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SEDIMENT CONTROL MEASURES AND IMPROVEMENT EFFECTS OF PHYSICAL CONDITION AND ENVIRONMENT BY SEDIMENT FLUSHING - A CASE STUDY IN THE YAHAGI DAM [*]

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1. INTRODUCTION

Recently, permanent measures against sediment in dam reservoirs, which involve discharging sediment that flows into the reservoirs to the lower reaches during floods, are being actively investigated in order to effectively utilize existing infrastructures and maintain the function of the reservoirs. The impacts of the sediment flushing to the lower reaches need to be understood before deciding implementation of the measures.

Yahagi Dam, which is located in the Chubu region, was completed 36 years ago 1971. A large amount of sediment flowed into the reservoir during the Keinan Storm in 2000 and caused serious sediment accumulation.

[*] *Mesures de lutte contre l'envasement et impacts des chasses sur les conditions physiques et environnementales – Etude de cas – Barrage de Yahagi.*

Today, the sediment exceeds the design sediment capacity, and measures for removing sediment should be urgently taken to restore the function of the reservoir.

This paper describes investigations of measures for removing sediment from Yahagi Dam and analyses on the impacts by sediment flushing to the lower reaches. [1]

2. STATUS OF THE YAHAGI RIVER BASIN

1. OVERVIEW OF THE BASIN OF THE YAHAGI RIVER

The Yahagi River rises in Nagano Prefecture (elevation: 1,908 m) at the southern end of the Kiso mountain range, which form the backbone of Japan, and flows into Mikawa Bay. It has a main stream length of about 118 km and a basin area of about 1,830 km^2 and is a Class A river.

The basin can be separated into the upper, midstream, and lower reach from riverbed gradient and riverbed materials as shown in Figure 1: Physical characteristics of the river. Yahagi Dam is located in the upper end of the midstream reach.

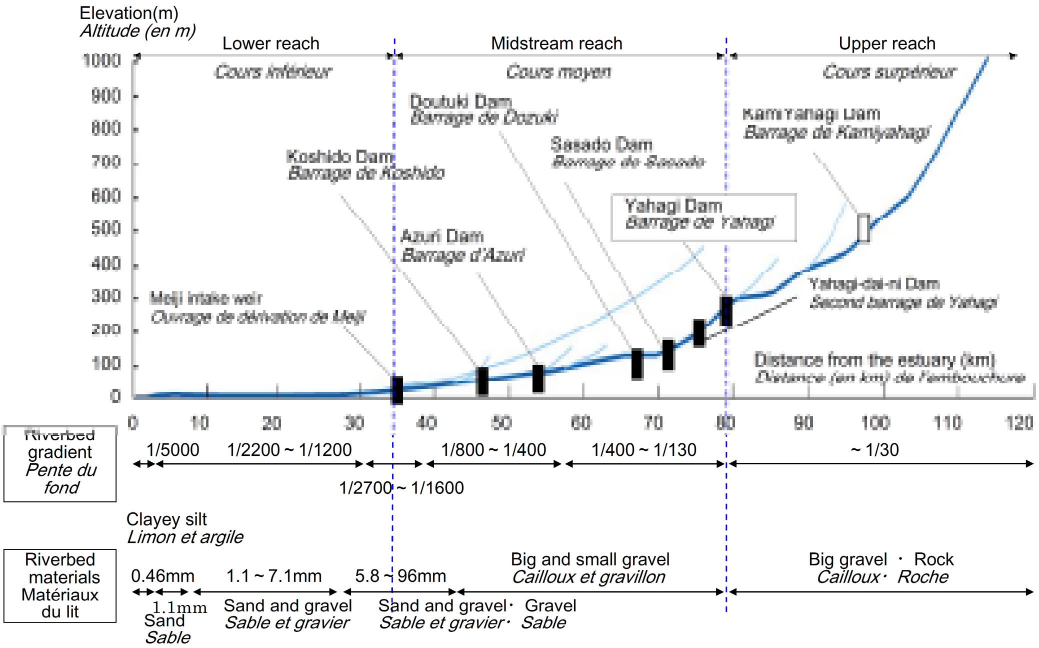


Fig.1

Physical characteristics of the Yahagi River

Caractéristiques physiques du lit de la rivière Yahagi

a. RIVER ENVIRONMENT OF THE YAHAGI RIVER

The upper reaches of the main stream and tributaries of the Yahagi River are covered by weathered granite. During storms and floods, large amounts of sediment have flown down the river and formed a typical landform of a sand river in the lower alluvial plain. Today, the Yahagi River is facing the following phenomena due to increased water use, sand and gravel mining, and dam construction.

1) The river has degraded, decreasing the inundation frequency of flood and the disturbance by flood, and thus allowing trees to grow in the river course.
2) Flood discharge has changed, resulting in increases in the sand size of riverbed materials.
3) The amount of sediment flowing down the river decreased, resulting in the river course to be fixed, channel bars to be reduced, and sandbars to change forms.
4) The water quality satisfies the environmental standards in general.

b. OVERVIEW OF YAHAGI DAM AND SEDIMENT ACCUMULATION

Yahagi Dam is a concrete arch dam against floods, supplying agricultural, city and industrial water and power generation. The dam specifications are a dam height of 100 m, crest length of 323 m, catchment area of 504.5 km^2, total storage capacity of 80 M(million) m^3, effective storage capacity of 65 M m^3, flood control capacity of 15 M m^3, and design sediment capacity of 15 M m^3.

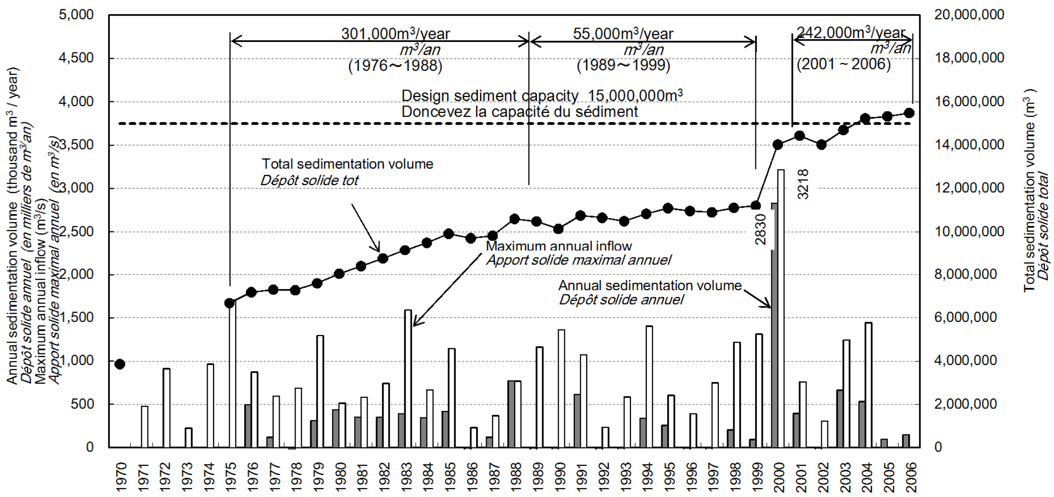


Fig. 2

Sediment accumulation in the Yahagi Dam

Évolution des dépôts solides dans la retenue de Yahagi

Sediment accumulation in Yahagi Dam up to the end of fiscal 2006 are shown in Figure 2. Since the geology in the upper areas of the dam is highly weathered granite, approximately 300 thousand m^3 of sediment accumulated in the reservoir every year after the completion of the dam. In and after the 1989s, forestation advanced and the area where the land collapsed decreased. Thus the amount of sediment was reduced to 55 thousand m^3 a year on average. However, during the Keinan Storm in 2000, 2.8 M m^3 of sediment deposited in the reservoir. Sediment has kept accumulating thereafter at a rate of about 240 thousand m^3 a year on average. The sediment in the reservoir now exceeds its design sediment capacity (Figure 2). Therefore, a measure for removing sediment should be urgently taken to restore the flood control capacity of the dam.

