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Sediment Management Option by Sediment Sluicing in the Mimi River, Japan

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ABSTRACT

Currently, the reservoir sedimentation management strategy in Japan is changing drastically from just receiving and depositing to releasing and supplying to downstream river channels. In contrast to the emergent and local conventional countermeasures such as dredging and excavation, sediment bypassing, sediment sluicing and sediment flushing measures which aim at radically reducing the sediment inflowing and deposition are implemented. Unazuki and Dashidaira dams in the Kurobe River, Miwa, Koshibu and Matsukawa dams in the Tenryu River and Asahi dam in the Shingu River are well known as advanced examples. Recently, sediment sluicing has been introduced by retrofitting existing dams with deep spillway gates in several hydropower dams in the Mimi River. This paper shows these present state of the art methodologies of reservoir sedimentation in Japan and these effects on sediment passage based on sediment grain size distribution.

KEY WORDS: Reservoir sedimentation; Sediment flushing; Sediment bypassing; Sediment sluicing;

INTRODUCTION

In Japan, there are more than 3,000 dams with one or multiple functions, which become essential for such modern society. Storage reservoirs provide important functions such as flood mitigation, energy production, water supply and so on. However, their side effects are strong modifications in flow and discontinuity in sediment and declining river ecosystem health. In the past few years, in some of Japanese dams' serious sedimentation issues and loss of reservoir capacity have been exceeding than estimated. Consequently, more sediment has already accumulated than the design sediment yield and active storage capacity is decreasing year by year. Therefore, without immediate action plan some of these dams might have problems with maintaining dam functions and reservoir operation.

Japan is one of the current leaders in sediment management applications with nearly 25% of its dams restoring to sediment excavation, and a growing use as downstream supply (Kantoush et al. 2011). In order to sustain the downstream ecological functionality, we must design optimal sediment volumes and sizes, as coarser substrates are beneficial for benthic communities. As the sediment management was not considered at the early stage of dam planning and designing, it is a challenge to sustain reservoir functions, and to minimize down-stream impacts of sediment starvation (Kondolf et al. 2014).

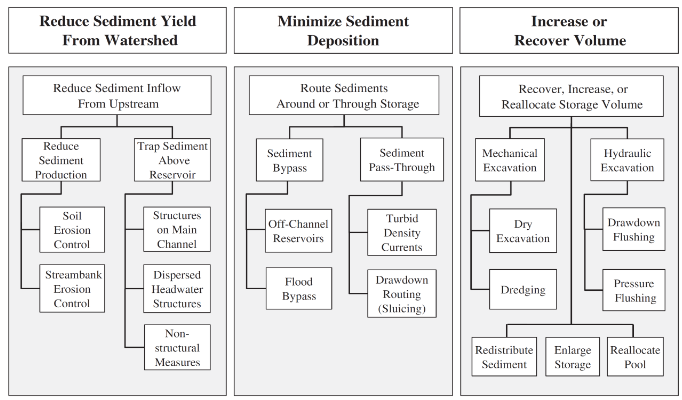

Fig. 1 Sediment management options (Kondolf et al. 2014)

There are various publications that classified techniques of reservoir sediment management (Morris & Fan 1998, Kantoush & Sumi 2010, Annandale 2013, Kondolf et al. 2014(Fig. 1)). Sediment bypass tunnels avoids reservoir sedimentation and replenishing sediments below dam with a wide range of rates and timing similar to pre-dam conditions (Sumi et al. 2012). During sediment sluicing (or routing) water level at dam has to be lowered sufficiently during high flows to maintain high velocities. While, sediment sluicing through retrofitted dams of Mimi River case study permits sediment to be transported through the reservoir rapidly to reduce siltation (Sumi et al. 2015, Peteuil et al. 2016). At the Kurobe River, both sediment drawdown flushing and sluicing are performed every year, where flushing channel is formed and re-suspending sediments deposited in the reservoir flushed through bottom outlets to downstream (Sumi et al. 2009). This paper overviews these sediment management options and discusses the effects of unique retrofitting project in the Mimi River basin for sediment sluicing.

