STUDY ON THE APPLICABILITY OF THE ASSET MANAGEMENT FOR RESERVOIR SEDIMENT MANAGEMENT

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1. INTRODUCTION

In Japan, asset management is now being introduced in the road field and many other areas of public infrastructure, in preparation for a predicted rapid increase in the cost of maintaining all public infrastructures. However, in the dam field, studies of mechanized systems with short service lives have been carried out, but the applicability and effectiveness of asset management in this field have not been clarified.

So in order that dams function for more than a century and that the burden of their maintenance is not concentrated on the next generation, we must clarify challenges to the application of asset management to dams, which are structures made up of a variety of elements with differing service lifetimes, function, etc., to lower their life cycle costs (LCC) and to smooth their maintenance costs.

Present annual dam maintenance costs are an average of a little more than

300 million yen for the dams which were surveyed, and the largest maintenance category as a percentage of total maintenance cost is "operating and control equipment related" at 20%. But in recent years, the problem of sedimentation in reservoirs has appeared and a variety of sedimentation countermeasures have been taken, mainly in river systems where large sediment loads flow into dam reservoirs located in Chubu and other regions. But sedimentation is also progressing at dams in river systems where the sediment production is not particularly high, so that at many dams constructed during the period of high speed growth following World War II, it is estimated that sedimentation will reach the planned level between 40 and 50 years from the present day [1], so that in the future, strategic dam asset management including preventive maintenance type sedimentation countermeasures will be an important challenge.

Five dams including The Takayama Dam which was completed in 1969 are now being maintained as a group of water resource development dams located on the upstream Kizu river. This research was conducted focusing on these upstream Kizu River dams to study ways to prolong the service lifetimes of dams through sedimentation countermeasures and to clarify precautions followed to perform asset management of a dam reservoir by taking sedimentation countermeasures.

2. ORGANIZATION OF THE STATE OF SEDIMENT DEPOSITION IN THE KIZU RIVER UPSTREAM DAM GROUP

The Japan Water Agency maintains a group of water resource development dams consisting of five dams including the Takayama Dam which was completed in 1969 on the upstream part of the Kizu River (Fig. 1).

Table 1 shows the state of sedimentation in the Kizu River upstream dam group (FY2006). It shows that at all five dams, sedimentation has progressed faster than hypothesized in the original plan. And 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.

Focusing on annual fluctuation of sediment load shows that at the Takayama Dam, annual average sedimentation is approximately 100,000m^3, but the maximum sedimentation in a single year is 620,000m^3. The maximum annual sedimentation at the other dams is about 10% to 15% of sedimentation capacity, and the past maximum sedimentation in a single year was equivalent to that occurring in a 10 to 15 year period (Table 2) [2].

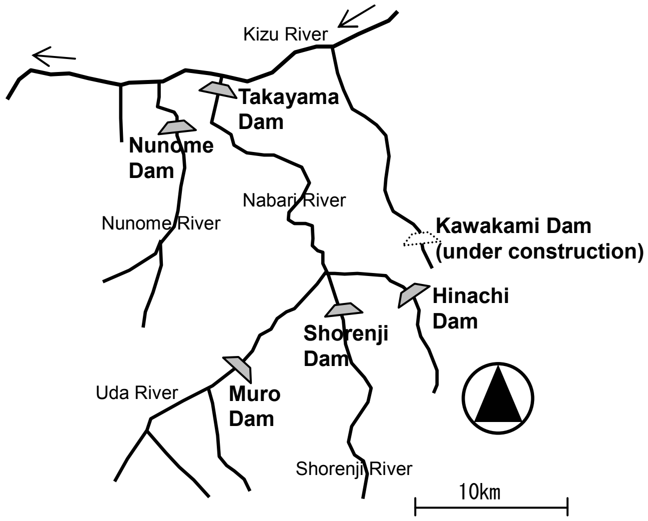

Fig.1 Kizu River Upstream Dam Group on the Yodo River System

Table 1 Rate of Sedimentation of the Kizu River Upstream Dam Group (2006)

	Years elapsed	Planned sedimentation capacity (1,000m^3)	Measured sedimentation in 2006 (1,000m^3)	Sedimentation rate
Takayama Dam	37	7,600	3,648	48.1%
Shorenji Dam	36	3,400	1,484	43.6%
Muro Dam	32	2,600	1,120	43.1%
Nunome Dam	16	1,900	243 (344)	12.8% (18.1%)
Hinachi Dam	9	2,400	410	17.1%

※ Sedimentation rate in the above table is a value based on the planned sedimentation.

※ The values in brackets for the Nunome Dam represent sediment already dredged from its auxiliary dam.

Table 2 Estimated Annual Maximum Sedimentation in the Upstream Kizu River Dam Group

	Planned sedimentation capacity (million m^3)	Actual maximum annual sedimentation		
		Sedimentation (thousand m^3)	Percentage of planned sedimentation 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

3. ASSET MANAGEMENT OF DAMS THROUGH SEDIMENTATION COUNTERMEASURES

3.1 STATE OF ASSET MANAGEMENT OF DAMS THROUGH SEDIMENTATION MEASURES [3]

Efforts have been made to introduce asset management in many fields including paving, bridges, ports and harbors, water supply and sewage systems, and so on, in the face of the soaring cost of maintaining the expanding stock of public infrastructures and resulting financial dilemmas. The purpose of asset management is to introduce private sector methods to reduce life cycle costs and smooth the burden of paying these costs in order to improve efficiency, and at the same time to clarify and to fulfill the responsibility to explain the relationship between covering maintenance cost and the level of services.