3. SEDIMENT REMOVAL MEASURES AT YAHAGI DAM

3.1. URGENT MEASURES

Since the sediment in Yahagi Dam has already exceeded the design sediment capacity, urgent measures are being taken as schematically illustrated in Figure 3.

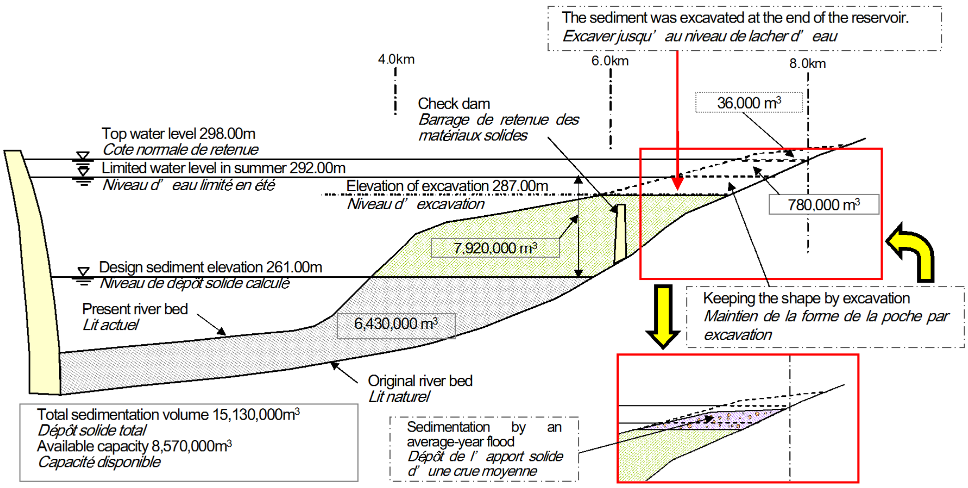


Fig.3

Schematic diagram of sedimentation state in Yahagi Dam
and the urgent sediment control measure

Comblement de la retenue de Yahagi et schéma de la mesure d'urgence

It involves removing the sediment from the upper zones of the reservoirs to restore the initial flood control capacity and prevent sedimentation in the effective capacity from progressing. In practice, it involves excavating about 260 thousand m^3 of sediment horizontally up to the level (EL 287 m) at which the necessary capacity for pre-release can be ensured and excavating at the upstream end of the reservoir. The excavated open space is to be maintained by excavating the amount of sediment equivalent to the sediment inflow (about 180 thousand m^3 a year) to keep the flood control capacity until the facility for permanent sediment control measure is completed.

3.2. PERMANENT SEDIMENT CONTROL MEASURES

A facility for permanent sediment control will be completed in about ten years. The permanent measure aims to remove the entire amount equivalent to the inflow sediment (250 thousand m^3 a year) and remove the sediment in the capacity for water utilization.

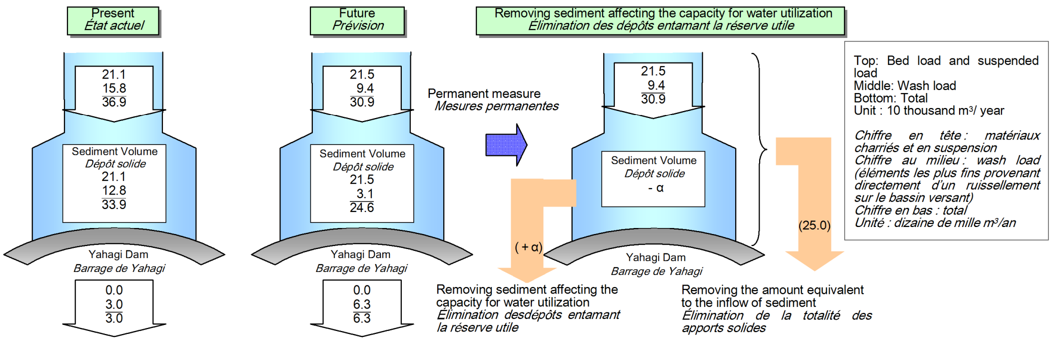


Fig.4

Sediment balance by permanent sediment control measures in Yahagi Dam

Bilan d'ensablement de la retenue de Yahagi avant et après la mise en œuvre des mesures

a) Feasible sediment flushing methods

Methods of sediment flushing were organized as shown in Figure 5 by considering the present operation methods and sedimentation states of the dam.

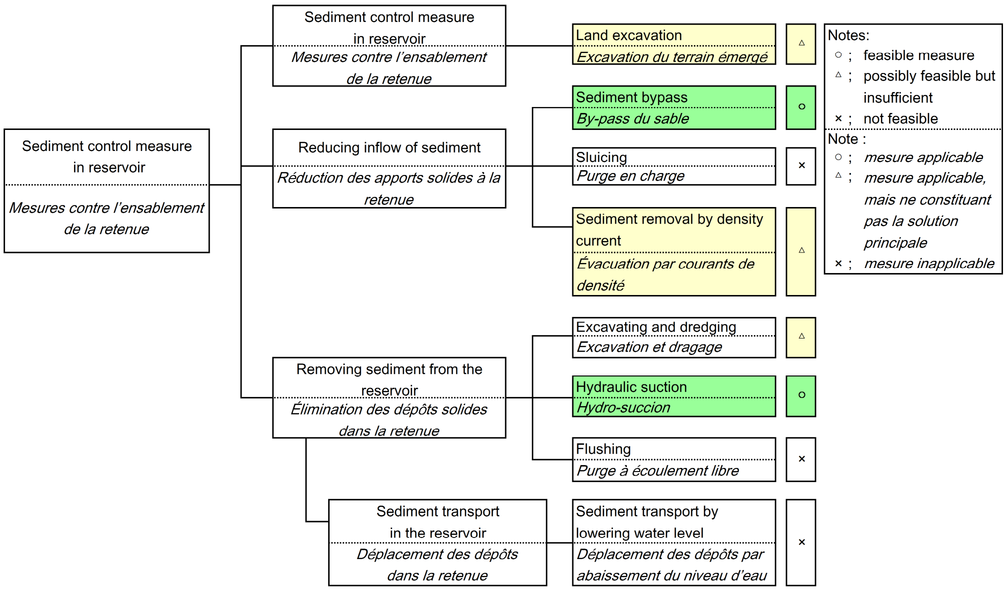


Fig.5

Selecting applicable methods of sediment removal

Méthodes de dessablement possibles

For Yahagi Dam, land excavation and dredging are not feasible because they are expensive and excavated sediment is difficult to dispose of, sediment removal by density current is difficult to decide the timing of discharging sediment, sluicing and flushing of sediment are difficult because the spillway has to be remodeled and the water utilization cannot be ensured, and removal by lowering the water level is not feasible because the water level can be lowered only very slightly. Measures that were possibly feasible were sediment bypass and sediment suction, and they were comparatively investigated.

