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Comprehensive sediment management model in Yahagi River basin based on Yahagi Dam sediment Bypass project

K. Tomita
Civil Engineering and Eco-Technology Consultants Co., Ltd., Tokyo, Japan

T. Sumi
Water Resources Research Center in Disaster Prevention Research Institute, Kyoto University, Kyoto, Japan

T. Sugita
Yahagi Dam and Reservoir Management Office, Chubu Regional Bureau, MLIT, Toyota City, Aichi, Japan

ABSTRACT: This study examines measures for the effective and efficient management of sediment in connection with the operation of the sediment discharge Bypass (BP) being considered for the Yahagi Dam, including merits and demerits in the downstream river. Specifically, based on the area where excavation for maintenance will be required for flood control after the sediment discharge facility (BP) starts operation and the amount of sediment to be excavated, examination was made on the measures for effective use of sediment resources by the development of tidal flat at the river mouth and shallow bottom/tidal flat in the port area and the recycle of excavated sediment (for material etc.). As a result, development of a stockyard as an adjustment base for sediment management in the mid-stream area proved to be effective. Further examination was made as a case study on potential sites for stockyard leading to optimum cost effectiveness and "sediment management" (draft) for optimizing flood control, water utilization, and environment for the overall river system.

1 INTRODUCTION

Concern has been raised about the impact on the downstream river by the sediment discharge Bypass (BP) being considered for the Yahagi Dam.

Sediment discharge from the Dam, when implemented, is expected to have adverse effects on flood control and water utilization functions due to rise in bed height of downstream river, while the coarse grain of the current river bed material will be refined again due to the fine sediment to be supplied by the discharge to the river, which leads to the expectation of restoration of sandy dry river bed, recovery of biota appropriate for the sandy river bed, and restoration of tidal flat or shallow bottom in the river mouth and shore area.

In the sediment management aiming for comprehensive management of sediment in the Yahagi Dam and Yahagi River (Fig. 1), appropriate excavation of sediment, transportation thereof, sediment replenishment to rivers and seashores, recycling of sediment, etc. are discussed as a case study so that the management may be optimum over the whole river system for the stakeholders in conflict of interest concerning the river.

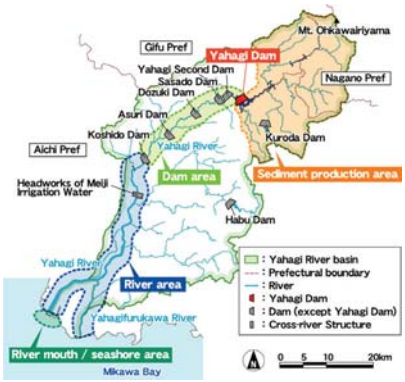

Figure 1. Yahagi River basin.

Specifically, consideration will be required for the following items.

1. Forecast and consideration of the section of sedimentation expected from the discharge.
2. Consideration about the section of excavation of river channel and the amount of sediment

required for flood control in connection with the decrease in discharge capacity expected from sedimentation resulting from sediment discharge from the Dam.
3. Transportation for dealing with excavated sediment.
4. Determination of the appropriate amount of sediment replenishment to rivers, beaches, etc. using sediment effectively.
5. Consideration about uses and possible amount for recycling of sediment resources.
6. Consideration about the location and capacity of a transfer station and sediment Stockyard (SY) as time-related regulating capacity concerning the amount of sediment in order to realize sediment management.
7. Consideration about sediment management for optimal operation of the aforementioned items in the river basins.
8. Verification of feasibility and consideration of economy concerning excavation, transportation, etc.
9. Identification of issues for adjustment with stakeholders, etc.

This study, as a case study, assumed the amount of sediment discharge from the sediment BP to be about 250,000 m^3 per year in average, and areas to be excavated for maintenance and the amount of sediment for the sections from the downstream of the Dam to river mouth or beaches according to grain sizes of discharged sediment. Based on this assumption, cost minimization was discussed with the condition of replenishment of excavated sediment to rivers and beaches and recycling of sediment resources.