Efforts have been made to apply asset management to machinery and equipment with short service lifetimes used at dams, to diagnose the deterioration of hydropower dams [4] and to survey the state of dam maintenance costs [5]. But an overall image of asset management including dam bodies has not been clarified. This is presumably a result of the fact that a dam body has such a long service lifetime it is difficult to specify it, and that at a relatively new dam, the need to discuss the optimum repair plan is generally low.

Overseas, State Water which is an enterprise owned by the State of New South Wales in Australia has prepared the Total Asset Management Plan, and evaluates dam risk and presents examples of the grounds for the price of water [6]. It also touches on the difficulty of applying the optimum renewal decision method to major facilities with lifetimes that exceed 200 years and for which there is no standard deterioration curve. And the U.S. Bureau of Reclamation uses facility reliability indices based on restrictions on reservoirs and their operation and on response to safety advisories to perform asset management of important dams.

3.2 APPLICATION OF ASSET MANAGEMENT TO DAMS

Infrastructure assets (infrastructure assets for daily human life) are generally predicted to be used semi-permanently and characterized by long service lifetimes. In the case of a dam, the dam body that is the major asset is also assumed to have an extremely long service lifetime, but it is important to evaluate its reliability, because deterioration of the body could have serious consequences.

A breakdown of normal maintenance costs based on research by Kondo et al. [5], shows that a little more than 20% are “operating and control equipment related” costs, and between 10% and 15% are “discharge and intake equipment related”, “repairs and other maintenance and management equipment related”, and “reservoir countermeasure related” costs respectively. Cost reductions achieved through asset management are expected to occur, mainly in the cost of maintaining of machinery and equipment, and electrical equipment etc. that have relatively short service lives.

Sedimentation is handled by setting 100 year capacity as the planned sedimentation capacity. But, it is possible to prolong service lifetimes by taking appropriate sedimentation countermeasures, and sedimentation countermeasures play an important role in the study of the life cycle costs of dams.

Because, as explained above, the length of service life and priority of management activity vary between facilities, it is necessary to apply asset management according to these differences (Table 3).

The level of services provided to manage assets usually varies according to needs. In particular, when its object is an extremely long period, it is difficult to determine needs, but at the decision making level, it is classified as shown in Table 4.

Consequently, in this study, the level of asset management services provided by the Japan Water Agency that is the implementing body is set to ensure the service level stipulated by plans etc.

Table 3 Categorization of Facilities and Management Priorities by Renewal Period

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

Table 4 Categorization Based on Decision-making Level

	Decision-making level	Implementing organization level
Body	- Policy-making departments of governmental and public bodies.	- Implementation departments of governmental and public bodies (Japan Water Agency)
Service level	- Judgments accompanying change of service level - Decisions to construct, improve functions, or to demolish	- Ensuring a service level stipulated by policies - Construction and maintenance of structures stipulated by the plan
Means to satisfy responsibility for explanation	- River improvement plans, basic water resource development plans, policy evaluations.	- Annual reports, evaluation committee, project evaluation, implementation plan, maintenance plan, explanations for users etc.
Principal evaluation indices	- Effectiveness of policies	- Efficiency of ensuring service level

3.3 ASSET MANAGEMENT OF DAMS BY SEDIMENTATION COUNTERMEASURES

Dam sedimentation is clarified by periodical measurements. And generally, in cases where increasing sedimentation has obstructed the functions of a dam, sedimentation countermeasures are taken. So large scale sedimentation countermeasures now taken often include disaster restoration following the inflow of sediment or redevelopment to ensure reservoir capacity, and at dams where no particular obstruction of reservoir functions has occurred, only measurements are performed.

When a large-scale sedimentation countermeasure is taken, obtaining a much yard is generally a challenge, and it is necessary to lower costs by using the soil effectively and by taking advantage of the tractive force of the river. And 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.

3.4 COST OF IMPLEMENTING COUNTERMEASURES

At the Makino Dam which received the inflow of vast quantities of sediment as a result of the Nagano Prefecture West Earthquake (1984), for a total of 9 years, sedimentation countermeasures were taken to remove approximately 5.48 million m^3 of sediment at a total cost of about 30 billion yen [7].

a) If it is assumed that the project cost per cubic meter is identical to that at the Makino Dam, it would cost from 10 to 40 billion yen per dam to remove sediment equal to the sedimentation capacity of the entire Kizu River dam group (1.9 to 7.6 million m^3/dam).
b) In a case where it is impossible to obtain a muck yard near a dam, at a dam near a city for example, if it is assumed that, at the most, costs are incurred transporting sediment to the sea, the sediment treatment cost per unit of volume for the transportation distance L (km) is represented by Eq[1] according to Oya et al. [8].

$$C = p \cdot L + q \qquad [1]$$

Where, C : sediment disposal cost, And based on research by Oya et al, p = 75 yen/m^3/km, and q = 3,000 yen/m^3. From the upstream dams on the Kizu River to Osaka Bay, L = approx. 100km, so the cost of disposing of sediment equal to the sedimentation capacity of each dam increased from about 20 to 140 billion yen.

This means that according to the simple average for 100 years, at each dam, the cost is 100 million yen to 400 million yen/year in case a) and it is from 200 million yen to 1.4 billion yen/year in case b).

