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Evaluation of River Management by Sediment Bypassing and Management - Optimization and Cost Benefit Analysis of Comprehensive Sediment Management -

Kunihiro Tomita
ME, MBA, Civil Engineering and Eco-Technology Consultants Co., Ltd., Japan
tomita@kensetsukankyo.co.jp

Tetsuya Sumi
D.Eng., Professor, Water Resources Research Center, Disaster Prevention Research Institute, of Kyoto University, Japan

Mamoru Watanabe
Former manager of Yahagi Dam Management Office, Ministry of Land, Infrastructure, Transport and Tourism(MLIT), Japan

ABSTRACT:
Sedimentation is an essential issue on long-term management of dam reservoirs. Cost and benefit of the comprehensive sediment manage project is now a challenging issue by taking account not only keeping the reservoir capacity but also other important issues such as the improvement of downstream environment by necessary sediment supply, the effect of recycling of sediment, additional costs for downstream facilities, CO_2 emission by excavating and transporting of sediment. In this study, we studied how to integrate these costs and benefits for the economic evaluation of comprehensive sediment management projects. The benefits of improving river and coastal environment were estimated by the results of CVM (Contingent Valuation Method) and Conjoint Analysis on Yahagi River. We have also proposed that preparing a stock yard in the middle river reach is a key factor to manage various objectives.

Keywords: Reservoir sedimentation, Comprehensive sediment management, Cost benefit analysis, CVM, Conjoint Analysis

1. INTRODUCTION

In the Yahagi Dam, as part of the comprehensive sediment management for sediment transport, a sediment removal project using sediment bypass (BP) is proceeding. In a project to remove sediment from a dam reservoir, it should be evaluate both the advantages and disadvantages for the maintenance of reservoir capacity and the effect on environmental performance in downstream river channel. Advantages expected from sediment replenishment include both environmental improvement in downstream and promotion of sediment resource recycling, while issues estimated as disadvantages include an impact of sediment discharge on both flood control functions and water utilization ones in downstream river, and increase maintenance costs for dams or weirs resulting the accumulation of sediment. In this study, we adopted the Contingent Valuation Method (CVM) and Conjoint Analysis (CA) covering the areas immediately downstream of the Dam, and seashore area, and evaluated the effect of sediment bypassing on the environmental improvement. Finally, we conducted cost- benefit analysis on the comprehensive sediment management of the Yahagi River sediment transport system. Based on the results of such revaluation, we studied the effect of the sediment BP project and its effectiveness and validity in terms of cost and benefit.

Moreover, since it is also considered important for the Yahagi River to promote sediment recycling, we conducted a social experiment on the utilization of sediment resource, which studied the status of utilization of sediment bypassed from Yahagi Dam by providing a stockyard in the Koshido Dam area along the downstream of Yahagi Dam and obtaining the participation of a private-sector business in the experiment. Based on the results of the questionnaire survey on the sediment users, we analyzed the feasibility and validity of sediment recycling and examined practical issues. Furthermore, based on the results of such analysis and examination, we considered the development of a system that economically optimizes the utilization of sediment resources with sediment management using stockyard.

2. OUTLINE AND EFFECT OF THE YAHAGI DAM SEDIMENT BP PROJECT

During The 2000 Keinan Heavy Rainfall , about 2.8million m^3 of sediment had accumulated in the Yahagi dam reservoir.

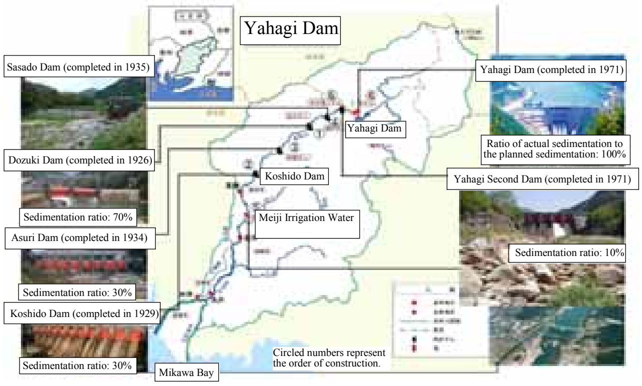

Figure 1. Main Facilities concerning Sediment Replenishment in Yahagi River Basin

It is therefore expected to implement measures against sediment as soon as possible in order to maintain the soundness of dam functions and extend the life of the reservoir. As one of such measures, a sediment BP project is planned in order to remove sediment in case of flood.