As the result, it was proved to be effective to replenish 30,000 to 50,000 m^3 of sediment per year to river mouths and beaches for environmental improvement by providing sediment stockyard around the Koshido Dam in the midstream and to recycle sediment resources including use for new materials and machines while watching market demand. Moreover, system and organization framework to realize the studied case was examined by providing a similar practical case.

2 EXAMINATION OF SEDIMENT BALANCE IN DEVELOPMENT OF SEDIMENT BYPASS (BP)

2.1 *Issues with the present sediment balance in Yahagi River*

2.1.1 *Inflow area of Yahagi Dam (Sediment production area)*

The inflow area of the Yahagi Dam is increasingly devastated since a large amount of sediment is discharged due to hillside collapse, etc. The areas of collapsed land and bare hills had been decreasing since the 1940's, but turned to increase since the 2000 Keinan Heavy Rain. However, the inflow of sediment into the Dam has been moderate in recent years.

2.1.2 *Yahagi Dam reservoir*

Sedimentation in the Yahagi Dam reservoir has been increasing at a pace of about 300,000 m^3 in yearly average after the completion of the Dam (see Fig. 3). Particularly, the 2000 Keinan Heavy Rain increased one-year sedimentation to 2.8 million m^3, about 9 times the yearly average. The present amount of sedimentation in the reservoir has already exceeded the planned sedimentation capacity of 15 million m^3, so excavation of deposited sediment is going on as an urgent measure against sedimentation.

2.1.3 *Yahagi Dam downstream river (river area)*

As a geological feature of the Yahagi River basin, granite on the surface is likely to weather ("masaka") and collapse. As a result, a large amount of sediment has been discharged in the event of rain, forming an alluvial plain.

In the recent years, however, sediment movement in the sediment transport system has been prevented due to the development of the Yahagi Dam or electric dams, and the Headworks of Meiji Irrigation Water, excavation of gravels on the river bed has been conducted, and disturbance frequency has decreased as a result of the stable flow regime. Consequently, establishment of water route and increase in land area formed by sand bar are proceeding, sandy dry river bed, which is the characteristic landscape of the Yahagi River, has decreased, and the grain of river bed material is becoming coarse in the down-stream of the Dam.

2.1.4 *River mouth/harbor areas*

In the mouth of Yahagi River, the total area of reed field reduced in 1982 to less than a half of the area in 1973 and thereafter resulted in an increase or decrease of 10 to 20 ha.

Meanwhile, the tidal flat area at the river mouth had been decreasing every year since 1965, even to about 20% of the 1965 level in 1985, while little change has been recognized after 1985.

Also, in the Mikawa Bay area, the area of tidal flat and shallow bottom decreased about 1,200 ha in several years since around 1965 due mainly to landfill and channel dredging. Moreover, the decrease in the tidal flat and shallow bottom in the Mikawa Bay is said to have increased the total number of days of reported red tide. See Figure 2.

