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The aging of Japan's dams: Innovative technologies for improving dams water and sediment management

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ABSTRACT: Dams are probably the most important hydraulic structure that are expected to be operated for the longest life. The major challenge to extend dams' life is siltation in reservoirs. In order to sustain dam functionality for long-life and solve associate issues as dam safety, flood and sediment management, we must consider the necessity of upgrading and retrofitting of such aging dams. As they have long service life, if we can solve the associated issues of sediment management, extreme flood, monitoring dam structure, operation and gate control system, the dam will extend life with proper management. The main purpose is to explain, how to select appropriate sediment management strategy in each reservoir according to sedimentation conditions within reservoir and in downstream reaches. The other is how we can recovering, increasing, extend reservoir functions. It is possible to increase the reservoir life by implementing proper sediment management method, and they are important in dealing with dams' life cycle cost. The paper highlight the potential benefits of the asset management and coordinating reservoirs management in the river basin scale. However, still missing are the necessary cost benefits assessment to evaluate the sediment management investments.

1 INTRODUCTION

1.1 *Necessity of dam redevelopment*

Dams are probably the most important hydraulic structure that are expected to be operated for the longest life. The aging of Japan's dams and continuous loss of storage capacity due to reservoir sedimentation, coupled with increasing environmental needs, will cause the social, economic, environmental, and political importance of dams to constantly increase. Removing such stored sediments is often recommended as a potentially better way to recover reservoirs storage capacities than dam heightening or building new dams. The rapid reservoir sedimentation not only decreases its storage capacity, but also increases the flood risk in the upstream reaches and e greatly reduce the sediment load in the river.

In order to sustain functions of dams for long-life and solve associate issues as dam safety, flood and sediment management, we must consider the necessity of upgrading and retrofitting of such aging dams. As they have long service life, if we can solve the associated issues of sediment management, extreme flood, monitoring dam structure, operation and gate control system, the dam will extend life with proper management. Figure 1 presents a proposed approach to increase dam service life by recovering, improving, and extending dam functions. This approach is comprised of three assessment levels of dam functions (Fig. 1). The first for damaged functions and priority investment is needed to recover the original function

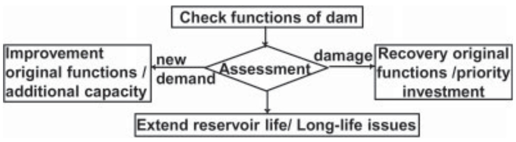

Figure 1. Necessity of upgrading and retrofitting aging dams.

and the second for additional function newly required by improvement and retrofitting the dam, and finally the third by extend dam life.

1.2 *Management of siltation in reservoir*

The major challenge to extend dams' life is siltation in reservoirs. A comprehensive paper review from five continents experiences in managing reservoir siltation and mitigation downstream impacts summarized by Kondolof et al., (2014). There are a wide range of publications classified sediment management techniques as Morris and Fan, (1998) and Kantoush and Sumi, (2010). They categorized such techniques for three strategies based on reducing sediment delivery from upstream, maintain reservoir capacity, and provide sediment to downstream reaches. Most of these strategies are planned and implemented without any consideration for the necessity of upgrading by improvement, recovery, and extend dam life. This paper categorizing sediment management technologies based on the conceptual diagram in Figure 1 from dam reservoir

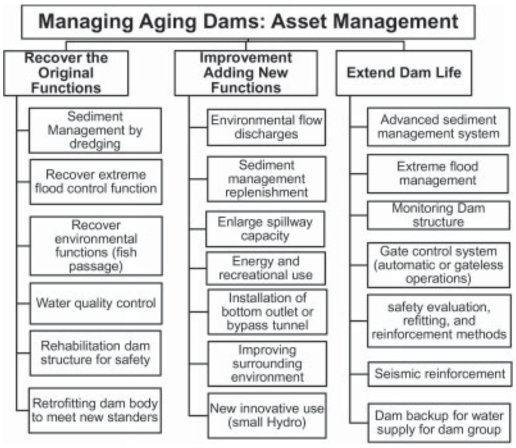

Figure 2. Necessity of upgrading and retrofitting aging dams.