BASIC CONCEPT OF SEDIMENT PASSAGE AND RECOVERING STAGE OF SEDIMENT TRANSPORT RATE

Sediment management techniques are classified by effects of sediment passage and recovering stage of sediment transport rate. Table 1 indicates the frequency of sediment passages from reservoirs to downstream reaches that are composed of fine and coarse sediments. There are different sediment pulses replenished to the downstream reach with each different reservoir sediment management method, where the reservoir pool is completely, partially or not lowered.

Table 1 Classification and characteristics of sediment passages for reservoir management strategies

Sediment Replenishment Methods		Lowering Reservoir Pool	Frequency of sediment passage	Sediment Passages	
				Coarse pulses	Fine pulses
Storage Dam		No	No	No	Nearly No
Drawdown Flushing		Complete	Once a year	All (Concentrated)	All (Concentrated)
Sediment Bypass Tunnel		No	Several times per year	Almost all (Frequent)	All (Frequent)
Sediment Sluicing		Partial	Several times per year	Almost all (Frequent)	All (Frequent)
Adding Excavated Sediment		No	Several times per year	Partial (Concentrated)	Partial (Concentrated)

Figure 2 shows that each Sediment Management method has different effects levels on downstream reaches below dams and recovery of river health. Adding excavated sediments is suitable method in the normal stage among other sediment management techniques. However, during flood stage the downstream recovery level is very limited. In order to achieve higher recovery level to the downstream conditions, we have to shift to other methods as sediment bypassing, sediment sluicing or drawdown flushing according to the reservoir size. Therefore, optimal design of sediment transport rate by suitable combination of flow discharges, and quantity and quality of sediment is needed to improve morphological effects.

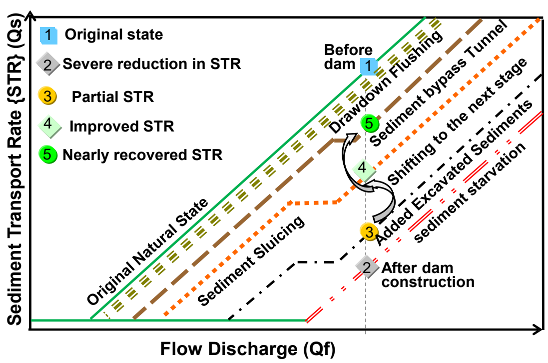

Fig. 2 Effectiveness levels of sediment management methods to recover the sediment transport rates below dams

SEDIMENT SLUICING IN THE MIMI RIVER

Mimi River (Mimi-kawa) system is 94.8 km in length flowing into the Pacific Ocean, located in the southeast of Kyushu in Miyazaki prefecture of Japan with a catchment area of 884.1 km^2 (Fig. 3). There are seven dams which are Kamishiiba, Iwayado, Tsukabaru, Morotsuka, Yamasubaru, Saigo, and Ouchibaru dams. They are operated by the Kyushu Electric Company (KEPCO). Dam reservoirs are normally designed to have a capacity to store 100 years, worth of sediment in the deepest parts close to the dams. Recently, rainfall and water volume flowing into dams in September 2005 exceeded the designed dam reservoir flood for all seven dams. Flood damages occurred were extensive as four power plants were flooded and overflow of Tsukabaru, Yamasubaru and Saigou dams. Moreover, damages were enlarged as 10.60 Million cubic meter (MCM) of sediments and driftwood flowing to the river and the seven reservoirs as mountain slope failures in various locations occurred.

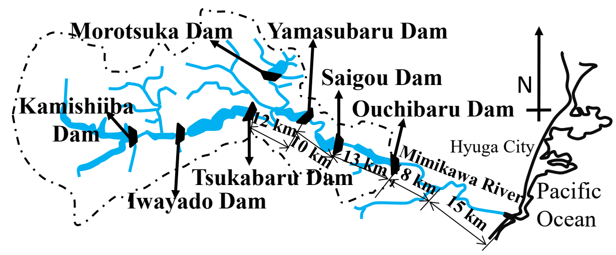

Fig. 3 Location map of dams along Mimi River Basin

Table 2 Dams and reservoir sedimentation in the Mimi River

Name of Dam	Dam height (m)/ Year of opening	Total storage Capacity (10^{3}m^3)	Total sedimentation volume (10^{3}m^3)	Annual sediment volume (10^{3}m^3)
Kamishiiba	**110/1958**	**91,550**	**12,600**	**217.80**
Iwayado	**/1972**	**8,310**	**5,560**	**77.20**
Tsukabaru	**87/1975**	**34,330**	**6,980**	**91.80**
Morotsuka	**/1952**	**3,480**	**1,060**	**20.30**
Yamasubaru	**29.4/1981**	**4,190**	**2,590**	**32.00**
Saigo	**20/1984**	**2,450**	**1,010**	**12.00**
Ouchibaru	**25.5/1957**	**7,490**	**1,930**	**33.80**