The Yahagi River was originally a sand-bed river, but now an average of about 310,000 m^3 of sediment flows into the Yahagi Dam reservoir every year. Out of this quantity, about 250,000 m^3 of bed load and suspended load accumulate in the reservoir, and about 60,000m^3 of wash load (fine-grained sediment) flows into the downstream of the dam through flood spillway (See Fig.2). After sediment BP is completed, it is expected that about 200,000m^3 of sediment mainly consisting of sand is newly supplied to the downstream through BP and that the sediment transport environment of the Yahagi River restores to the original state.

Meanwhile, there are also issues of the impacts on the downstream environment, adjustment with stakeholders, since some utilization facilities are located in the downstream of the dam, including hydropower dams, and river-based activities such as fishing and recreation at water front, are proceeding. Then, it would be necessary to establish an optimum sediment management approach that covers the overall basin (see Figs. 1 and 2).

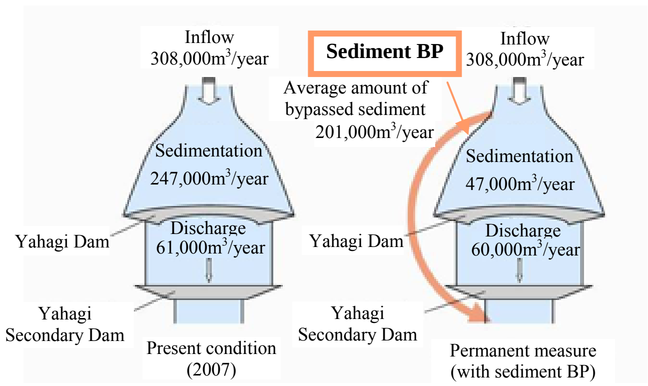

Figure 2. Sediment Balance and Effect of Sediment BP in Yahagi Dam

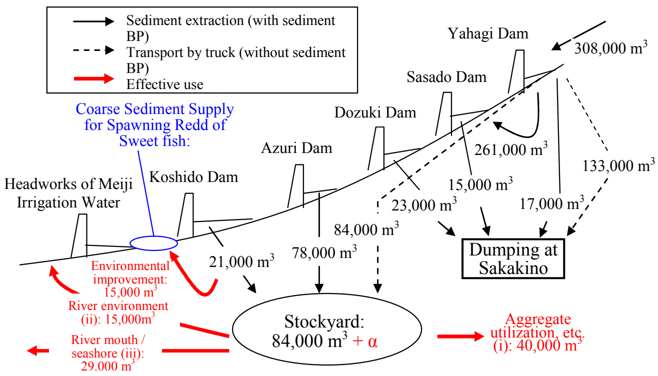

Figure 3. Sediment Movement / Excavation / Transport Model after Completion of Sediment BP in Yahagi River

Setting the Yahagi River basin as a model, we adopted CVM and CA to examine the effect of environmental improvement in the river and coast area resulting from construction of sediment BP in the Yahagi Dam and included results of the examination in the cost-benefit calculation. Then, estimating the costs of various measures arising from sediment discharge from the dam, we evaluated the project by computing costs and benefits concerning construction of sediment BP. Further, for the comprehensive sediment management of the whole basin, it should be considered how to take a balance of allocation for river environment improvement / utilization and sediment recycling while maintaining the flood control / water utilization functions, which are in a relationship of trade-off, and where from and where to sediment should be excavated / transported and how sediment should be utilized in order to achieve the most appropriate economic effect. For these reasons, we have set a sediment stockyard near the Koshido Dam to allow business operators to carry out sediment freely, and conducted a follow-up questionnaire survey to them to study the actual state of sediment recycling and its conditions.

Comprehensively considering the data obtained, we studied economically optimal sediment management.

3. ECONOMIC EVALUATION OF SEDIMENT MANAGEMENT

3.1 Model Setting

We have set a model of sediment management to the Yahagi Dam after sediment BP is completed.

