin can be significantly affected and improved over time, or sometimes through unprecedented natural disasters. Subsequently, changes in values and awareness of prosperity among local communities can be seen. For the organization responsible for dam installations, it is important to work together with local communities and have an attitude that allows it to adapt flexibly towards various environmental changes, including those in the natural environment.

ACKNOWLEDGEMENT

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