Sediment accumulation and dam characteristics are shown in Table 2.The table shows that sedimentation in all seven dams has progressed faster than that of the original plan. Approximately 5.2 MCM have been deposited in reservoirs of Mimi river system. It is clearly noticed that, if the group of dams will continue with the current operations rules without recovering or adding new dam function, the sediment will continue to be deposited in the reservoirs and aggregation will occur. Therefore, new investment for creating new function by sediment sluicing is proposed, where sediment upstream of reservoirs will be drawdown and passing through dam to the downstream reaches. In particular, it was confirmed that there would be improvement of dam function through sediment replenishment as well by excavating sand and gravel and supply to the downstream of river reaches.

Dams in Mimi river are losing original functions due to sever sedimentation occurred recently after Typhoon. 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, and has drawn up a plan for sediment sluicing, incorporating Yamasubaru, Saigou, and Oouchibaru Dams. In recent years, various countermeasures have been studied. As shown in Fig. 4, it has been proposed that using CAP/MAR (Total capacity/Mean annual runoff) and CAP/MAS (Total capacity/Mean annual inflow sediment) as parameters, sediment measures can be classified, which will assist in selecting an appropriate countermeasure. According to Sumi 2008, with an increase in CAP/MAR (that is, a decrease in dam regulating reservoir turnover rate), the appropriate sediment measure will vary between: sediment flushing, sediment bypass, sediment sluicing, sediment check dam, excavating and dredging, or no necessity for a sediment measure to be applied. The reason for this is that these various sediment measures depend largely on the amount of water that can be used for sediment management, which in turn depends on the scale of the dam regulating reservoir. CAP/MAR and CAP/MAS data for each of the 7 dams in the Mimi River Basin is shown in Fig. 4. According to this, it can be seen that compared to Kamishiiba, Tsukabaru, and other dams upstream, Yamasubaru, Saigou and

Oouchibaru Dams 1) have low CAP/MAS and therefore have a substantial need for sediment measures and 2) dam-regulating reservoir turnover rate is high (CAP/MAR is low), making sediment flushing and sediment sluicing appropriate. Based on this, the retrofitting of dams for sediment sluicing operation was initiated.

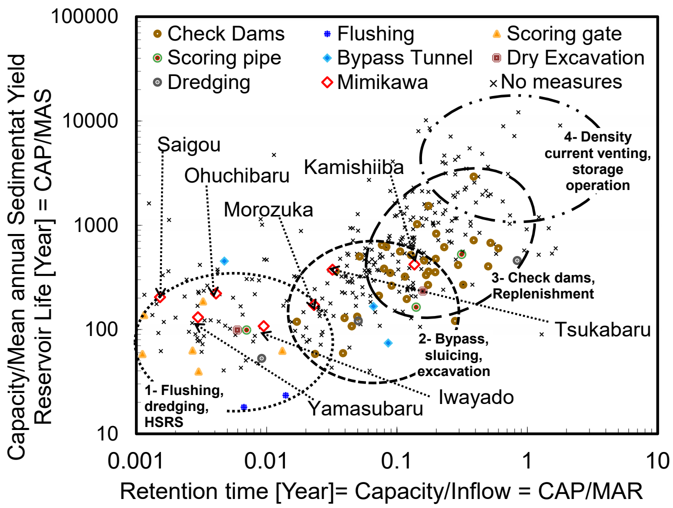

Fig. 4 Proposed sediment management techniques and dams in the Mimi river system

The river administrator established the Mimi River Basin Integrated Sediment Flow Management Technical Committee, in which river basin stakeholders participate. Rather than focusing on each problem separately, the prefecture came to a proper understanding of these various sediment related problems over the entire river basin, including the mountainous areas, dams, the river itself and the coastal areas. And with the aim of restoring the original sediment flow, while balancing flood control, water usage and environmental conservation, formulated a policy to advance integrated sediment flow management. In October 2011, the Mimi River Basin Integrated Sediment Flow Management Plan was compiled. The plan established matters such as the work to be carried out and stakeholder roles, with the aim of resolving problems caused by sediment in the basin.