Plan A (suction):

A suction facility is constructed near the extremity shoulder of a delta, and the sucked sediment is to be discharged through a pipe and tunnel for discharge sediment to the lower reaches.

Plan B (sediment bypass + suction):

A diversion weir is constructed at the upstream end of the reservoir to discharge part of flood water directly to the lower reaches together with sediment. The sediment that passes the weir is sucked and discharged to the lower reaches.

Here, suction denotes removing sediments and sediment that flows into the reservoir using energy equivalent to water pressure difference (h = 15 m). It involves sucking sediment from two or more holes installed at the bottom of sediment-removing pipes using negative hydrodynamic pressure of the water flows into the pipe from an open end. In practice, soil-removing pipes with switch gears at the holes are installed near the shoulder of a delta. When sedimentation advances, sediment is sucked by opening the holes and is discharged to the lower reaches through a tunnel for discharging sediment.

b) Comparison of methods

Conditions at which sediment can be removed from Yahagi Dam are as follows .

1) The inflow discharge is at least the power generation discharge of 94.7 m^3/s.
2) The level in water is frequently low in Yahagi Dam due to large water demands. Thus, priority should be given to raise reservoir capacity near the limit water level in order to secure the capacity for water utilization.

Plan A (suction) is efficient because sediment can be stored in the excavate place when flood cannot be used to discharge the sediment and be discharged to the lower reaches at an arbitrary concentration (not exceeding 10%) when the flood discharge exceeds 94.7 m^3/s. The plan is also economical and is advantageous to Plan B. Plan B (sediment bypass) is inefficient because the capacity for water utilization should be secured first in Yahagi Dam and sediment can be discharged through the bypass only after the capacity is restored (at concentrations not exceeding 1%), which results in limited flood time (Table 1). Thus, Plan A (suction) was decided to be used.

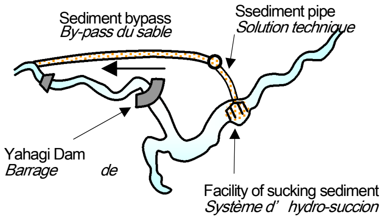
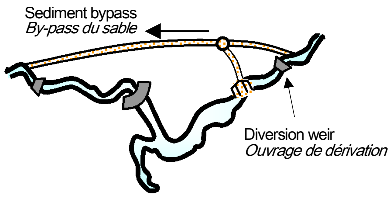
Since the results showed that the sediment in Yahagi Dam contains much sand and is prone to accumulate, a facility for sucking sediment was decided to be constructed near the shoulder of a delta (4.0 km) in the reservoir as shown in Figure 3. Sediment equivalent to the mean annual inflow (250 thousand m^3) was decided to be discharged at a maximum rate of 100 m^3/s and a concentration of 2% to the downstream of Yahagi No.2 Dam through a bypass so that the sediment does not accumulate in the dam.

The suction system is appropriate but is a newly developed technology. Thus, measures against subjects should be investigated, and the reliability of the system should be raised by conducting verification tests.

Table 1

Comparison of permanent measures for removing sediment

Comparaison entre les mesures permanentes de dessablement envisagées

Work *Solution technique*	Plan A: suction *Solution A : hydro-succion*	Plan B: Sediment bypass + suction *Solution B : by-pass du sable + hydro-succion*
Overview *Schéma*		
Basic policies *Principe*	Sediment is sucked by the facility constructed near the shoulder of a delta, is discharged through a pipe and tunnel for discharge sediment to the lower reaches. *Les matériaux solides enlevés par le système d'hydro-succion situé près de l'épaule du delta d'alluvionnement sont évacués à travers la galerie de chasse vers l'aval.*	A diversion weir is constructed at the upstream end of the reservoir to discharge part of flood water directly to the lower reaches together with sediment. The sediment that reaches the reservoir is sucked and discharged. *Une partie des eaux de crue est dérivée avec ses apports solides par l'ouvrage de dérivation situé près de la tête de la retenue et évacuée vers l'aval à travers le by-pass détournant la retenue. La part des apports solides non dérivée est évacuée par le système d'hydro-succion.*
Characteristics of the method *Caractéristiques techniques des solutions*	Sediment, mainly sand, is sucked and discharged using differences in water pressure. The sucked sediment is possible to clog the pipe or holes for discharging sediment, and the coarse-sand fraction needs to be trapped in the upper area. The facility is possible to be damaged during a flood driftwoods, and should be constructed at a site that is little prone to damage. The facility is difficult to operate during normal times because it may affect the environment in the lower reaches. The amount of sediment to discharge and duration can be controlled. The method is new and should be verified. *Ce procédé est applicable principalement au sable et utilise la différence de la pression hydraulique pour sucer et évacuer des matériaux solides.* *L'évacuation par hydro-succion des graviers peut poser des problèmes, tels que l'obstruction de la conduite de chasse, et nécessite donc le captage en amont des éléments grossiers.* *Le système d'hydro-succion doit être mis en place de telle manière qu'il ne soit pas endommagé par le passage des bois flottants en période de crue.* *L'exploitation en dehors des périodes de crue est difficile, compte tenu de ses influences sur l'environnement en aval.* *Le volume des matériaux évacués et la durée d'opération peuvent être contôlés.* *Étant une nouvelle technologie, ce procédé nécessite une vérification*	All kinds of sediment flushing be removed, including sand, gravel, silt and clay. Since flood water needs to be diverged, the proportion of sediment that can be discharged is about the proportion of the flood water diverged. The bypass tunnel is more expensive than that in Plan A. Since the demand for water for utilization is large, the amount that flows into the bypass is small (and so the amount of detouring sediment). The characteristics of the suction method are as described on the left column. *Ce procédé est applicable aux matériaux de toute granulométrie allant de gravier et sable à limon et argile.* *Comme une partie des eaux de crue est dérivée, le volume des matériaux évacués est proportionnel approximativement au débit dérivé.* *Le by-pass est très couteux par rapport à la solution A* *La demande en eau étant importante, le débit liquide (et solide) entrant dans le by-pass est faible.* *Le système d'hydro-succion adopté dans cette solution a les caractéristiques décrites dans la colonne gauche.*
Comprehensive evaluation *Évaluation synthétique*	The technology is new and has several problems, but is efficient because sediments can be stored in the excavated open space sockets during normal times and discharged at an arbitrary concentration (not exceeding 10%) during floods. It is more economical than Plan B. *C'est une nouvelle technologie qui laisse à désirer. Elle constitue toutefois une méthode efficace permettant, dès que le débit de crue devient utilisable, d'évacuer à une concentration voulue (jusqu'à 10 %) les matériaux stockés dans la poche ouverte durant la période où l'évacuation de la crue vers l'aval est impossible. Par ailleurs, ce procédé a l'avantage d'être plus économique que la solution B.*	The sediment bypass is little efficient because ensuring the water for utilization is a matter of priority at Yahagi Dam and flood water is detoured after the reservoir water level is restored (concentration: not exceeding 1%). *Le maintien de la réserve utile étant prioritaire pour le barrage de Yahagi, l'évacuation de la crue (à une concentration inférieure à 1 %) à travers le by-pass ne peut se faire qu'après la remontée du niveau du lac et pendant une période très limitée. Ce n'est donc pas une solution efficace.*
	○	△