Considering that this will accumulate every year as countermeasures are needed for the next fifty years, the amount needed each year can be represented by Eq[2].

$$C_r = \frac{C_t \cdot r}{(1+r)^n - 1} \qquad [2]$$

Where, C_r : annual required amount, C_t : countermeasure project cost, Interest rate r = 0.04, Accumulation period n = 50 years.

In case a), it is from 70 million to 260 million yen/year, and in case b) it is from 130 million to 920 million yen/year.

Turning to the maintenance cost of the existing dams, according to research by Kondo et al. [9], the annual maintenance cost is an average of a little more than 300 million yen for the dams that were surveyed, and "operating and control equipment related" costs that account for more than 20% of total costs, is the highest cost category. Therefore, if it is premised that the dams will function for more than 100 years, the sedimentation countermeasure cost may exceed this cost category.

Judging from the above, it is important to apply asset management not only to the electrical equipment related and to the machinery and equipment related categories that are now the major maintenance cost categories, but also to sedimentation countermeasures.

3.5 SEDIMENTATION COUNTERMEASURE IMPLEMENTATION SCENARIOS

If these measures are simplified premised on causing a dam to function for a long period exceeding a century, the scenarios considered are taking measures to smooth the inflowing sediment load after the service level has been reduced in the absence of countermeasures (Scenario 1), ensuring the initially planned 100 year sedimentation capacity by taking large scale restoration measures after the service level has been reduced in the absence of countermeasures (Scenario 2), and reducing the frequency of large scale restoration measures (Scenario 3) by taking sedimentation control measures (Fig.2).

With sustained measures, restoring sediment downstream using the tractive force of the river can mitigate the blockage of sediment movement by the dam, and simplify the task of utilizing the sediment as a resource. On the other hand, in order to implement large-scale restoration, a large muck yard and transportation system are necessary; a problem that has an impact on the environment whose cost cannot be evaluated. (Table 5)

Table 5 Comparison of Continuous Measures and Large-scale Restoration

	Continuous measures	Large-scale restoration
Transportation, muck yard	Can use tractive force of the river	Requires a large muck yard and transport system
Environmental impact	Can reduce blockage of sediment movement by restoring sediment downstream.	Environment impact caused by muck yard and transport road
Effective utilization	Simplifies effective utilization of sediment as a resource	Difficult to effectively use the sediment as a resource