As shown in Fig. 3, as new destinations of sediment that passes through the dam after sediment BP completion, we considered a combination of supply (sediment replenishment) to river channel and seashore and sediment recycling. If no sediment BP is provided, to achieve the above with excavation from the dam reservoir and truck transport, it will be necessary for trucks to drive a long distance along the dotted lines on Fig. 3, emitting a large amount of CO_2. When sediment BP is provided for use, an average of about 200,000 m^3 of sediment will newly flow every year through the river channel and a sediment flow environment is expected to restore favorably. Further, from a viewpoint of sediment recycling, the distance of transport to the point of demand will be shortened, which is favorable in terms of cost and transport environment. Meanwhile, the flow of sediment is anticipated to cause local accumulation on the channel and raise the bed height. This study assumed that a bed height is maintained to a certain level determined on the discharge capacity of the channel and that sediment in excess of the set height is excavated with age. In addition, as sediment volume required for the improvement of channel environment, it was estimated based on bed height, predicted changes to grain size, etc. to replenish 15,000 m^3 of sediment to the downstream of Koshido Dam, 15,000 m^3 to the downstream of the Intake weir of Meiji Irrigation Water, 29,000 m^3 to the river mouth / seashore, and to use 40,000 m^3 as sediment resources for aggregate utilization. In this setting, a stockyard of 84,000 m^3 or more is required near the Koshido Dam for temporary storage and adjustment of sediment to be reused.

Including these conditions, we built a "Sediment Movement / Transport Model" (See Fig. 3).

3.2 Economic Evaluation Method of Comprehensive Sediment Management

The items for economic evaluation of comprehensive sediment management are organized and compared according to two cases where (i) sediment BP is provided and (ii) sediment is transported by truck. It is common in the economic evaluation of infrastructure improvement to calculate costs (C) and benefits (B) and to make evaluation based on cost-benefit ratio (B/C) or difference (B-C). For an existing project that has been operating for many years, like Yahagi Dam, since it would be practical to make economic evaluation for a case of starting a (sediment BP) project as a new option at the present time, without considering the project costs so far spent and effects, evaluation at the present time (real option) was adopted in this study.

Evaluation items etc. are as follows.

3.2.1 Evaluation items

• Cost calculation

In addition to the construction and maintenance costs of sediment BP, we calculated the costs of measures for reduced generation from the hydropower dam due to increased supply of sediment to the downstream channel, excavation of sediment from Yahagi Dam, hydropower dam, etc., truck transport, and environmental measures to reduce CO_2 resulting from truck transport. Stockyard maintenance and other costs are taken into consideration after details of the project are determined, including business entity and management method.

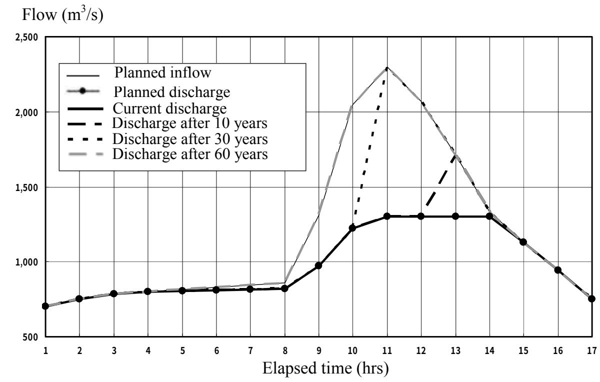

Figure 4. Expected Benefits from Dam Life Extension

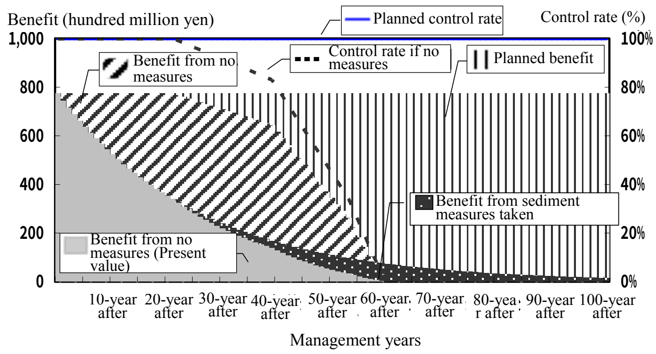

Figure 5. Benefits from Life Extension (sediment removal)

・Benefit calculation

As a benefit of dam life extension, we calculated the benefit of flood control resulting from the effects that sediment BP enables the dam reservoir capacity to be kept at the planned level and that reduction of flood cut can be avoided (see Figs. 4 and 5).

In addition, the effect of river environmental improvement was calculated with CVM and CA covering the whole basin of Yahagi River from the Yahagi River downstream to Mikawa Bay seashore.