4. INVESTIGATING THE IMPACTS TO THE LOWER REACHES BY SEDIMENT FLUSHING

4.1. INVESTIGATING THE EFFECTS OF SEDIMENT FLUSHING

As a large amount of sediment will be permanently supplied in the Yahagi River after the implementation of the permanent sediment control measure, a plan was drawn up for investigating the impacts for which responses can be predicted by preparing an impact-response diagram in which changes in physical environment by sediment supply and resultant effects on facilities and biological environments are considered.

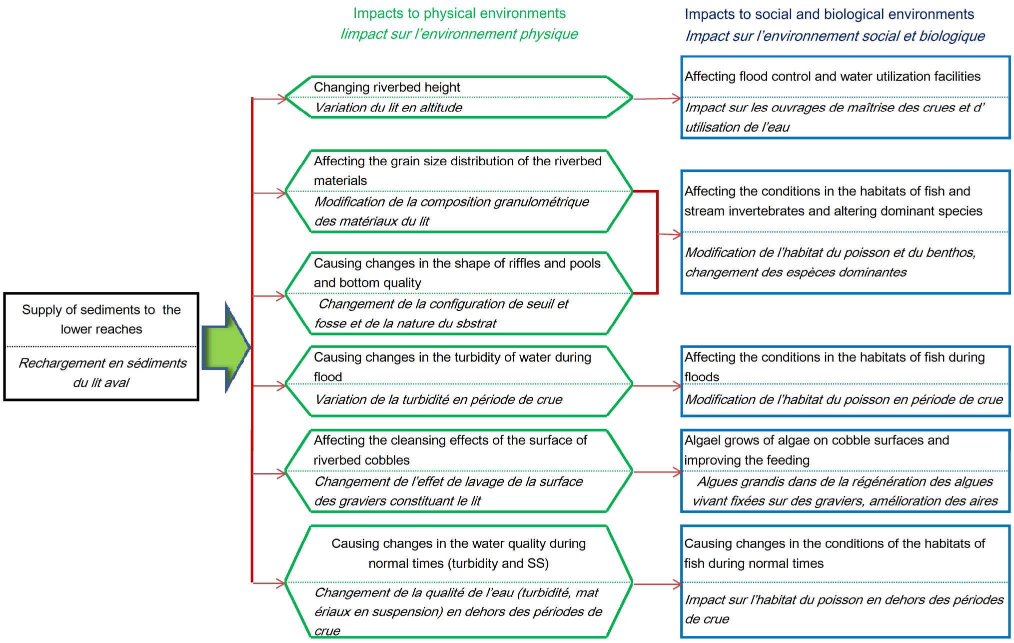


Fig.6

Possible impacts and responses by sediment flushing

Relation impact – réponse estimée du dessablement

Simulation analysis of riverbed changes and sediment supplying were decided to be used to predict and assess the effects. The investigations were decided to be conducted in a flow shown in Figure 7 by investigating sediment control measures in the lower reaches.

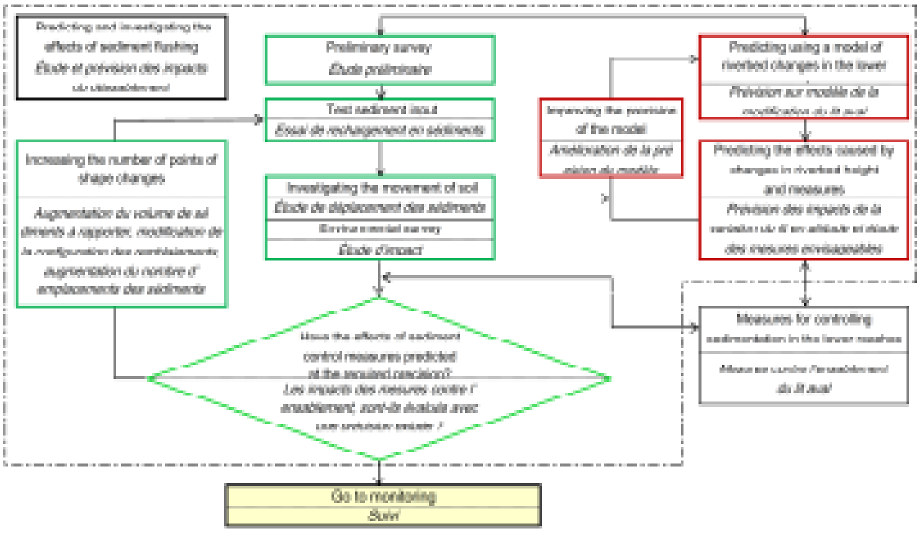


Fig.7

Flow chart for predicting and assessing the effects of sediment flushing

Organigramme de prévision et d'évaluation des impacts du dessablement

4.2. PREDICTING EFFECTS ON THE PHYSICAL SITUATION IN THE LOWER REACHES

In order to predict changes in physical situation in the lower reaches caused by permanent sediment flushing, a simulation analysis was conducted using a model for calculating the changes in the riverbed at the lower reaches.

(1) Conditions of investigation

Table 2
Conditions used for investigation
Conditions d'étude

Item *Catégorie*	Conditions *Conditions*
Period of investigation *Période d'étude*	32 years up to 2003 (flow regime in 1971 to 2003) *32 ans à partir de 2003 (régimes de 1971 à 2003)*
Section calculated *Zone d'étude*	From the estuary to the point where sediment is to be discharged *entre l'embouchure et le point d'évacuation des matériaux solides*
Structures across the river *Ouvrages sur la rivière*	Fujii ground sill, Meiji intake weir, Koshido Dam, Azuri Dam and Douzuki Dam *seuil de fond de Fujii, ouvrage de dérivation de Meiji, barrage de Koshido, barrage d'Azuri, barrage de Douzuki*
Sediment discharge condition *Conditions de dessablement*	Mean sediment volume to be discharged: 249 thousand m^3 / year *V olume moyen annuel des matériaux évacués : 249.000 m^3/an*

The amount of sediment discharged from the dam is the sum of the sediment that passes the dam (mainly wash load) and the sediment absorbed and discharged (mainly sand). The amount of sediment is shown in Figure 8 for each year (1979 is removed from the data because it was a draught year). As shown in Figure 9, the sediment mainly consisted of sand.