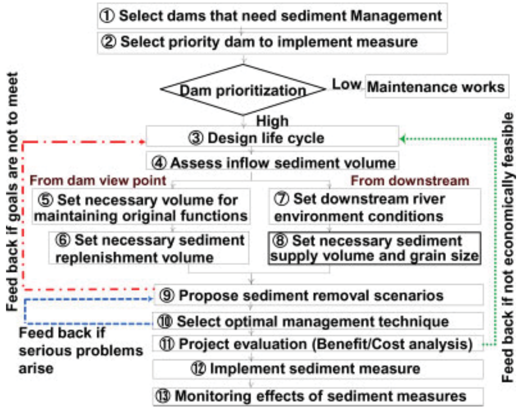

Figure 3. Proposed approach to design effective sediment management strategy.

functions. The main purpose is to explain, how to select appropriate sediment management strategy in each reservoir according to sedimentation conditions within reservoir and in downstream reaches. The other is how we can recovering, increasing, extend reservoir function. It is possible to increase the reservoir life by implementing proper sedimentation countermeasures, and they are important in dealing with dams' life cycle cost. In this paper, the results of study in Japan that used redevelopment and asset management are presented. The examples provided demonstrate the use of sediment excavation and retrofitting.

This paper focuses on one critically important element of these challenges: the need to retrofit or modify the design and operation of existing dams. The retrofitting of dams for modified operation by sluicing refers to cutting dam body and installing (a) New spillways, (b) bottom outlet, (c) bypass tunnel, (d) modify and enlarge existing spillway gates. Moreover, understanding of the necessity of upgrading and retrofitting of aging dams in Japan will be necessary to support the difficult management decisions that ultimately will have to be made. Figure 2 categorizing managing of the aging dams from the standpoint of reservoir recovery, extending, and adding innovative new functions.

Possible management issues for aging dams include sediment management techniques to increase the reservoir capacity, extend dam life, dam modification, dam removal, changes in reservoir operational practices, habitat availability and quality, and the environmental consequences of any actions taken. The sustainable development have proliferated, but the following concepts are most relevant from the standpoint of retrofitting dams:

- Guaranty security and acceptable functioning of the reservoir for its purposes;
- Today's patterns of infrastructure development should preserve the capacity of the reservoir and maximum possible time of functioning;
- Produce minimum impact to the environment and maintain biological diversity;
- Minimize the potential for catastrophic disasters resulting from dam failure;
- Avoid activities that create a legacy of environmental restoration or dam rehabilitation obligations that disproportional on future generation;
- Consider all processes: hydrological regime, erosion, climate change, environment and associated ecosystems, water and sediment continuity.

Requiring a reservoir life measured in terms of thousands years instead of decades will demand new methods of analyzing costs and benefits.

For all these reasons, developing new techniques to evacuate the fine and coarse sediment to maintain the functionality, and at the same time ecologically re-habilitating the involved landscape would be economically and environmentally beneficial for all types of reservoirs. Figure 3 shows the proposed procedure for setting up sediment management strategy. At first, we prioritization the selection of the dam that needs countermeasures for sediment management purpose, set its lifecycle for redevelopment project for such dam to calculate investment cost and benefit and the duration to implement the sediment countermeasures. Then, based on historical measurements of sedimentation, we can estimate future expected annual average amount of inflow sediment and total inflow sediment.

Then choose the best scenario based on this in terms of maintaining both dam original functions and the environment of the rivers and coasts. The other is to design sound river environment de-scribed representatively such as by river bed elevation, grain seize and morphological dynamics and design necessary sediment supply volume and grain size. Finally, we should combine these two needs and decide appropriate scenario to dis-charge sediment from dams. Based on the proposed scenarios, we can select optimal sediment management measures from several possible options such as reservoir flushing, dry excavation, sediment

Figure 4. Location map of dams along Mimi River Basin.

bypass tunnel, sluicing, density current venting, dredging, siphoning, and HSRS. If technical significant problems may arise, we should modify the scenario. Selected sediment management measure should be evaluated by benefit/cost analysis and, if the project is not economically feasible, we should revise the project from the master planning stage. Sediment management of reservoirs is very much complicated project which will affect reservoir sustainability and also maintaining downstream river health. So we should start to implement step by step basis by conducting filed monitoring under the adaptive management concept. Two case studies are presented in this paper to discuss implementation of sediment management techniques from recovering and improving functions in Mimi River System. The second case study discussing the asset management of dam reservoirs by implementing sediment management techniques to extend dam life in Kizu River System.