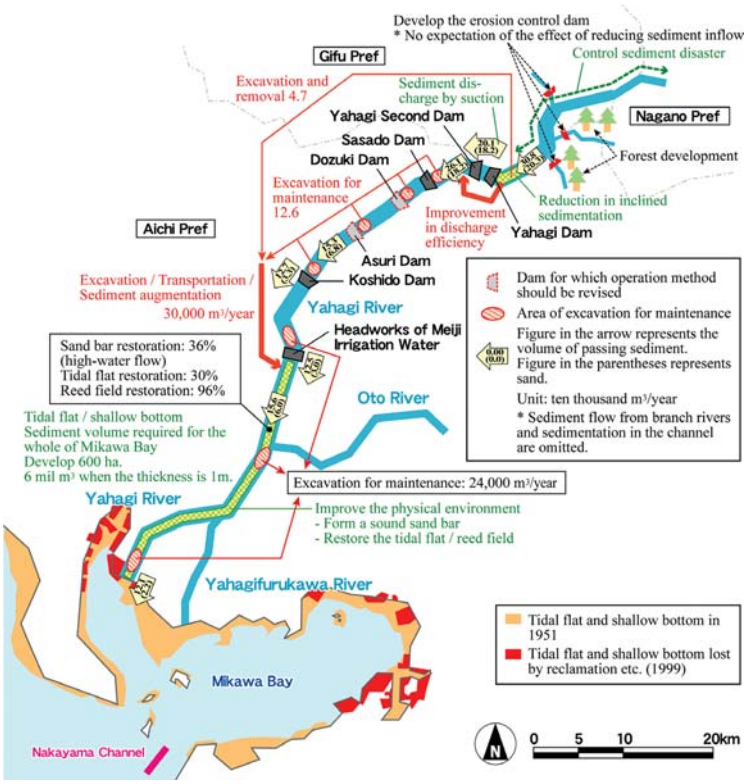

Figure 2. Image of sediment management scenario in the Yahagi River comprehensive sediment management plan (draft).

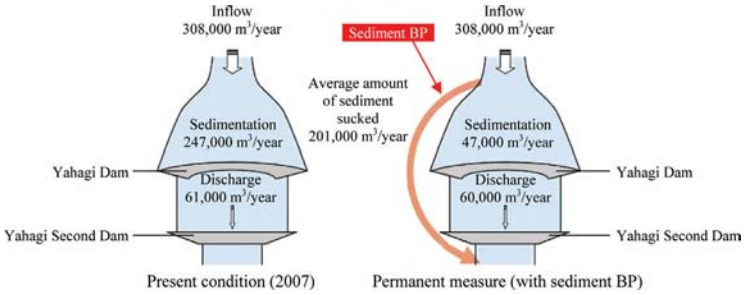

Figure 3. Increase in sediment transport by sediment BP.

2.2 *Sediment balance after development of sediment BP (forecast)*

For the forecast of sediment balance after development of the sediment BP, treatment of sediment and measures for effective use of sediment were examined based on the amounts of passing sediment and excavation for maintenance, which were obtained by the sedimentation balance calculation under the Sediment Management Scenario (Fig. 2), which is being examined by the "Yahagi Dam River System Comprehensive Sediment Management Committee."

2.3 *Issues after development of the sediment BP and measures in sediment management*

Development of the sediment BP will bring expectation for long life of the dam (by securing

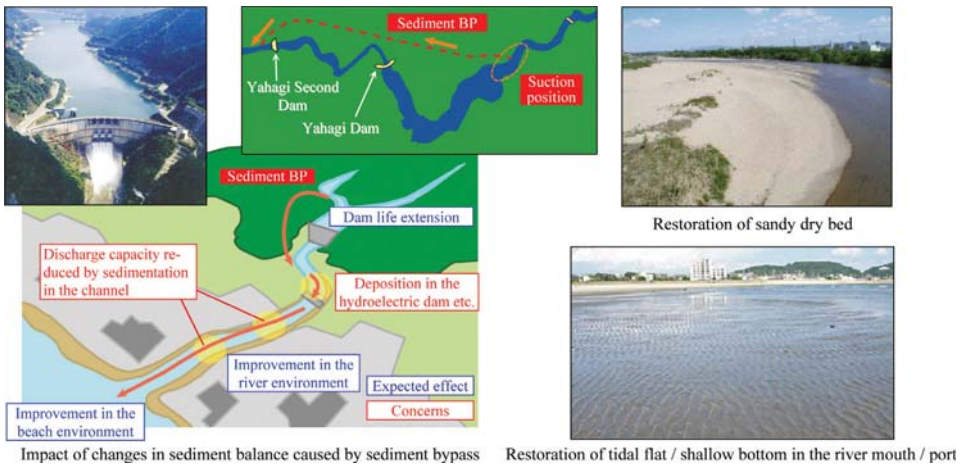

Figure 4. Issues after sediment BP development and merits in sediment replenishment.