For the benefit of sediment recycling, we calculated more practical benefit by analyzing transaction prices, applications, transport destinations, etc. with the data of the survey conducted near the Koshido Dam to examine the utilization of sediment discharged from the Yahagi Dam.

3.2.2 Goal of sediment management

We aimed at a situation that achieves the largest (optimal) cost effectiveness by realizing "dam life extension" by bypassing sediment from the dam reservoir, while maximizing the benefits of the whole basin through improvement of the environment of the downstream river and seashore, promotion of sediment recycling, etc. and minimizing the project cost. Accordingly, the goal of sediment management is total optimization of the whole basin.

3.3 Economic Evaluation

3.3.1 Implementation of CVM and CA

According to existing studies, sediment discharge from the dam is expected to bring environmental improvement effects such as "improvement of landscape and living / growing environment of living things" from river downstream to seashore. For environmental goods, which are not traded in the market, it is effective for measurement to use CVM, an approach to evaluate the effect of environmental improvement on a monetary basis, or CA.

Therefore, we calculated the effect of environmental improvement of downstream area. with CVM and calculated willingness to pay (WTP) with the method designated by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT). We also conducted CA in order to grasp what factors of environmental improvement are highly evaluated by local residents and utilize them for sediment management.

The research areas covered were Toyota City, an area immediately downstream of the dam, in fiscal 2009, and Okazaki City and seashore (Okazaki City etc.), downstream areas, in 2010.

For the number of necessary samples, we secured the numbers of samples needed in the case where reliability is 95% and absolute accuracy is 5% as specified in CVM Guideline. For the questionnaire of CVM, the multi-stage (5 stages) YES / NO question type was used, and for CA, card-selection type with 4 questions was used. In reference to the past questionnaires, we assumed the questionnaire collection rate to be 30% and valid response rate to be 60%, and distributed 1,000 copies of the questionnaire by mail to each area and collected them (See Table 1).

Table 1. Questionnaire Covered Areas and the Number of Households

Areas	Municipalities covered	Total number of households
River area (upstream)	Toyota City etc.	153,539 households
River area (downstream)	Okazaki City etc.	368,421 households
Seashore area	Okazaki City etc.	390,198 households

Table 2. Collection Rate and Valid Response Rate

Item	Number of copies distributed	Number of copies collected (rate)	Number of valid responses (rate)
River environment	1,000	469 (46.9%)	228 (49%)
Seashore environment	1,000	463 (46.3%)	314 (68%)
Reference: 2009 Upstream river environment	1,000	472 (47.2%)	336 (71%)

The questionnaire consisted of questions about project effect scenario and expected effects, question about the amount of WTP for CVM, reasons for approval, reasons for opposition, explanatory factors of CA and explanation of how to answer questions, image of explanatory factors, questions about CA, and attributes of the respondent.

The collection rate of the questionnaire was very high around 50% -- 46.9% for river environment and 46.3% for the seashore environment--, which shows that local residents are highly concerned about sediment supply. Eliminating invalid and biased responses from the above, we made analysis based on the valid response forms (River environment: 228 forms, Seashore environment: 314 forms) (see Table. 2).

3.3.2 Estimation of the effect of environmental improvement effect (WTP) in river area

Based on the valid responses from 200 residents, we estimated a curve line showing acceptance to the amount provided by CVM using the parametric method with an estimation model. As a result, the average amount of WTP for sediment discharge from the dam to the downstream of Yahagi River was 378.2 yen/month per household (see Fig. 6). This is about 60 yen higher than the WTP of the area immediately downstream of the dam (covering Toyota City) of 317.4 yen, which shows a slightly higher expectation for sediment replenishment in the downstream area.

Meanwhile, the amount of marginal willingness to pay (MWTP: WTP per unit) according to CA for each item in the downstream area is shown in Table 3, which indicates that WTP for "sandy river bed" was low in the upstream (area immediately downstream of the dam), while it was high in the downstream area. This would suggest that the awareness of returning to "sandy river bed" as "original landscape" of Yahagi River might be stronger in the downstream area. MWTP for "paddling pool" is also high at 234 yen, which would suggest strong aspiration for "formative experience" that they played in sandy river bed in their childhood.