2 RECOVERING AND IMPROVING DAM FUNCTIONS IN MIMIKAWA RIVER SYSTEM

2.1 *The study area*

Mimi River (Mimi-kawa) system is 94.80 km in length flowing into the Pacific Ocean, located in the south-east of Kyushu in Miyazaki prefecture of Japan with a catchment area of 884.1 km^2 (Figure 4). There are seven completed dams in the Mimi River System, Kamishiiba, Iwayado, Tsukabaru, Morotsuka, Yamasubaru, Saigo, and Ouchibaru dams as shown in Figure 4.

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 and their dam control facilities flooded as well. 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. Sediment accumulation and dam characteristics are shown in Table 1. The table shows that sedimentation in all seven dams has progressed faster than that of the original plan.

Table 1. Dams and reservoir sedimentation characteristics in Mimi River Basin.

Name of dam	Dam height (m)/Year of opening	Total storage capacity (10^3m^3)	Total sedimentation volume (10^3m^3)	Annual sediment volume (10^3m^3)
Kamishiiba	110/1958	91,550	12,600	217.80
Iwayado	57.5/1972	8,310	5,560	77.20
Tsukabaru	87.0/1975	34,330	6,980	91.80
Morotsuka	59.0/1952	3,480	1,060	20.30
Yamasubaru	29.4/1981	4,190	2,590	32.00
Saigou	20.0/1984	2,450	1,010	12.00
Ouchibaru	25.5/1957	7,490	1,930	33.80

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.

2.2 *Sustainable selection of sediment techniques*

Dams on Mimi River are losing original functions (flood control, water supply, and recover the downstream environmental conditions) due to the sever sedimentation problems 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 up until now, and has drawn up a plan for sediment sluicing, incorporating Yamasubaru Dam, Saigou Dam, and Oouchibaru Dam. In recent years, various countermeasures for sediment flow management policies have been studied.

As shown in Fig. 5, 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 2010, 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

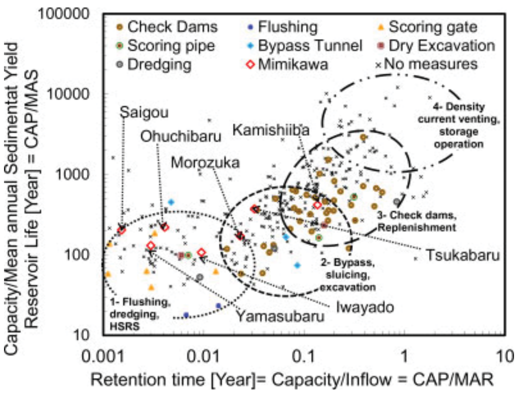

Figure 5. Proposed sediment management techniques and dams in the Mimi River system.

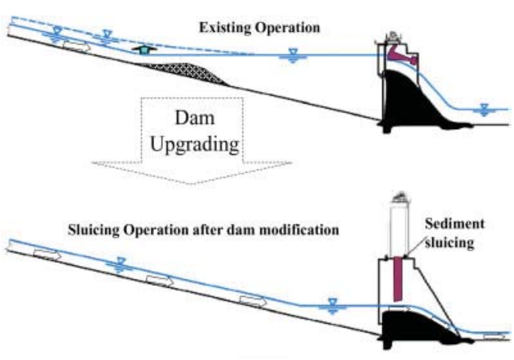

Figure 6. Retrofitting concepts to sediment flow management in dam-regulating reservoirs by cutting down spillway crest height.

dam-regulating reservoir. CAP/MAR and CAP/MAS data for each of the 7 dams in the Mimikawa River Basin is shown in Figure 5. According to this, it can be seen that compared to Kamishiiba, Tsukabaru, and other dams upstream, Yamasubaru, Saigou and Oouchi 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.

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.

2.3 *Recovering dam function*

This class includes the recovery or rehabilitation of reservoir functions, i.e. reservoir storage volumes and levels from losing the functionality due to reservoir sedimentation. For dams in such losing function condition, sediment management techniques are implemented to restore the effective reservoir capacity needed to regulate flood events or water supply and to guarantee live storage. There are various structural and nonstructural methods can be engaged are: (a) dry excavation, (b) permanent dredging facility, (c) redevelopment of old spillway by replacing gate and valves, (d) recovery environmental functions for river by constructing fish passage and sediment supply, (e) water quality conservation measures for the three major issues of long-term turbidity, temperature, and eutrophication in reservoirs.