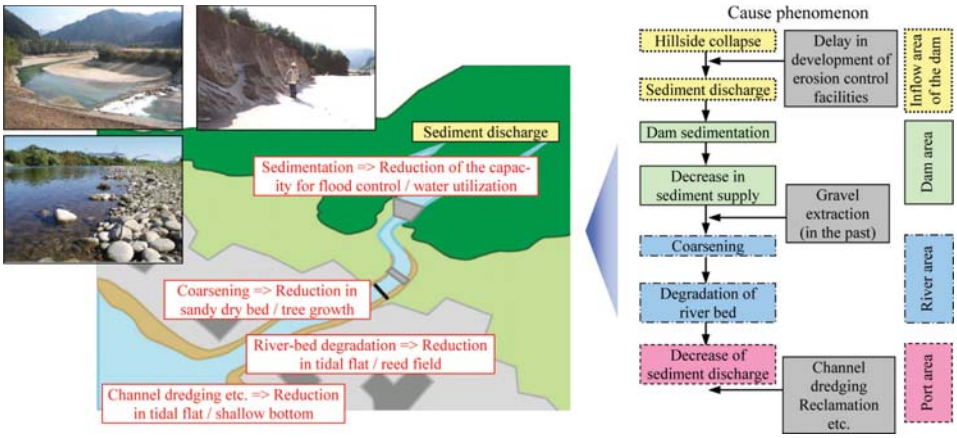

Figure 5. Issues with the present state of sediment balance in Yahagi River.

the capacity for flood control/water utilization) and improvement in the downstream river environment (restoration of sandy dry river bed, etc.), while it will also give rise to concern about decrease in the discharge capacity (flood control function) due to sedimentation in river channel. For these reasons, for the sediment generated by excavation for river channel maintenance, which will be required after development of the sediment BP, examination was made on the sediment management (proposal) for the optimization by conducting economic evaluation with the sediment management approach considering the balance between flood control, water utilization, and environmental conservation measures. See Figures 2, 4, and 5.

3 EXAMINATION FOR EFFECTIVE USE OF SEDIMENT WITH SEDIMENT MANAGEMENT

For effective use of sediment, it will be advantageous to be close to the place of demand in light of the cost of transporting excavated sediment. Since supply and demand will be well balanced for the present in the upstream of the Asuri Dam after development of the sediment BP, consideration was made about the plan to recycle sediment excavated for maintenance in the downstream of the Asuri Dam and use the sediment for the downstream section of the Yahagi River and Mikawa Bay.

Note that sediment whose transportation is costly, i.e., sediment excavated for maintenance of

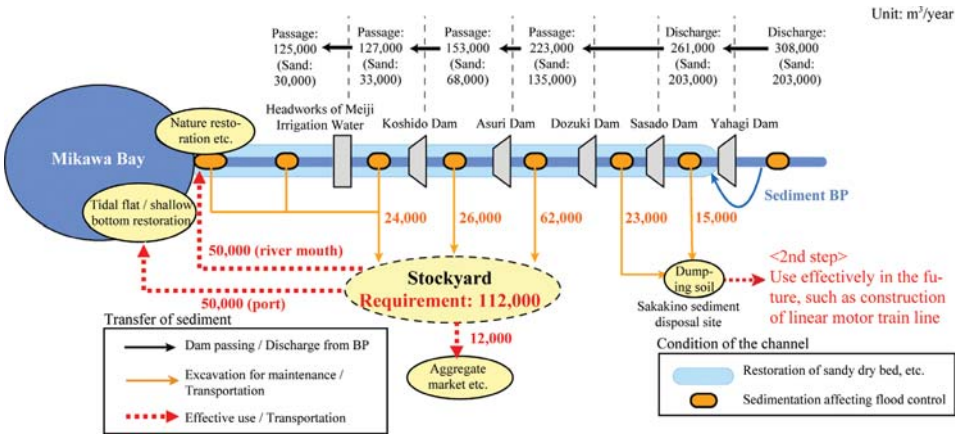

Figure 6. Area of excavation for maintenance and amount of sediment, and image of effective use under sediment management.

Table 1. Results of conjoint analysis concerning the environment of Mikawa Bay.

Items	MWTP (yen/month per household)
Tidal flat/shallow bottom	139
Water quality	105
Clam-digging	33
Beach	37
Aquatic life	140

the Sasado Dam and Dozuki Dam and sediment excavated from the Yahagi Dam reservoir, will be disposed of in the disposal site, etc. in the upstream, and use of sediment for the construction of linear motor train line was determined to be considered after effective use becomes available. See Figure 6.