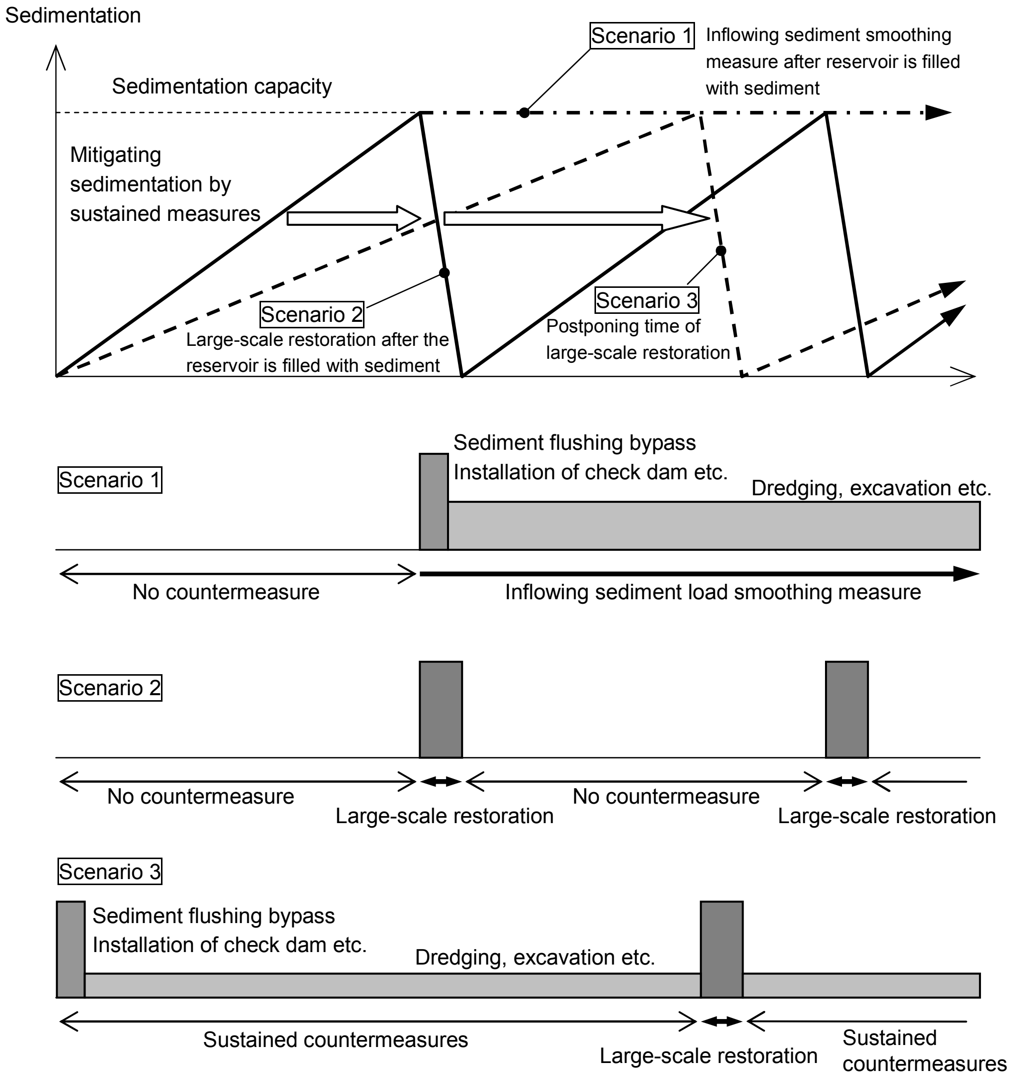

Fig.2 Image of Sedimentation Countermeasure Scenarios and their Costs

At dams where the inflowing sediment load is light, at dams where the river flow rate is high so that hydraulic flushing removes large quantities of sediment load, and at other dams where smoothing measures (inflowing sediment load = discharged sediment load) can be taken easily, Scenario 1 is effective, and at dams where it is easy to obtain a sediment processing site and to transport sediment, Scenario 2 is effective. But at dams where, in addition to the reduction in tractive force caused by the construction of the dam, the region around the dam is urbanized so that it is difficult to dispose of or to transport the sediment, as it is on the Yodo River System, it is necessary to study combining measures and the time to implement them based on Scenario 3: performing sedimentation control measures to postpone large-scale restoration as long as possible and to minimize its frequency.

And Scenario 3 becomes Scenario 1 and 2 depending on whether or not an initial investment is made and when it is made, on whether or not continuous measures are taken, and according to the time implementation begins. Therefore, there is also a generalized investment Scenario for cases premised on permanent reservoir maintenance.

Normally, to consider life cycle cost, the study includes the cost of waste disposal, but when investment is made looking ahead 200 years into the future, the present price based on the normal discount rate of 4% becomes zero and cannot be evaluated.

Therefore, premised on a dam’s functions being maintained for a long period, the life cycle cost can be represented by Eq[3].

$$LCC = \sum C_i + \sum C_m + \sum C_r \qquad [3]$$

Where, LCC : life cycle cost of sedimentation countermeasure, C_i : initial investment, C_m : sustained countermeasure cost, C_r : cost of large-scale measure converted to present prices.

This means, that although sedimentation countermeasures differ from reconstructing a facility as in the case of roads, bridges, etc. (demolishing and reconstructing an old facility), it is possible to represent in a form such that large scale restoration resembles the renewal of another facility.

4. APPLICATION OF SEDIMENTATION COUNTERMEASURES TO THE KIZU RIVER UPSTREAM DAM GROUP

4.1 ORGANIZATION OF STUDY CONDITIONS

(1) ORGANIZATION OF SEDIMENTATION COUNTERMEASURES

Table 6 shows the sedimentation countermeasures that were studied. And the same table shows key points in long-term management.

(2) CLARIFYING THE PROPERTIES OF SEDIMENTATION IN EACH DAM RESERVOIR

Because the sediment particle diameter that can be flushed varies for each sedimentation countermeasure, the particular diameter of the inflowing sediment load is an important factor in the study of the applicability of a sedimentation countermeasure. So the particle diameter of inflowing sediment load is classified in three categories: washload (d≦0.075mm), sand (0.075<d<2.0mm), and gravel (2.0mm≦d). Table 7 shows the results of the clarification of the properties (quantity and quality) of inflowing sediment load and deposited sediment load in the Kizu River upstream dam group.

(3) SETTING THE TARGET SEDIMENTATION RATE

As stated above, the actual maximum annual sedimentation (maximum value of inflowing sediment load occurring unexpectedly) is approximately 10% to 15% 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 10% to 15%. 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).

Table 6 Sedimentation Countermeasures Studied

Countermeasure	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
Flushing	Temporarily draw down 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	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 the 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

Table 7 Properties of the Inflowing and Deposited Sediment at the Kizu River Upstream Dam Group

	Annual average inflowing sediment load (m^3)	Annual inflowing sediment load by particle diameter (m^3)			Washload capture rate	Annual average sedimentation (m^3)	Annual sedimentation by particle diameter (m^3)		
		Washload ≦0.075mm	Sand 0.075< <2.0mm	Gravel 2.0mm≦			Washload ≦0.075mm	Sand 0.075< <2.0mm	Gravel 2.0mm≦
Takayama Dam	104,550	46,770	53,380	4,400	44.3%	78,500	20,720	53,380	4,400
		44.7 %	51.1 %	4.2 %			26.4 %	68.0 %	5.6 %
Shorenji Dam	41,740	29,080	11,390	1,270	57.9%	29,500	16,840	11,390	1,270
		69.7 %	27.3 %	3.0 %			57.1 %	38.6 %	4.3 %
Muro Dam	45,510	31,070	14,250	190	73.9%	37,400	22,960	14,250	190
		68.3 %	31.3 %	0.4 %			61.4 %	38.1 %	0.5 %
Nunome Dam	23,550	15,400	7,980	170	82.8%	20,900	12,750	7,980	170
		65.4 %	33.9 %	0.7 %			61.0 %	38.2 %	0.8 %
Hinachi Dam	56,810	36,760	19,860	190	71.4%	46,300	26,250	19,860	190
		64.7 %	35.0 %	0.3 %			56.7 %	42.9 %	0.4 %

4.2 CASE STUDY OF TAKAYAMA DAM

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.