It is assumed that in response to the change in the amount of flow of sediment due to sediment sluicing operation at dams, that there will changes in the river environment and it is therefore necessary to make an assessment of the impact. However, there are no specific guidelines to assess the impact of sediment sluicing on the river environment. Therefore, at first it is necessary to implement adaptive management based on an initially adopted plan that is subject to review while monitoring is carried out, during which time a new plan for an assessment method appropriate to the characteristics of sediment sluicing at dams on the Mimi River will draw up.

When drawing up a plan for assessment methods, it is important to appropriately set both the impact of sediment sluicing at dams, and the response. The setting for impact is based on calculated fluctuations in sediment flow, using a one-dimensional analysis of riverbed variation. The setting for the assumed response has been made based on the setting for impact.

2.4 *Adding new functions*

By adding new functions to the existing dam, such as flood control and disaster risk reduction, rehabilitation activities have to be implemented. In order to create addition of new function, the following upgrading and retrofitting means can be considered:

1. Increasing the capacity of the reservoirs by excavating/dredging the deposited sediments;
2. Increasing flood discharges by improving discharge facilities and adding new outlet;
3. Increasing dam height will add extra effective storage for flood control or other purposes;
4. Exchange reservoir storage functions among group of dams by linking several single adjacent dams in the basin so that the storage capacity can be effectively used;
5. Modify reservoir operation rules by preliminary drawdown water level in the reservoir and keep it flexible during flood period. Thus, by increasing flow volumes, an additional reservoir storage capacity will be guaranteed;

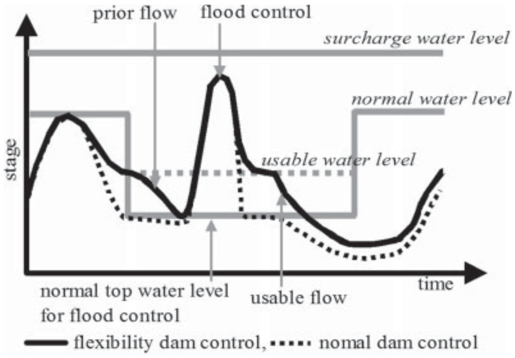

Figure 7. Multipurpose dam operation system and flexible dam operation system.

6. Increase dam safety and ability of the dam body to resist earthquake and other disasters;
7. Improving the existing functions for energy recreation and amenities;

The Flexible Dam Operation (FDO) is a dam management method to enhance conservation and restoration of the river environment located in the downstream of a dam via utilizing "usable capacity" without interrupting prime flood control.

The "usable capacity" is a vacant portion of dam's capacity, which is reserved for actual flood event during the rainy/typhoon seasons. The water stored in the capacity is called "usable water". The FDO requires storing water temporarily up to its design level or "usable water level" within the flood control storage capacity as illustrated in Figure 3.

This utilization storage capacity that has been newly created is used for utilization discharge as follows:

- Discharge to increase the instream flow: Its purpose is to improve the scenery and the habitat for fishes.
- Flushing discharge: Its purpose is to stir up the riverbed and flush out silt and slack water on the riverbed.

Since 1997, a "Flexible Dam Operation" has been underway at dam under the jurisdiction of MLIT with the purpose of improving the river environment downstream of dams. The positive effects that have been obtained by the investigation are summarized in Table 2 according to each discharge type.

3 EXTENDING DAM LIFE BY ASSET MANAGEMENT IN KIZU RIVER SYSTEM

3.1 Networking dam group for reservoir sediment management

Five dams in the Kizu river system are sustained in group by Japan Water Agency (JWA) for water resource development including Takayama, Nunome, Hinachi, Shourenji, and Murou dams as shown in Figure 8. The current conditions of reservoir sedimentations in all five dams has progressed faster than

Table 2. Results of the FDO tracks for different flows.

Kizu River Upstream Five Dams Group	Planned Sedimentation capacity (million m^3)	Actual maximum annual sedimentation		
		Volume (1000 m^3)	Percentage planned capacity (%)	Occurrence probability assessment
Takayama Dam	7.6	621	8.2	1/52 years
Shorenji Dam	3.4	336	9.9	1/35 years
Muro Dam	2.6	314	12.1	1/45 years
Nunome Dam	1.9	230	12.1	1/51 years
Hinachi Dam	2.4	140	5.8	1/12 years