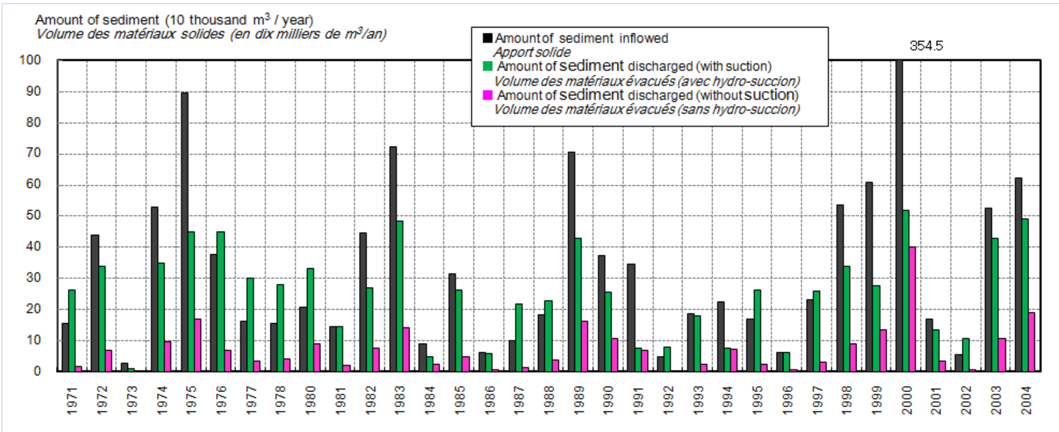


Fig.8
Inflow or removed Sediment at Yahagi Dam
Évolution des volumes des matériaux entrés et évacués de la retenue de Yahagi

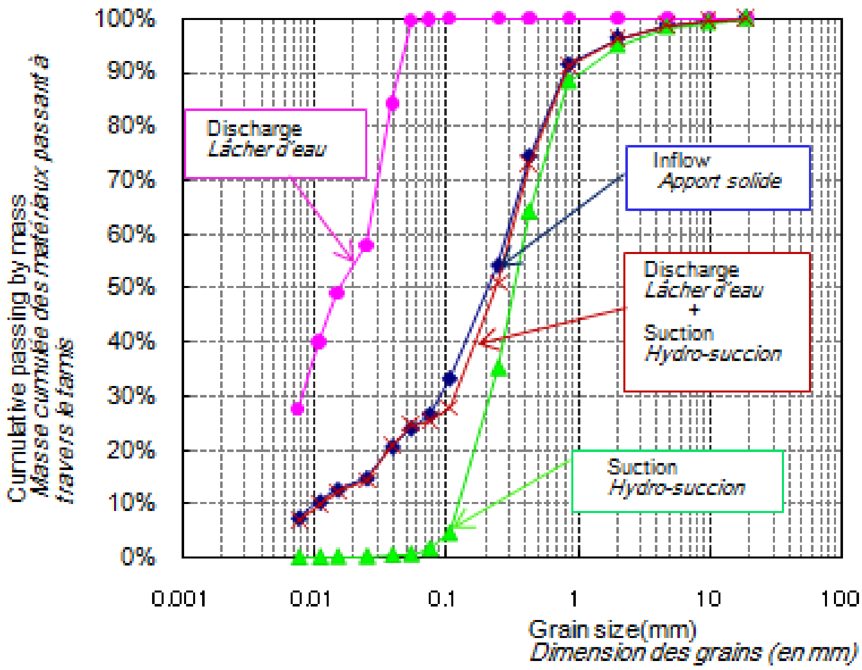


Fig. 9

Sand size distribution of the discharged or Inflow sediment

Granulométrie des matériaux entrés et évacués

(2) Calculation cases

The analysis was conducted following three calculation cases: with and without suction under the present dam gate operation for power generation and with suction by leaving the gate open.

1) Changes in riverbed height (Figure 10)

Case 0:

Sediment will accumulate in the water storage area of Azuri and Koshido Dam reservoir because the gates are infrequently opened during floods, which decelerates the flow.

Case 1-1:

Sediment will accumulate in Douzuki, Azuri and Koshido Dams because the flow decelerates in the reservoirs. The effects of sediment flushing to the riverbed height will be small at the downstream of Koshido Dam.

Case 1-2:

Sediment will accumulate in Douzuki, Azuri and Koshido Dams, but the rises will be smaller than in Case 1-1 because the gates will be always left open. The riverbed will rise at the downstream from 30km because sediment will be easy to flow down to the lower reaches.

Table 3
Calculated cases
Cas de calcul

Case *Cas*	Suction and discharge *Hydro-succion*	Operation of the gates of the power generation dam *Manœuvre des vannes du barrage de production d'énergie*
Case 0 *Cas 0*	No suction *inapplicable*	As today *consignes de manœuvre actuelles*
Case 1-1 *Cas 1-1*	With suction and discharge ($249{,}000 m^3$/year on average) *Applicable* *(en moyenne249,000 m^3/a/n)*	As today *consignes de manœuvre actuelles*
Case 1-2 *Cas 1-2*		Gates are assumed to be always open. *supposant que les vannes restent ouvertes en permanence*

(3) Results of prediction

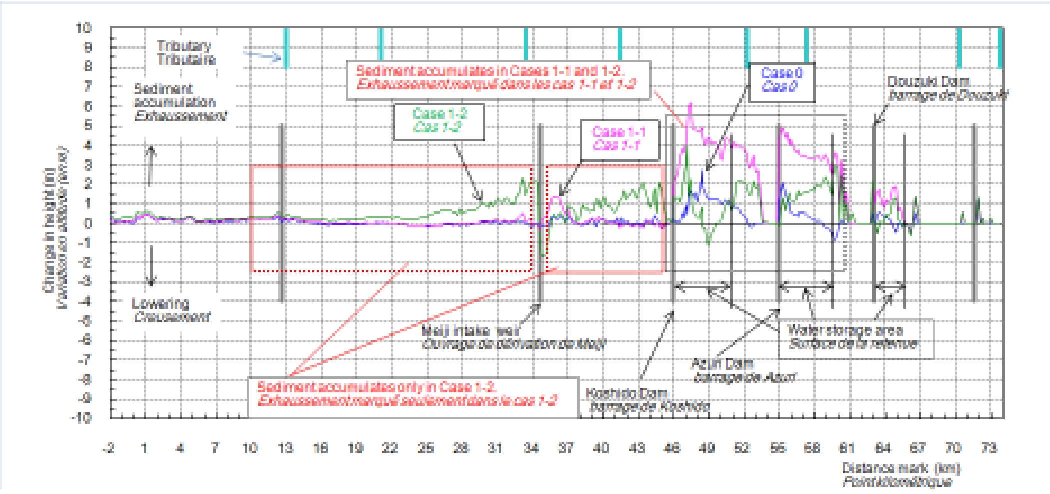


Fig.10
Changes in the height of the riverbed
Variation du lit en altitude

2) Changes in riverbed materials (Figure 11)

Cases 0 and 1-1:

Since sediment will accumulate in dams for power generation, relatively large stones will accumulate in the upstream of the Meiji intake weir as in the very past. The sand size in the section upper than Koshido Dam will decrease because sediment that contains much fine sand will be supplied from Yahagi Dam, where the sediment is sucked in.