(1) EFFECTS AND COSTS OF COUNTERMEASURES

a) Cost of dry excavation with the reservoir emptying

So in addition to normal sedimentation countermeasure methods, a comparative study of "dry excavation" is also performed (see Table 6). 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 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 (1m^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. Table 9 organizes costs necessary to perform water level reduction excavation at the Takayama Dam based on the above.

Table 8 Loss of Capacity by the Draw Down (Calculated based on the Hinachi Dam)

Water supply capacity	Allocation of cost of water for public water supply systems	Annual required cost for 100 years of water supply services	Capacity unit price
15.3 million m^3	¥34,843,490,000	¥348,435,000	23 yen/m^3/year

Table 9 Cost Required to the draw down at the Takayama Dam (once/10 years)

Compensation for reduction of power generation	Cost-loss of capacity loss
43.7 million yen/year (unit price: 8.76 million yen/hr)	31.740 million yen (Actual loss 317.4 million yen/time)

b) Effects and cost of the sedimentation countermeasures

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)”. The effects and costs of each sedimentation countermeasure are presented on Table 10.

Table 10 Effects and Cost of Implementing the Sedimentation Countermeasure Menu

	Cost		Inflowing load removal rate(%)			Annual sediment removed (m^3/year)		
	Investment to build the facility (initial cost)	Running cost	Wash load	Sand	Gravel	Washload (*including natural removal) Inflowing sediment 46,770	Sand Inflowing sediment 53,380	Gravel Inflowing sediment 4,400
Excavation	–	4,000 yen/m^3	10%	50%	100%	28,123	26,690	4,400
Dredging	–	35,000 yen/m^3	100%	100%	100%	46,770	53,380	4,400
Sediment check dam (+ excavation)	5.4 billion yen/dam (sediment check dam)	4,000 yen/m^3	10%	70%	100%	28,123	37,366	4,400
Flushing	10,1 billion yen/channel (sediment flushing gate installation)	22 million yen/year	100%	100%	50%	46,770	53,380	2,200
Sediment bypass	13.163 million/channel (constructing sediment bypass)	121 million yen/year	50%	60%	100%	36,410	32,028	4,400
Dry excavation with the reservoir emptying	–	2,500 yen//m^3 (excavation cost) 75 million yen/year (compensation for reduction of power generation, water supply loss)	100%	100%	100%	46,770	53,380	4,400

(2) STUDY OF COMBINED COUNTERMEASURES

The previous section of this report presented the sediment removal rate of each type of countermeasure.

Because aside from dredging and dry excavation, these countermeasures do not achieve removal rates of 100%, sedimentation caused by sediment that cannot be completely removed even when measures are taken continues until eventually the sedimentation capacity is exhausted. So considering the need to continuously ensure reservoir functions, it has been hypothesized that even after these countermeasures have been taken, dredging or dry excavation are also performed at the point where the target sedimentation rate has been reached. Table 11 shows the effectiveness and the cost of implementing combinations of countermeasures.

※ It is assumed that when actually removing sediment, limits on temporary storage sites for the sediment which has been removed and limits on the ability to remove it with trucks impose an upper limit on the quantity removed. However, this section focuses on selecting highly applicable methods, but does not set upper limit values on the quantity of sediment removed (quantity of inflowing sediment load is assumed to be that which can be completely removed □ that controlled by smoothing countermeasures). The upper limit of the removable sediment is studied in detail in the next section.

Table 11 Results of Studies of Combination Countermeasures

	Quantity removed (m^3/year)	Quantity which cannot be completely removed (m^3/year)	[Proposed combination] Annual cost (1,000 yen)	
			Dredging	Dry excavation
Sediment check dam (＋excavation)	69,889	34,661	1,213,135	214,084
Excavation	59,213	45,337	1,586,795	256,788
Sediment bypass	72,838	31,712	1,109,920	202,288
Flushing	102,350	2,200	77,000	84,240

This shows that countermeasures other than flushing are effective when combined with dry excavation. But it is more effective to combine sediment flushing with dredging. It also shows that there is little residual sediment after flushing, so dry excavation is relatively costly (because of the small quantity handled).

(3) EVALUATING THE PROPOSED SEDIMENTATION COUNTERMEASURES AT THE TAKAYAMA DAM

The super long-term sediment control plan for the Takayama Dam was studied by evaluating the combinations suggested above. The results are shown in Fig.3, Fig.4, and Table 12. Investment in the future exceeding 200 years is difficult to evaluate as it reaches almost zero in today's prices, so the evaluated cost is the total cost converted to current prices 300 years in the future. Based on this, the proposed countermeasure based on [excavation + dry excavation] is the most economical. Sediment bypass and flushing countermeasures provide high sediment removal rates, but their initial investment means they are uneconomical in terms of their total cost.