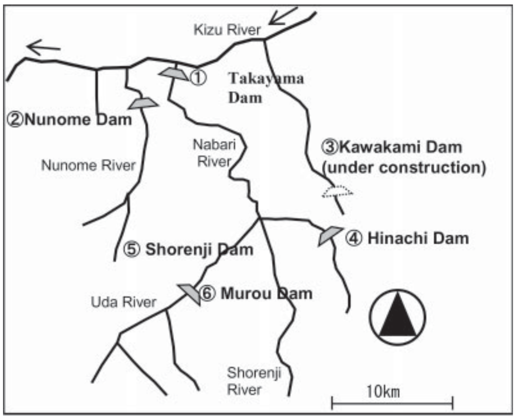

Figure 8. Location map for networking reservoir sediment management on Kizu River upstream adjacent dam group.

assumed in the original plan (In Japan, the planned sedimentation capacity is set by the sedimentation of 100 years).

Moreover, at the Takayama Dam, Shorenji Dam, and Muro Dam, that were constructed more than 30 years ago, sedimentation has reached 40 to 50% of the planned sedimentation. By focusing on annual variations of incoming sediments revealed that at the Takayama dam, annual average sedimentation is approximately 100,000 m^3, but the maximum sedimentation in a single year is about 620,000 m^3. The maximum annual sedimentation at the other dams is about 5% to 12% of sedimentation capacity, and the past maximum sedimentation in a single year was equivalent to that occurring in a 5 to 12 year period (Table 3)

Reservoir as an asset is generally predicted to have semi-permanently long service lifetimes. Therefore, it is important to evaluate its reliability, because deterioration of the dam could have serious consequences on the society. A traditional common design concept of reservoir is to provide a dead storage space for sediment deposition. This concept is incorrect as the delta formation and siltation is prevalent in the active storage space from the early stage of the dam construction. Moreover, sedimentation is handled by setting 100 year capacity as the planned sedimentation capacity.

Table 3. State of sedimentation in the 5 dams group.

	Objectives	Results
Instream flow	Improving fish habitat and migration opportunities	Enhancing continuity of stretch and increasing in fish population
	Improving water quality	Maintaining desirable water quality
	Improving Vicinity	90% of community at the trial location observed vicinity improved
	Conservation of downstream environment	Restoring wetlands on downstream of dams
Flushing flow	Enhancement of rejuvenation of algae	Removing part of old colonies
	Solving odor and vicinity problem	Flushing stagnant water
	Improving vicinity	Removing problematic floating algae, sediments and attached mud

Table 4. Categorization of facilities and management priorities by renewal period.

Renewal period	Facility	Management priorities	Remarks
Short (a few years to a few decades)	I. Machinery & equipment II. Electrical equipment III. Buildings	I. Reducing total cost of inspections, improvement, repair, and renewal	I. Improving the service level II. Responding to technological progress
Long (a few decades to a few centuries)	I. Reservoir sedimentation	I. Prolonging service lifetime II. Lowering life cycle costs	I. If appropriate measures are implemented, renewal period is extended.
Extended life (infinity)	I. Dam structure body	I. Inspections II. Reducing maintenance costs III. Risk assessments	I. If appropriate sediment management is performed, renewal is unnecessary for a very long time, and the present value of renewal costs cannot be assessed.
Contingent	I. Reservoir slopes II. Landslides III. Earthquake response	I. Inspections II. Emergency response	I. Response when constructing to a stipulated level.

Table 5. Scenarios and options of studies sediment management techniques.

Strategies	Focus and costs incurred
Excavation	• Mechanically discharging natural soil from inside the reservoir onto the land • Initial investment: none in particular • Running cost: excavation cost
Dredging	• Mechanically discharging sediment from inside the reservoir onto the land. It is more costly than excavation. • Initial investment: none in particular • Running cost : dredging cost
Sediment check dam (+ Excavation)	• Installing a sediment check dam at the upstream end of the reservoir and mechanically discharging sediment captured in the check dam from the check dam onto the land. • Initial investment: cost of building a sediment check dam • Running cost: cost of excavating the sediment check dam
Drawdown Flushing	• Temporarily drawdown to create an open channel inside the reservoir so that tractive force will flush out the sediment. • Initial investment: installing a sediment flushing gate • Running cost: Equipment wear prevention measures, and according to circumstances, compensation for reduced energy generation
Sediment bypass tunnel	• Bypassing inflowing sediment load downstream through a tunnel so it does not settle in the reservoir. • Initial investment: Installing the sediment bypass • Running cost: Cost of tunnel wear prevention measures
Dry excavation with reservoir emptying	• Once each specified number of years, completely reservoir emptying so that all deposited sediment is moved to the land by dry excavation. • Initial investment: none in particular (when there is no draw down system, it must be installed) • Running cost: excavation, compensation for reduced energy generation, compensation for capacity loss