Case 1-2:

Because the gate of the power generation dam will be left open, the sediment in the reservoir of Yahagi Dam, which contain much fine sand, and the reservoir of the power generation dam will flow down to lower reaches, the sand size will decrease in the riverbed upper than the Meiji intake weir.

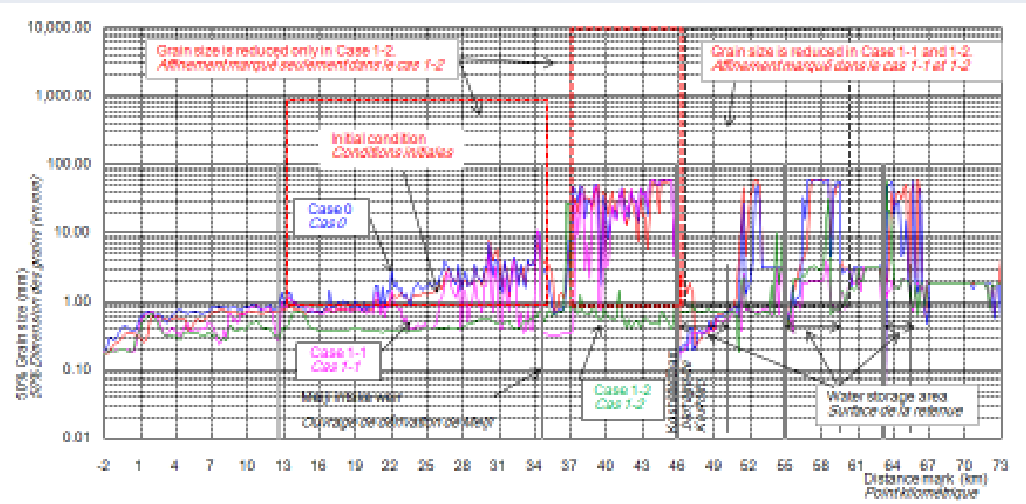


Fig.11

Changes in riverbed materials

Modification des matériaux du lit

3) Changes in flux (sand) (Figure 12)

Case 1-1:

160,000 to 120,000 m^3 of sand will flow to the Azuri Dam reservoir. The sand flux will decrease to 50,000 m^3 in the reaches lower than Koshido Dam. This is because the friction velocity will fall below the criteria for moving sand.

Case 1-2:

160,000 to 140,000 m^3 of sand will flow up to the intake weir of Meiji. The flow will decrease to 80,000 m^3 by Fujii ground sill. This is because the gates will be left open, increasing flow velocity and traction force.

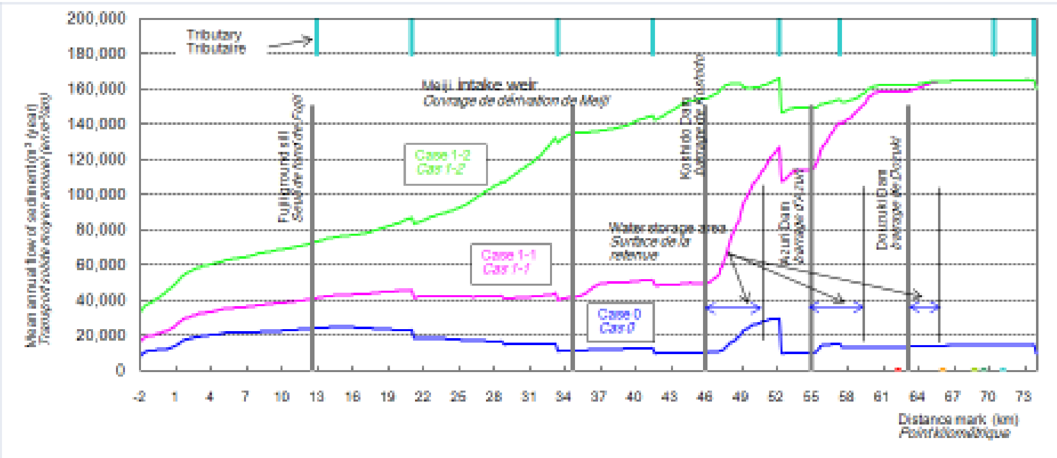


Fig.12

Changes in flux (sand)

Variation du flux (de sable)

2. SEDIMENT SUPPLY

Sediment supplying (dam sediment is transported to a downstream site and is discharged during a flood) was according to the flow shown in Figure 7 by investigating the amount of sediment, input shape and sites can predict the sediment flushing from dams. In the sediment supply, the effects were investigated by noting the following points:

1) Reference data that sediment supplying is not influenced by dam reservoir was obtained by investigating the upstream of dam reservoirs and tributaries of similar scales.

2) Since the amount of sediment is smaller than the actual amount to be supplied by sediment flushing, the effects were estimated by also studying the results of riverbed fluctuation calculations and river environment surveys conducted before the construction of the dams

3) The geomorphology of the river was surveyed by taking special attention to sites (such as pools) that easily changes in riverbed height.

2.1. AMOUNT OF SEDIMENT SUPPLING AT A TIME

Sediment flushing from Yahagi Dam is planned at a maximum rate of 100 m^3/s and a concentration of 2%. Thus, 4,000 m^3 of sediment supplying at a time by calculating the amount discharged by a peak inflow of 200 m^3/s equivalent to once a year discharge at Yahagi Dam.

Sediment was supplied on the right and left banks at Odo (Figure 13). At each site, 2,000 m^3 was placed to have cross section profiles shown in Figures 14 .