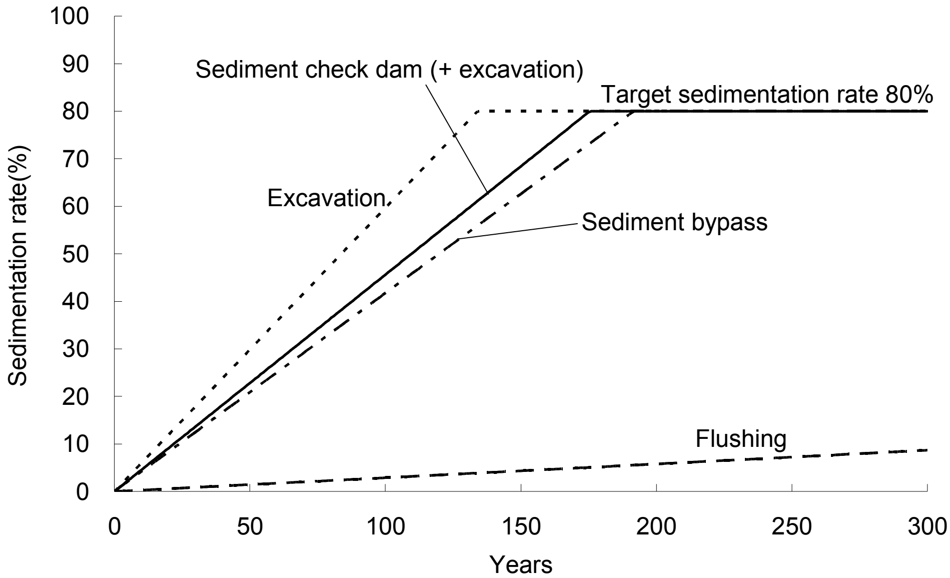

Fig.4 Takayama Dam: Change Over Time of Sedimentation Rate by Each Sedimentation Countermeasure

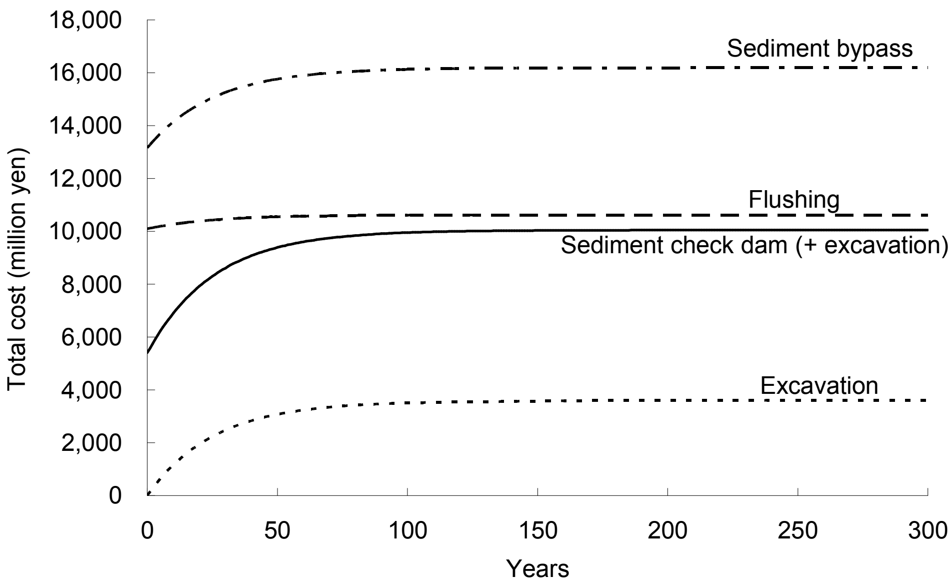

Fig.5 Takayama Dam: Change Over Years of Total Cost by Each Sedimentation Countermeasure

Table 12 Total Cost of Each Countermeasure After 300 Years

Countermeasure	Combined with	Total cost after 300 years (million yen)
Sediment check dam (+ excavation)	+ Dry excavation	10,050
Excavation	+ Dry excavation	3,609
Sediment bypass	+ Dry excavation	16,191
Flushing	+ dredging	10,625

4.3 STUDY OF APPLICABILITY OF SEDIMENTATION COUNTERMEASURES

(1) STUDY METHOD

So the results of the study of Takayama Dam described above were used to study the applicability of the same proposed sedimentation countermeasures to four other dams (Hinachi Dam, Shorenji Dam, Muro Dam, and Nunome Dam). Table 13 was based on the Takayama Dam. It organizes basic methods of calculating the cost of sedimentation countermeasures at each dam.

Table 13 Basic Methods of Calculating Sedimentation Countermeasure Cost at Each Dam

Sediment check dam (+ excavation)	- The land acquisition cost (impact on back water of sediment check dam) is calculated using specific dam body area of the sediment check dam based on the specifications of the Takayama Dam.
Sediment bypass	- Tunnel cost computed by same unit price as Takayama Dam - The body volume of the diversion dam is calculated based on the specific sedimentation capacity of each dam based on the specifications of the Takayama Dam - The cost of the intake gate is the same as at the Takayama Dam. - Land acquisition cost is the same as that at the Takayama Dam - Tunnel diameter is the same as in the specifications of the Takayama Dam
Flushing	- The sediment spillway used for flushing is a 1,000m tunnel assuming it is bored in natural rock at all dams. - Costs of training dam, intake gate, etc. are same as those at the Takayama Dam. - Tunnel diameter and compensation for reduced power generation are identical to those at the Takayama Dam (Nunome Dam and Muro Dam do not generate power, so compensation for reduced power generation are not counted for these dams.)