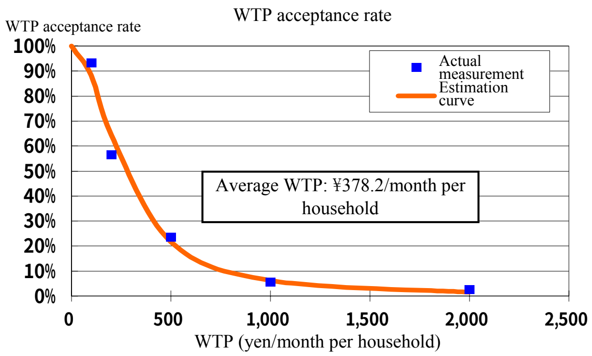

Figure 6. Estimated WTP for River Environment Improvement in Yahagi River Downstream Area

Table 3. Results of Conjoint Analysis in Yahagi River Downstream Area

Item	MWTP (yen/month per household)	Per unit
Water quality	111	Muddy water per -5 days
Reed field	3	per +10%
Sandy river bed	110	per +10%
Paddling pool	234	per +5 locations
Ecosystem	187	per -5 types

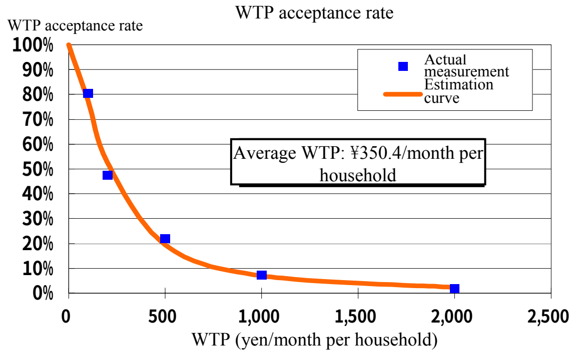

Figure 7. Estimated WTP for Seashore Environment Improvement

Table 4. Results of Conjoint Analysis in Seashore Are

Item	WTP (yen/month per household)	Per unit
Shallow bottom / tidal flat	139	per +50 ha
Water quality	105	Red tide per -10 days
Clam-digging area	33	per +100%
Beach	37	per +100%
Aquatic life	140	per +5 types

3.3.3 Estimation of the effect of environmental improvement effect (WTP) in seashore area

As a result of estimating an acceptance rate curve from 314 valid responses of the questionnaire, average WTP for environmental improvement of seashore was 350.4 yen/month per household (see Fig. 7), which was lower than 378.2 yen of WTP for river environment. Meanwhile, the amount of MWTP calculated according to evaluation items with CA was higher in "Shallow bottom / tidal flat (landscape)" and "Aquatic life" (see Table 4), which would suggest that residents have a strong aspiration for them, while WTP for recreation activities including "clam digging" and "sea bathing" was lower.

3.3.4 Survey on the effective use of sediment resources

In order to study the feasibility of effective use of sediment in the Yahagi Dam, we conducted a social experiment using a temporary sediment stockyard in the dam downstream, and analyzed the results of the questionnaire survey we conducted for private-sector operators who carried out sediment from the stockyard for business purpose.

According to the questionnaire results, as the cost of using sediment, the sum of "waste removal cost" and "transport cost" amounted to about 770 yen /t on average. Since the market research conducted in 2009 showed that the estimated sales price of sediment discharged from the dam was 300 yen/t, sales price based on this survey would be approximately 1,070 yen/t as a result of adding 770 yen (sum of disposal and transport costs) provided in this questionnaire survey to the 300 yen. Since the circulation price of sediment at the time of the 2009 research was 1,860 yen/t, the sediment discharged from the dam could be sold about 800 yen/t lower than the circulation price. The use of such difference as the cost of stockyard maintenance in the future would be worthy of consideration.

In addition, according to the request stated in many responses, there is a seasonality in the distribution of aggregates, i.e., 60-70% of the annual consumption concentrates on a season from October to next March, so that an issue is whether a sufficient amount of sediment can be distributed during this season.

In the future, it should be considered how to ensure operational cost reduction and stable supply (balance of supply and demand) and it would be important to promote utilization for the development of shallow bottom / tidal flat in the seashore (coast of Mikawa Bay), which was highly evaluated in the CVM questionnaire survey. Therefore, it would be necessary for sediment management to study a system that promotes the use of dam sediment for seashore area and a flow of sediment from the dam to seashore.