Such dead storage space for sediments is actually a stagnant water storage with less deposition comparing to the active space deposition. It is necessary to account for such loss in active reservoir storage space early on during the life of a project and to recognize its impact on the reliability of water and power supply, and on flood control. As the length of service life and priority of management activity vary between facilities, it is necessary to apply asset management according to these differences as shown in Table 4. It is possible to prolong service lifetimes by creative dam design concept through appropriate sediments and fish passages, including sediment management strategies which become relevant in the study of the life cycle costs of dams. In Japan, as a common practice a periodical monitoring for reservoir sedimentation is conducted before and after flood. In cases of increased reservoir siltation and the dam lose its functions, an immediate intervention for sediment management to recover the original dam functionality or upgrading dam facility to ensure reservoir capacity. When a large-scale sediment management techniques is implemented, obtaining a large storage yard for removed sediments is a challenge, and it is necessary to reduce costs by using sediment material effectively combined with flushing flow. Regarding the environment, blocking the continuity of sediment by a dam impacts rivers, coastlines and the ocean, so it is necessary to restore sediment downstream from dams. But the quantity that must be restored downstream to conserve the environment, and the environmental benefits of this downstream restoration have not been evaluated. Judging from the above, clarifying cases where applying asset management to sedimentation countermeasures and taking sustained sedimentation countermeasures are beneficial from the cost perspective, and it is possible to reduce life cycle costs and at the same time, reduce the environmental impact of a dam.

3.2 *Effects of management strategies in extending dam life*

A case study was performed of sedimentation countermeasures at the furthest downstream end of the dam group: the Takayama dam with the dam group's largest reservoir. The effects of implementing each sedimentation countermeasure hypothesized by this study are organized considering the application to the study of maintenance plans over long periods of time, and hypothesizing the "annual sediment removal rate (percentage of inflowing sediment load which can be removed by taking the countermeasure)". So in addition to normal sedimentation countermeasure methods, a comparative study of "dry excavation" is also performed (see Table 5). Table 5 shows the sedimentation countermeasures and key issues in long-term management for the Kizu River dam group. Dry excavation is performed by shutting down the dam for one year at an interval of a specified number of years, completely emptying the reservoir and removing sediment by dry excavation. Therefore, to perform dry excavation, it is necessary to carry out a comparative study with other methods to determine whether or not it is an effective method considering the loss of reservoir functions caused by draw down and relationship and merits and demerits of removing sediment by low cost dry excavation. The cost of dry excavation includes, in addition to compensation for reduced power generation and excavation unit price, the loss caused by draw down which is calculated treating the loss of the

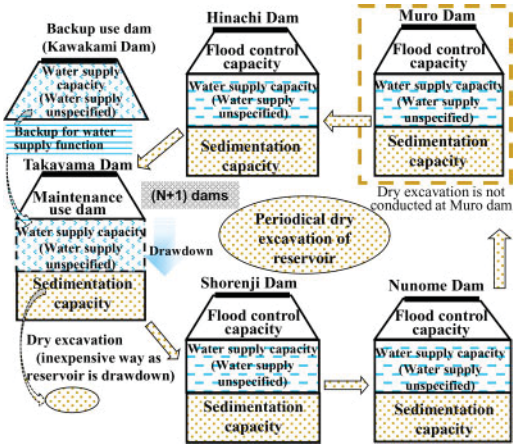

Figure 9. Schematic Diagram of integrated operation of upstream Kizu River group of dams by an N+1th Dam.

capacity itself is as the loss-cost. So the loss of reservoir functions by dry excavation is reflected in the cost as shown below.

If excavation is done during a non-flood period, only the water use capacity is used. Therefore, the loss-cost for the lost reservoir capacity is calculated by allocating the cost of water supply capacity to the operator of a multi-purpose dam (allocation cost).

However, the following study uses the relationship of the cost allocation with the water use capacity at the Hinachi Dam that is the newest of the Kizu River upstream dam group.