KEPCO formulated an action plan to recover the original state. Retrofitting works on Yamasubaru and Saigou dams (Fig. 5) have started in November 2011. In Japan, it will be the first time that an existing dam will be modified by the addition of a new sluicing function after 80 years of commissioning. Figure 6 shows the concept of sluicing operation at Yamasubaru, Saigou and Oouchibaru Dams, by temporarily lowering of reservoir water levels to make the flow of water in dam regulating reservoirs close to the original, natural state of the river, thereby allowing inflow sediment to be transported below dams. It has to be noted that due to the ongoing retrofitting works, changes have been already experienced regarding the quantity of sediments passing the reservoirs. In the particular case of the Saigou dam, a significant rise of coarse sediment fluxes has been observed since the beginning of the works as a result of the water depth drop and flow velocity increasing. It is important to understand and monitor the sediment input from the river basin that is affected by factors such as the relationship between river flow volume and amount of fluctuation.

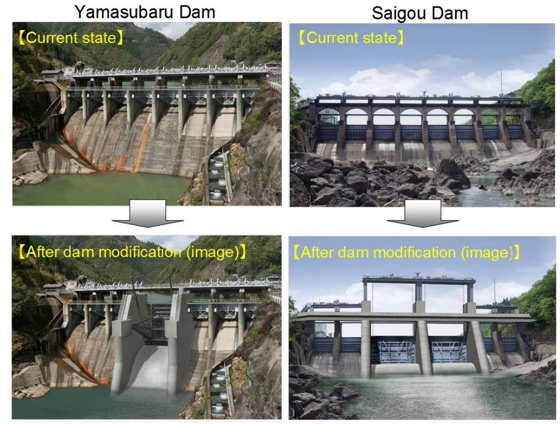

Fig. 5 Retrofitting works of Yamasubaru and Saigou dams

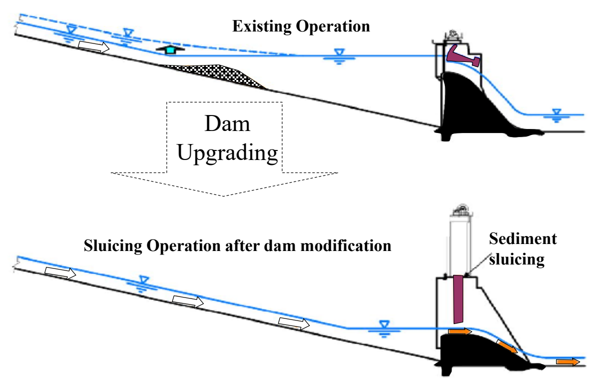

Fig. 6 Schematic view of sediment sluicing

In order to do this, one dimensional analysis of riverbed variation was carried out, and the effect of sediment sluicing at dams verified for the approximately 58 km stretch of the main river, covering the three dams where sluicing is to be carried out, from the area upstream of the Yamasubaru Dam regulating reservoir down to the river mouth. Figure 7 shows a comparison between riverbed elevation for Yamasubaru Dam after 33 years under current operation (without sluicing) and with sluicing operation. It has been confirmed that if current dam operations are continued, sediment will continue to be deposited in the reservoirs. Whereas if sediment sluicing operation is carried out, sediment upstream of regulating reservoirs will be transported downstream, which will cause morphological changes in the downstream reaches.