- Method for Effective Use of Sediment Excavated for Maintenance (Proposal)
  - Utilization for restoration of tidal flat/shallow bottom in Mikawa Bay
  - Utilization for restoration of sandy dry river bed in downstream river zone
  - Supply to the market as aggregate
  - Supply to the market as value-added material, such as glass and building material (collar sand)

3.1 *Utilization for restoration of tidal flat/shallow bottom in Mikawa Bay*

The areas of tidal flat and shallow bottom in the Mikawa Bay are said to have disappeared about 1,200 ha (See Fig. 2.) but were restored by the development with about 600 ha under the Blue Sea Project using the sediment dredged for channel development for the Nakayama Channel.

When considering the target value to restore the tidal flat/shallow bottom that disappeared, sediment for further development of about 600 ha (6 mil. m^3 assuming the height of development to be 1 m) will be required. Hence, utilization of the sediment dressed from the Yahagi River for this development would be considered. According to the conjoint analysis (Table 1) conducted in fiscal 2010 covering the residents in the Mikawa Bay area, the Marginal Willingness to Pay (MWTP) for "Creation of tidal flat/shallow bottom" was as high as "Preservation of aquatic life," which shows the high needs of local residents for the restoration of tidal flat/shallow bottom (Table 1).

Results of an interview survey involving port managers also showed that there are high needs for sediment to be used for the development of tidal flat/shallow bottom in the Mikawa Bay and that about 30,000 to 50,000 m^3 of such sediment is available in a year, which will require transportation of such sediment to the Port area, screening according to grain sizes, and treatment of impurities in the stockyard. To implement such scheme, the sediment management will require the development of management organization and framework.

<Results of the interviews with the persons concerned with the Port and fisheries about the utilization for restoration of tidal flat/shallow bottom in the Mikawa Bay>

- There is demand for using sediment in the country (Port Office)'s Ise Bay Regeneration Project and the prefecture's Satoumi (marine-coastal ecocystems) Restoration Project.

- The appropriate grain size of sediment using short-necked clam as an indicator is about 1 or 2 mm to 1 cm and variety in size is preferred.
- As a result of the test for utilization of the sediment deposited in the Yahagi Dam for the development project of the prefecture's fisheries division, the quality of the sediment proved to be good, but not suited for the development of fishing grounds mainly because fishing equipment cannot be used when large stones are mixed.
- For development projects, the prefecture's fisheries division has demand for sediment of 30,000 to 50,000 m^3 per year, and the prefecture's port division has demand for sediment amounting to 40,000 m^3 per year, so sediment utilization is likely to be commercialized with stable supply.
- The prefecture's port projects expect dredged sediment to be transported to the Port for use, so it is only necessary to transport the sediment to the stockyard of the port division or the development site. Since the national standard requires "within 50 km" for transportation of sediment, it is effective to discharge the sediment to be used for restoration to the downstream area to the extent possible.

3.2 *Utilization for restoration of sandy dry river bed/shallow bottom in the downstream zone*

In and around 1965, there were many areas like sandy beach in the dry bed of the Yahagi River, which were used for boat landing, playing in the water, and washing laundry. There was also tidal flat at the river mouth, providing valuable habitat for birds, shellfish, etc. At present, however, the areas of sandy river bed and tidal flat at the river mouth have decreased, so restoration of such areas is expected. As shown in Table 2, according to the results of the conjoint analyses conducted in fiscal 2009 (for upstream area (Yahagi Dam–Koshido Dam)) and in fiscal 2010 (downstream of Koshido Dam) concerning the river environment, the Marginal Willingness To Pay (MWTP) for restoration of "sandy dry bed" was higher among the residents of downstream area than those in upstream area. Accordingly, for utilization of sediment to restore sandy dry bed and tidal flat in the downstream area, it is expected to discharge the sediment from the BP into the downstream beyond the Koshido Dam to the extent possible or excavate and transport the sediment deposited in the upstream and discharge it in the downstream of the Koshido Dam.

Table 2. Results of conjoint analysis concerning the environment of Yahagi River.