(2) EVALUATING THE PROPOSED SEDIMENTATION COUNTERMEASURES AT EACH DAM

Super long-term sediment control plans for four dams in addition to the Takayama Dam (Hinachi Dam, Shorenji Dam, Muro Dam, Nunome Dam) were studied. The study results are shown in Table 14. The table shows that at all the dams, as in the case of the Takayama Dam, the countermeasure,“excavation + dry excavation” is economically beneficial. This clearly shows that the applicability to the Kizu River dam group of proposed countermeasures (for example, sediment bypass or flushing) which are implemented by making a facility investment at the initial stage and are intended to lower the inflowing sediment is low because the overall inflowing sediment load is small in this group.

The results of a study for a case where the inflowing sediment load at each dam is 4 times its present level (see Table 2) are shown in Table 15. (For example, trial calculation for a case where, at the Takayama Dam, the specific sedimentation is 1,056m^3/km^2/year (264m^3/km^2/year × 4 times)) According to this, beginning with the Takayama Dam, the applicability of flushing and sediment bypass will be improved overall. This result conforms to the fact that in Japan, many cases of flushing and sediment bypass measures have been taken on the Tenryu River System [9] [10], and these long-lasting sediment countermeasure facilities are presumably effective over the long term.

Table 14 Kizu River Upstream Dam Group: Total Cost After 300 Years of Each Countermeasure (unit: million yen)

Countermeasure	Combined with	Takayama Dam	Shorenji Dam	Muro Dam	Nunome Dam	Hinachi Dam
Sediment check dam (+excavation)	Dry excavation	10,050	4,526	3,729	2,453	3,506
Excavation	Dry excavation	3,609	987	1,043	570	1,384
Sediment bypass	Dry excavation	16,191	24,111	29,769	20,226	18,765
Flushing	Dredging	10,625	10,625	10,575	10,575	10,625

Table 15 Kizu River Dam Group: Total Cost of Each Countermeasure After 300 Years [Assuming the inflowing sediment load is 4 times current level]

Countermeasure	Combined with	Takayama Dam	Shorenji Dam	Muro Dam	Nunome Dam	Hinachi Dam
Sediment check dam (+excavation)	Dry excavation	26,781	8,545	8,795	4,741	10,620
Excavation	Dry excavation	19,583	4,533	5,672	2,446	8,038
Sediment bypass	Dry excavation	18,405	24,180	30,036	20,237	19,354
Flushing	Dredging	10,625	10,625	10,575	10,575	10,625

4.3 PRECAUTIONS WHEN STUDYING ASSET MANAGEMENT OF THE KIZU RIVER UPSTREAM DAM GROUP

Based on the results of the above study, precautions to be followed when implementing asset management at the Kizu River upstream dam group in the future have been organized.

(1) RESTORING EXCAVATED SEDIMENT TO THE DOWNSTREAM RIVER

Sediment that has been excavated and removed from the inside of the dam reservoirs should be placed downstream from each dam and allowed to return to the downstream river course, in order to take sustainable countermeasures and to ensure the continuity of sediment movement. The quantity of sediment disposed of in this way is restricted by conditions ① to ③ shown in Fig.6.

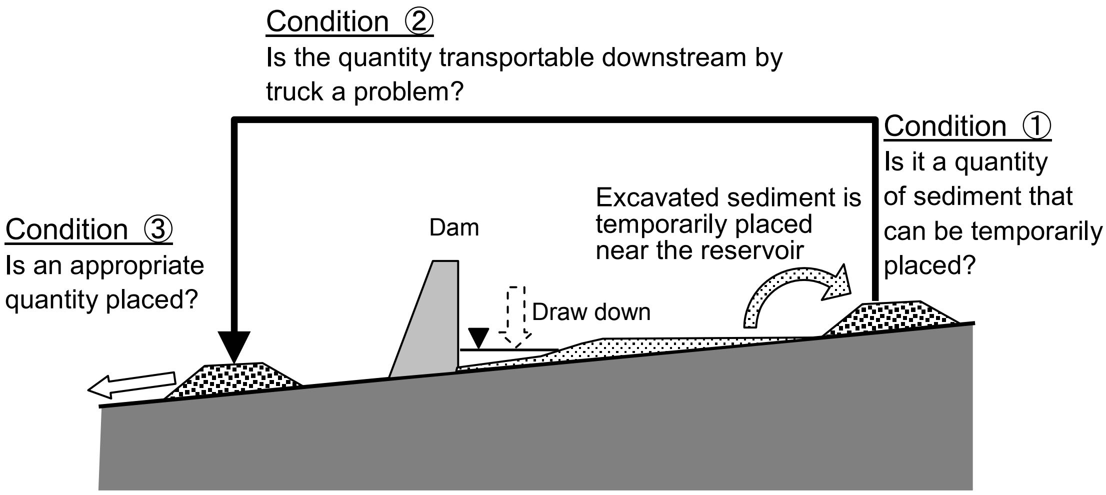

Fig.6 Method of Disposing of Sediment to Restore it to the Downstream River

(2) STUDY OF OPTIMIZATION OF SEDIMENT REMOVAL METHODS

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.)