- Assuming that the water use function can be provided for 100 years, the cost per unit capacity (1 m^3) per year is calculated as:
  (Cost of water use capacity)/ (water use capacity) / (100 years).
- Based on the above, it is possible to calculate the loss-cost for the case of a dam shut down for one year.
- If the cycle of emptying the reservoir is long, it is highly likely that sudden sedimentation will occur often, so considering the fact that there is a 1/10 year to 1/50 year probability of the occurrence of the maximum annual sedimentation that has occurred in the past in the Kizu River dam group, this study assumes that empty the reservoir every 10 years. Table 8 shows the cost-loss of dry excavation with the reservoir emptying as calculated based on conditions at the Hinachi Dam.

3.3 *Optimization of sediment removal methods*

As stated in Table 3, the actual maximum annual sedimentation (maximum value of inflowing sediment load occurring unexpectedly) is approximately 5% to 12% of the planned sedimentation capacity. So to ensure stable reservoir functions in the event of an unexpected inflow of sediment, when a dam is operated independently, backup by other dams cannot be counted on, so the sedimentation capacity should be maintained to constantly ensure leeway from about 5% to 12%. So the target sedimentation rate for case studies of each dam when operated independently was set at 80%. (Assuming that sedimentation load in the reservoir is controlled within 80% of the planned sedimentation capacity).The study should focus on the following points in order to achieve more efficient sediment removal.

a) As a result of the case study of long-term maintenance of the Kizu River upstream dams, it has been shown that more economical results at all the dams are obtained by carrying out the dry excavation with the reservoir emptying (predicting compensation for reduced power production and compensation for water use loss) than by countermeasure methods requiring initial facility investment (for example, sediment bypass, flushing sediment etc.).
b) The above results suggest the possibility of "optimization of sediment removal methods as a dam group (cheaply removing sediment by linking a dam group)".

Based on the above results, considering the fact that it is difficult to pay compensation for water use loss which dry excavation actually causes, and that dry excavation is performed very cheaply, in the future, long-term maintenance based on integrated operation (backing up water supply capacity, ensuring potential water resources, etc.) must be studied in order to "optimize sediment countermeasures as a dam group." Fig. 7 shows an image of coordinated dam group operation by N+1 dams.

√ Dry excavation with the reservoir emptying (inexpensive because it is land excavation) is performed at all dams in rotation, and a dam is positioned as a "refresh dam" while the draw down.
√ The N+1th dam installed to backup reservoir functions provides supplementary backup for the decline in reservoir functions while the draw down.

(● means that maintenance is performed by (N+1) dams: the minimum number of dams considered essential (N) plus a maintenance use dam.)

4 CONCLUSIONS

This study has outlined the necessity of upgrading and retrofitting the aged dams, asset management, and approach to design effective sediment management startgies required to construct future dams, maintain reservoir functions of existing dams, and contribute to total basin scale development. Tens if thousands of fams are multifunction with tens of thousands of sediment deposition volumes in deep, middle, and upstream tailwater parts of the reservoir. There are various sediment management methods siutable for each part of the reservoir as excavating, dredging, bypassing, flushing, and sluicing (Figure 9). These methods

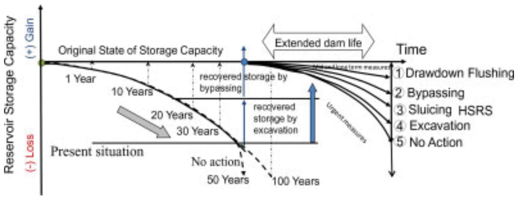

Figure 10. Scenarios for sediment management options to recover dam functions and extend dam life.

often compete, and one of the most common trade-offs involves choosing between no action or recovering dam function, and extending dam life. Sediment management needs investment with different costs based on evaluating the economical values of the selected method. The costs and benefits of asset management in coordination with changes in dam and downstream are important to understand the importance of the sediment management.

A new concept and methodology should be conceived to design an intergenerational, sustainable, self-supporting rehabilitation system for river basins with manmade reservoirs. An efficient asset management and a variety of sediment management methods in Kizu River upstream dams performed. Based on the results, precautions to be followed to perform asset management of dam reservoirs by sediment techniques were organized. And the results of the research have shown that at the Kizu River upstream dam group, it will be essential to study long-term maintenance in order to optimize sedimentation countermeasures as a dam group: sedimentation countermeasures by integrating the operation of a dam group, and the application of permanent sedimentation measures at the Takayama Dam. Measuring the benefits and costs of an improvement in water quality is often difficult. First, for a complete analysis, all relevant benefits and costs have to be measured.

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