	MWTP (yen/month per household)	
Items	Downstream of Yahagi River	Upstream of Yahagi River
Water quality	111	163
Reed field	3	106
Sandy river bed	110	22
Paddling pool	234	162
Ecosystem	187	194

3.3 *Supply to the market as aggregate*

In fiscal 2010, a pilot program was implemented to survey how the sediment provided to the public for free was used by preparing a sediment stockyard (developed temporarily) in an area near the Koshido Dam. This survey included a questionnaire to the sediment users (business operators). As the result, (i) the sediment was used for concrete, aggregate for asphalt, golf course sand, and plasterer's sand, and that (ii) about 770 yen was spent for waste disposal and transportation. It was found from these results that, assuming the sediment purchase price to be 300 yen/t (based on the results of the 2009 interview survey), the price of aggregate will be generally about 1,070 yen/t including the costs of disposal and transportation, which is about 800 yen/t lower than the estimated current acquisition cost of 1,860 yen/t.

This is expected to be used as an incentive for sediment management.

3.4 *Supply to the market as value-added material other than aggregate*

When glass material is assumed to be value-added material that may be available from sediment, the percentage of SiO_2 contained in silica sand (pit sand) is generally more than 90%, while as the result of analyzing the sediment taken from the Yahagi River, the percentage of SiO_2 was 72.8%, lower than that of general glass material to some extent.

Accordingly, to use sediment from the Yahagi River as glass material, such treatment as classification according to the percentage of SiO_2 would be required. Meanwhile, there are some glass workshops along the Hirose River (in Sendai City) etc., where river sand is directly processed to manufacture glass products. Hence, it would be possible to use the river sand in the Yahagi River as it is to manufacture local products (glass cups, flower vases, etc.). In addition, sediment taken from the Yahagi River was dried and colored to examine the possibility of use with added value as color sand for construction material after baking sediment in the hearth like earthenware and taking color treatment. As the result, it proved to be difficult to use the sediment for color sand products since

Figure 7. Samples produced by coloring sediment.

the lower percentage of SiO_2 in the sediment prevents generation of a single stable color (Fig. 7). However, the glittering of mica is characteristic and the color has a natural tone unlike single-colored material. If applications using such characteristics are devised, it would be possible to use the sediment for value-added material (e.g., sand picture material, wall material for Japanese-style buildings).

- Develop a site near Toyota Stadium as a sediment museum (also aiming to promote the effective use of good quality sediment).
- Develop a site near the Yahagi River Toyota Disaster Prevention Station, also aiming to save the sediment for disaster prevention.
- Develop a site in the river channel (downstream of Benten Bridge), also aiming to use as sediment augmented for restoration of nature in the downstream (restoration of sandy dry bed).

4 EXAMINATION FOR EFFECTIVE USE OF SEDIMENT WITH SEDIMENT MANAGEMENT

4.1 *Examination of potential Stockyard (SY) sites for effective use of sediment*

To use excavated sediment effectively, it would be necessary to develop a stockyard where sediment excavated for maintenance is temporarily stocked and supply-demand of sediment quantity is adjusted. Hence, the following potential sites were examined mainly from the viewpoints of securing site and reducing the cost of sediment transportation.

4.2 *Cost-benefit analysis of sediment management with optimization of the amount of effective use*

For the selected potential SY sites, the arrangement of SY expected to minimize total cost was examined according to the two patterns of "single-point concentration" and "multi-point distribution" using the cost of transportation calculated by multiplying the distances from the place of excavation to SY and from SY to the place of effective use by truck mileage based on the amount of excavation for maintenance the estimated amount of sediment for effective use.

Table 3. Results of cost-benefit ratio of sediment management (transport 50,000 m^3 to the river mouth and the port, respectively).

	Total cost	Cost (mil yen/year)
	Excavation cost (C (1))	112
*Up to stockyard	Transportation cost (C (2))	25
*From stockyard	Transportation cost (C (3))	17
	Total (C)	154
Distribution benefit	Benefit (hundred mil yen/year)	B/C
Aggregate utilization	24	0.16
Glass material	194	1.26
Color sand material	104	0.67

According to the results of examination, the cost of SY management was the minimum in "multi-point distribution." In addition, in order to reduce the cost of transportation by truck, there is a measure of increasing effective use of sediment in SY (i.e., cost of transportation from SY will be zero when aggregates are marketed in SY). For example, assuming to reduce by half the amount of sediment to be transported to the river mouth/port and to market all the sediment excavated from the Asuri Dam, 62,000 m^3/year, the total cost of sediment management was minimized due to the decreased transportation cost.