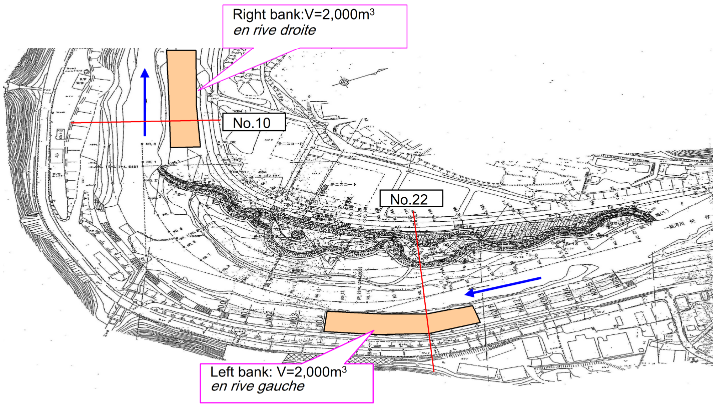


Fig. 13
Zones of sediment supplying
Emplacements des sédiments à rapporter

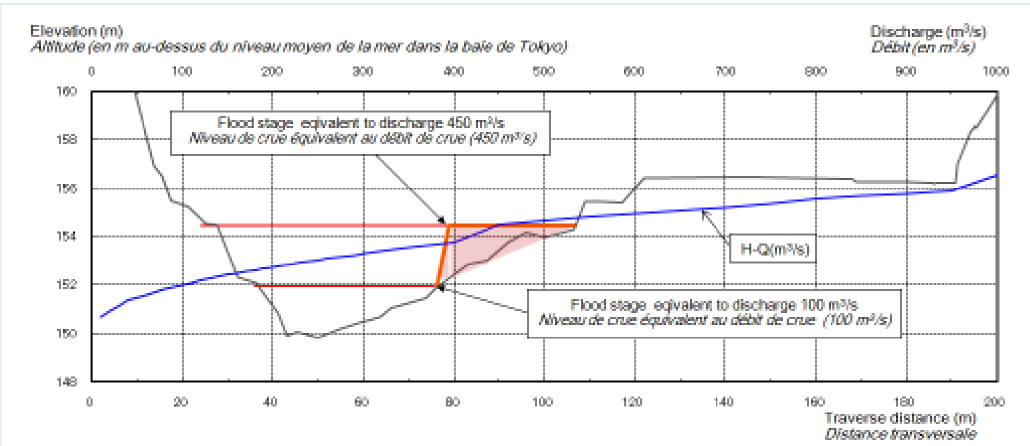


Fig. 14
Sectional profile of the right bank zone where sediment was supplied
Profil en travers du remblaiement en rive droite

2.2. INVESTIGATING EFFECTS

The effects of sediment supplying were investigated on sand size constitution, cross section, riverbed materials, water quality and organisms. An overview of the investigation is shown in Table 4.

Table 4

Contents of the survey on the impacts to the lower situation by sediment flushing

Étude d'impact du rechargement en sédiments sur le lit en aval

Pavticular *Pavticulier*	Target *Objet d'étude*		Item *Catégorie*	Contents *Contenu*
sediment supplying *Sédiments rapportés*	Grain size constitution *Composition granulométrique*		Grain size inspection *Analyse granulométrique*	Collecting data to understand the basic conditions *Récolte de donnée pour établir des conditions de base.*
Conditions of the lower reach *Cours d'eau aval*	Situation *Lit*	Shape *Topographie*	Cross sectional surveying *Levé de profils en travers (sondage)*	Conducting surveys at survey points and near existing dams and intake facilities *Levé effectué aux sites d'étude, au niveau des barrages et seuils existants et au*
			Precise surveying of riffles and pools *Levé minutieux des seuils et fosses*	Monitoring changes in riverbed height *Détermination de la variation du lit en altitude*
		Riverbed materials *Matériaux*	Visual inspection and grain size analysis at major points *Observation visuelle et analyse granulométrique en points principaux*	Preparing maps of riverbed materials by observing the river course visually Analyzing the distribution of sand fraction accumulating on downstream sides of rocks Taking photographs of quadrats Taking aerial photographs of the river from a radio-controlled helicopter *Établissement de profils des matériaux du lit à partir de l'observation visuelle du lit* *Détermination de la répartition des éléments sableux déposés à l'aval de gros blocs* *Prise de vue avec un quadrat* *Prise de vue aérienne du cours d'eau par un héricoptère télécommandé*
	lood control and water use facilitie *Ouvrages de maîtrise des crues et d'utilisation de l'eau*		Visual inspection at the field, interviewing *Observation visuelle sur le terrain et interview*	Checking the services, maintenance and operation of facilities Investigating the effects by returning soil *Fonctionnement et entretien des ouvrages,* *Impact du rechargement en sédiments*
	Water quality *Qualité de l'eau*		Turbidity (SS, degree of turbidity) *Eau trouble (matériaux en susupension, turbidit*	Measuring turbidity at the entrance and outlet of dams and at the upstream and downstream of the zones at which soil was returned Measuring grain size at the start, peak and end of a flood *Mesure de la turbidité en entrée et en sortie de la retenue ainsi qu'en amont et en aval des emplacements des sédiments rapportés* *Mesure de la dimension des grains au début, en période de pointe et à la fin de la crue*
			Water temperature, pH *Température de l'eau, pH*	Measuring temperature and pH as basic data *Récolte de données de base*
Environmental states in the lower reach *Environnement du cours d'eau aval*	Organisms *Biologie*		Fish species *Poisson*	Understanding the number of *Plecoglossus altivelis* and living states in each zone *Détermination, tronçon par tronçon, de la population et de l'habitat du poisson en particulier du saumon «ayu »*
			Stream invertebrates *Benthos*	Understanding the biodiversity of stream invertebrates by sampling at quadrats Understanding the number and population of dwelling species *Prélèvement d'échantillons du benthos à l'aide d'un quadrat pour déterminer sa diversité* *Détermination du nombre d'espèces et de leur abondance par type biologique*
			Attached algae *Périphyton algal*	Investigating the amounts of chlorophyll a and pheophytin *Détermination de l'abondance de chlorophylle a et de phéophytine*

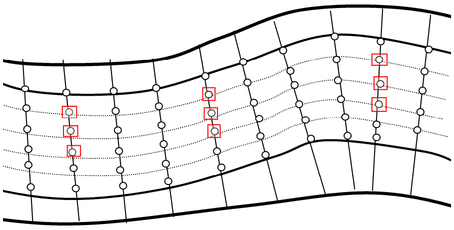
The distribution of riverbed materials were analyzed by visually determining the sizes of riverbed materials in quadrats of 1 to 2 m in dimensions (Figure 15) and preparing a two-dimensional map, which enabled changes in distribution before and after sediment supplying to be compared.

The accumulation states of sediment on the downstream side of large stones and the relationship with sediment flow were also investigated. Sediment that deposited among cobbles were sampled at representative points and was subjected to laboratory sand size analysis.

Biological environment was investigated by 1) organizing the characteristics of biological environment after sediment supplying by relating spatial and time historical changes and the changes in physical environment based on the impact-response diagram shown in Figure 6, 2) assuming changes in the environment of inhabiting organisms (effects and impacts), and 3) briefly examining especially noted species.

Fish, stream invertebrates and attached algae were decided to be investigated based on sediment supplying projects in other rivers and a manual prepared by the Water Resources Environment Technology Center entitled "Survey Manual of Environmental Impact due to Sediment Supply to River (first draft)" [2]. Particularly, stream invertebrates and attached algae were likely to quickly sediment supplying and were thus monitored.

The size of gravel immediate under the surface layer, which also affects the living environment of stream invertebrates, was also measured. Algae attached not only on the surface of gravel but also between them were surveyed.



○Grain size survey site along the traverse line
Position de détermination de la granulométrie le long des lignes du relevé
□Taking photographs of quadrats
Prise de vue avec un quadrat

Fig.15
Schematic view of the cross sectional surveying
Schéma de levé de profils en travers

2.3. RESULTS OF SEDIMENT SUPPLYING

(1) Location of sites investigated

Seven points in total were investigated: three for comparison (C-1 to C-3) and four (I-1 to I-4) for investigating the effects of sediment supplying. The locations of the points are shown in Figure 16. C-1 is at the upstream end of the reservoir of Yahagi Dam.