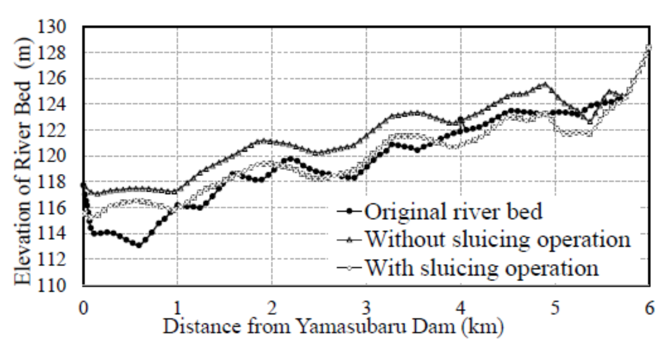

Fig. 7 Results of riverbed fluctuation analysis (Yamasubaru Dam)

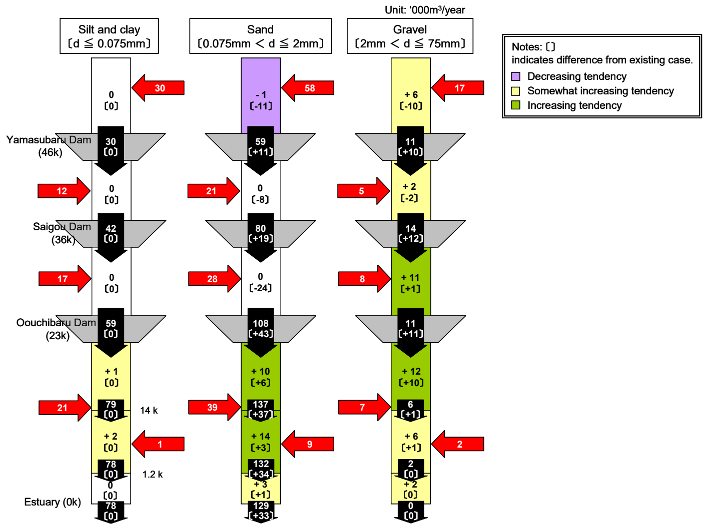

Fig. 8 Sediment budget change after sediment sluicing operation

Therefore, it is expected that the retrofitting will lead to reduce the flood risk and develop a healthier river environment, including the ecosystem, by controlling degradation and beach erosion in the dam downstream and in littoral areas, as well as by promoting diversification of riverbed materials. Using the tools mentioned, sediment flow simulations are being conducted under the assumption of various future risks, and specific methods for sediment sluicing at dams is being studied. These results are very encouraging and demonstrate that sediment sluicing is a promising measure for restoring the sediment continuity throughout the river system for a wide range of particles. Figure 8 is showing sediment budget change after retrofitting works. Sediment sluicing operation is providing more passage for sand and gravel materials.

It has to be noted that due to the ongoing retrofitting works, changes have been already experienced regarding the quantity of sediments passing the reservoirs. In the particular case of the Saigou dam, a very significant intensification of coarse sediment fluxes has been observed since the beginning of the works as a result of the water depth drop and flow velocity increasing. Those preliminary field evidences are very encouraging and demonstrate that sediment sluicing is a promising measure for restoring the sediment continuity throughout the river system for a wide range of particles. Field monitoring appears to be an essential management tool and is thus scheduled to continue for understanding and quantifying the impact of sediment sluicing operations performed at dams on the river environment.

CONCLUSION

In case of reservoir sediment management, it is necessary to assess the current situation and possible future scenarios from a reservoir sustainability point of view. For sediment management plan, combination of flow and sediment release should be appropriately designed to meet demands of various functions based on data of hydrology, water quality, river morphology and ecosystem, etc. Among several updated methodologies, sediment sluicing is one of effective and ecofriendly solutions. In order to maximize the benefit, selecting suitable timing, duration, frequency and water level or velocity in the reservoir are important based on target sediment volume and grain seize distribution. For existing dams, retrofitting works in the Mimi River, Japan will be an unique reference. By modifying spillway gates, sediment sluicing will increase the sediment fluxes released from reservoirs and is to minimize upstream flood risks and likely to induce morphological changes in the downstream river environment. Assessing the impact of such measure prior to its implementation is therefore necessary. To achieve this objective and better define the current state of the Mimi River in terms of sediment dynamics, a survey is being carried out, covering issues such as water quality, bed-materials characteristics, river channel morphology, as well as aquatic fauna and flora. 1D and 2D numerical modelling are also important to predict short term and long term sediment transport and morphological effects.

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