Further, for each of the two patterns above, the benefit from marketing in SY and the cost-benefit ratio based on excavation/transportation cost were calculated. As the result, assuming that 50,000 m^3 of sediment was transported to the river mouth and the port, respectively, the ratio of cost to benefit (B/C) will be no more than 1 unless the sediment is supplied as a high-value-added material like glass material (Table 3). On the other hand, if all the sediment excavated from the Asuri Dam, 62,000 m^3/year, can be fully distributed in the market, the ratio of B/C will be 0.99 even in the case of "use for aggregate," whose unit distribution cost is low, so the costs of excavation for maintenance and transportation can be covered by the benefit

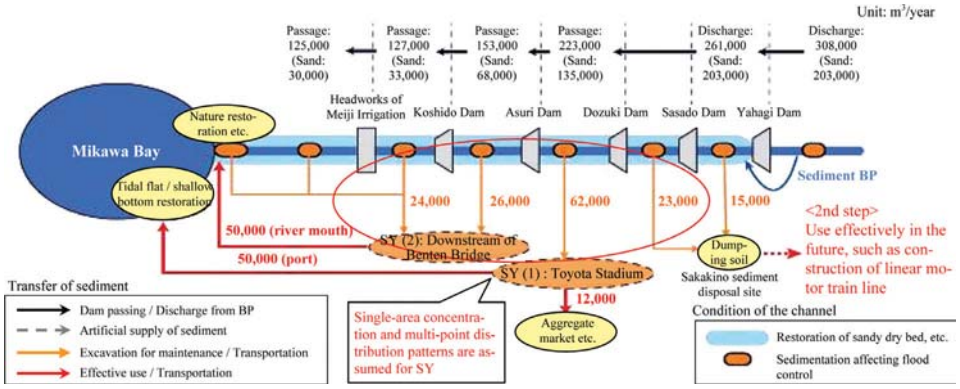

Figure 8. Image of stockyard arrangement for effective use of sediment.

Table 4. Results of cost-benefit ratio of sediment management (optimize the amount of effective use).

	Total cost	Cost (mil yen/year)
	Excavation cost (C (1))	112
*Up to stockyard	Transportation cost (C (2))	6
*From stockyard	Transportation cost (C (3))	8
	Total (C)	126
Distribution benefit	Benefit (hundred mil yen/year)	B/C
Aggregate utilization	125	0.99
Glass material	1004	7.97
Color sand material	536	4.25

of distribution. If it is possible to use the sediment for high-value-added material, such as glass material and color sand, the profit necessary for sediment management will be produced (Table 4).

5 ORGANIZATION OF SEDIMENT MANAGEMENT ORGANIZATION AND UTILIZATION OF PRIVATE-SECTOR VITALITY

To realize the effective use of sediment as described above, it is necessary to establish organization and system for management and operation. For example, the sediment management system of a certain dam in the Kanto Region has developed the scheme and system for selling sediment deposited in the reservoir and returning part of sales profits for local development.

For the sediment BP being considered for the Yahagi River, it is required to manage effectively the sediment discharged from the river considering for flood control, water utilization, and environmental function, while such effective management is also very significant for nature restoration in terms of returning to the conventional sediment balance. Therefore, it would be required to develop the scheme, management/operation organization, and system that lead to proper environmental restoration and local development, including cooperation of each facility manager and collaboration with private sector (finance, corporate CSR, etc.).

6 CONCLUSION

When development of the sediment BP is officially decided, adjustment with various stakeholders concerned with the Yahagi River will be required, including those to be affected by discharge of another sediment, those benefiting from environmental improvement, facility managers, and sediment users. In consideration of merits and demerits of such stakeholders, this study on sediment management has provided the possibility of discharged sediment as material for restoring the original nature and sediment balance of the Yahagi River and for contributing to the revitalization of local economy and local development by considering that the discharged sediment can be used effectively.

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