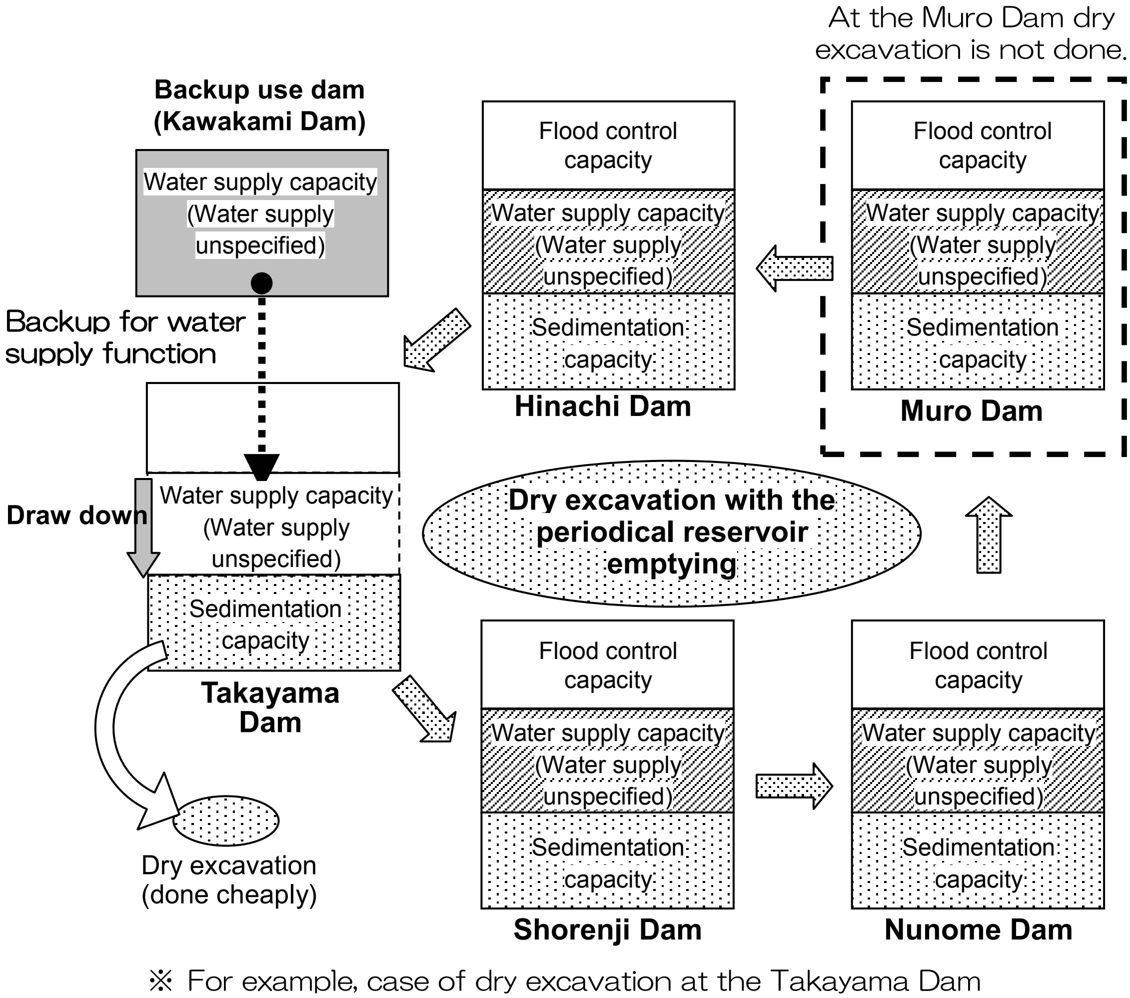

Fig.7 Schematic Diagram of Integrated Operation of Dams by an N+1th Dam

5. CONCLUSION

This research was a concrete study of the applicability of inflowing sediment properties and a variety of sedimentation countermeasure methods on the Kizu River upstream dams performed with [long-term reservoir maintenance] as the key. Based on the results, precautions to be followed to perform asset management of dam reservoirs by sedimentation countermeasures 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.

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SUMMARY

In Japan, asset management is now being introduced in the road field and many other areas of public infrastructure, in preparation for a predicted rapid increase in the cost of maintaining all public infrastructures. However, in the dam field, studies of mechanized systems with short service lives have been carried

out, but the applicability and effectiveness of asset management in this field have not been clarified.

So in order that dams function for more than a century and that the burden of their maintenance is not concentrated on the next generation, we must clarify challenges to the application of asset management to dams, which are structures made up of a variety of elements with differing service lifetimes, function, etc., to lower their life cycle costs (LCC) and to smooth their maintenance costs.

Present annual dam maintenance costs are an average of a little more than 300 million yen for the dams which were surveyed, and the largest maintenance category as a percentage of total maintenance cost is “operating and control equipment related” at 20%. But in recent years, the problem of sedimentation in reservoirs has appeared and a variety of sedimentation countermeasures have been taken, mainly in river systems where large sediment loads flow into dam reservoirs located in Chubu and other regions. But sedimentation is also progressing at dams in river systems where the sediment production is not particularly high, so that at many dams constructed during the period of high speed growth following World War II, it is estimated that sedimentation will reach the planned level between 40 and 50 years from the present day, so that in the future, strategic dam asset management including preventive maintenance type sedimentation countermeasures will be an important challenge.

Five dams including The Takayama Dam which was completed in 1969 are now being maintained as a group of water resource development dams located on the upstream Kizu river. In this study, we studied characteristic of inflow sediment of dam group and feasibility of various sedimentation management measures. By a case study of Takayama Dam, we evaluated the cost and the effect of sedimentation management quantitatively. As the result, we showed the advantage of dry excavation with periodical reservoir emptying and suggested the necessity for further study on the integrated sediment management such as dry excavation by turns in a group of dams.