3.3.5 Cost benefit evaluation

Annual benefit from the improvement of river and seashore environment was calculated based on the results of CVM survey with the formula, "Annual benefit = WTP under CVM x Number of households in target areas x 12 months. For the benefit of improvement in the river environment, since there is a difference in the section of sediment replenishment, the sum of values for the upstream and downstream of Yahagi River was adopted for sediment BP, while only the value of Yahagi River downstream was adopted due to the absence of sediment replenishment between Yahagi Dam and Koshido Dam (see Fig. 3).

Based on these data, we evaluated the costs and benefits of sediment management in the Yahagi Dam for the cases of "with BP" and "Truck transport (without BP)." The calculation period is 100 years to come and the future costs and benefits calculated were converted into the present values at the discount rate of 4% and cost-benefit ratios (B/C) were calculated in real option (see Table 5).

Table 5. Calculation Table for Cost Benefit Evaluation

		Sediment bypass (hundred mil. yen /100 years)	Transport by truck (hundred mil. yen /100 years)
Cost	Excavation cost	34.9	55.3
	Transport cost	111.1	296.8
	Cost of constructing bypass tunnel and suction facilities	129.0	-
	Cost of measures for hydropower dam	2.4	-
	Environmental spending	1.1	2.8
	Maintenance cost	41.4	mainly road maintenance cost
	Cost of measures for seashore	15.0	15.0
	Total	334.8	369.9
Benefit*	Dam life extension	3027.0	3027.0
	River environment	552.8	409.7
	Seashore environment	402.1	402.1
	Sediment recycling	25.3	25.3
	Total	4007.2	3864.1
Cost-benefit ratio (B/C)		120	10.4

*) Calculated by authors on a trial basis, not officially announced.

In Fig., Case 1 shows B/C calculated by limiting the benefit to only dam life extension (benefit of flood control); Case 2 limited the benefit to the effect of environmental improvement in the seashore and sediment recycling; and Case 3 indicates B/C in combination of Cases 1 and 2, i.e., dam life extension and the effect of environmental improvement etc. As the result, it was verified that the development of sediment BP greatly exceeds 1.0 in B/C evaluation and therefore has a sufficient effect as a project and high cost performance. Particularly, it was confirmed that even the effect of environmental improvement alone has an effect exceeding 2.0.

AS described, sediment BP has been verified to be an economically efficient and effective means from not only the effect of dam life extension (flood control) but also the project evaluation based on the comprehensive sediment management conducted including indirect effects such as environment improvement and sediment recycling.

4. CONCLUSION

In this study, economic evaluation was conducted for sediment discharge from the dam through sediment BP and river management based on sediment management, using the Yahagi River basin as a model.

The conclusions from this study are as follows.

(i) As the result of evaluating the effect (benefit) of sediment discharge from the dam and cost of measures, including the benefits of the effect of environmental improvement, which was examined with CVM, CA, etc., covering the whole basin of Yahagi River from the downstream to river mouth and Mikawa Bay seashore, the structure of cost-benefit on sediment supply and its factors have been clarified.

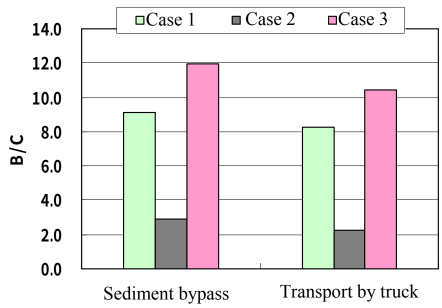

Figure 8. Comparison of B/C on Sediment BP and Truck Transport

(ii) Sediment BP project has been verified to have great economic advantages and social benefits as the result of evaluating indirect effects over the whole area of sediment transport system, including environmental improvement, in addition to the effect of flood control, i.e., the life extension of the reservoir resulting from measures against sedimentation in the dam.

(iii) We proposed an appropriate matching of supply and demand that optimizes cost effectiveness by setting a stockyard in the midstream of the river and conducting sediment management involving private-sector operators etc.

(iv) As an issue to address in the future, it is desirable to establish a project approach that enables economically viable operation by studying operation method including specific location and size, PFI, etc. for stockyard, which is expected to promote the functions of flood control, water utilization, and environment.

Note that this study has examined modeling of sediment management and economic evaluation model using the Yahagi Dam Sediment BP Project as a case study, and not evaluated this Project itself.

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