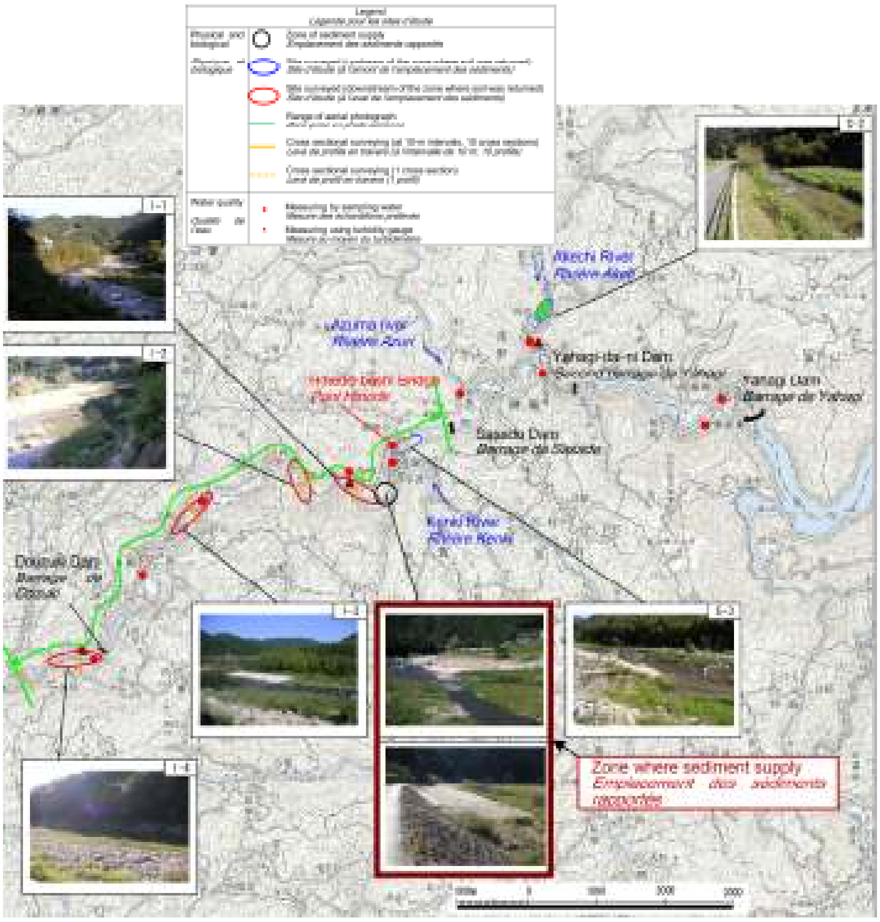


Fig. 16
Location of sites surveyed
Sites d'étude

(2) Flood (Figure 17)

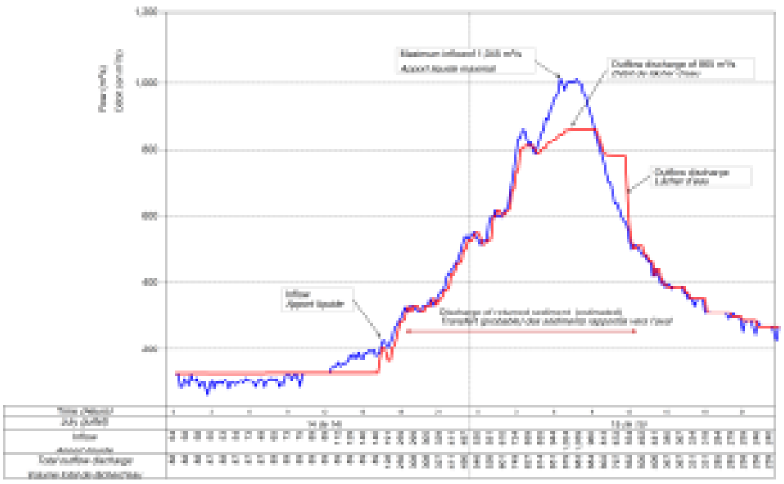
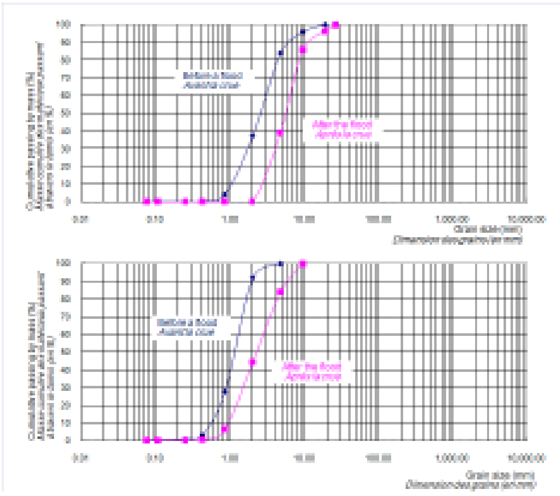


Fig. 17
Flood control situation at Yahagi Dam
Maîtrise des crues par le barrage de Yahagi

A flood of a five-year probability occurred on July 14 to 15, 2007, and washed away the entire 4,000 m3 of the sediment supply. The mean basin precipitation, inflow to the dam, and discharge during the flood are shown in Figure 17. The inflow to the dam marked the peak at 8 on July 15 with 1,045 m3/s, and the discharge from the dam was the largest at 9 of the same day with 883 m3/s. The estimated maximum flow at Odo (site of sediment supply) during the flood was about 1,080 m3/s.

(3) Changes in riverbed materials

Sand size cumulative curves before and after the flood at the upstream and downstream of the points where sediment was supplied are shown in Figure 18. At both up and downstream, the sand size increased, and no effects of sediment supply were observed. Views of the river at I-1 before and after the flood are shown in Photograph 1.

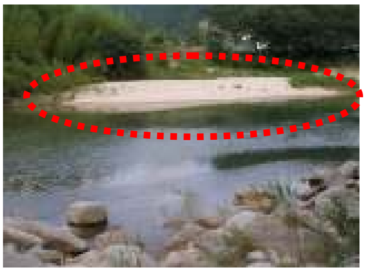


C-3
Upstream of the zone where sediment was supplied
En amont de l'emplacement des apports de sédiments

I-1
Downstream of the zone where sediment was supplied
En aval de l'emplacement des apports de sédiments

Fig. 18
Sand size cumulative curve
Courbe granulométrique

After the flood



No special change was observed in the riverbed sand and fine gravel fractions increased on the land sections of inner curves. Vegetation at riversides fell and washed away.
En rive convexe, on observe aucune modification du dépôt de sables. Les graviers fins progressent en abondance. La végétation, affouillée, tombe et est emportée par le courant

Situation before and after a flood (I-1)
État du lit avant et après une crue (I-1)

(4) Water quality

As shown in Figure 19, in which turbidity is compared between upstream and downstream of points of sediment supply, turbidity increased (70 degrees) on the downstream side. However, the rise in turbidity was likely to be not attributable to sediment supply because the peak of turbidity differed from that of discharge of the sediment supply and the wash load (sand size not exceeding 0.1 mm) in the sediment supply (4,000 m^3) accounted for about only 2%.

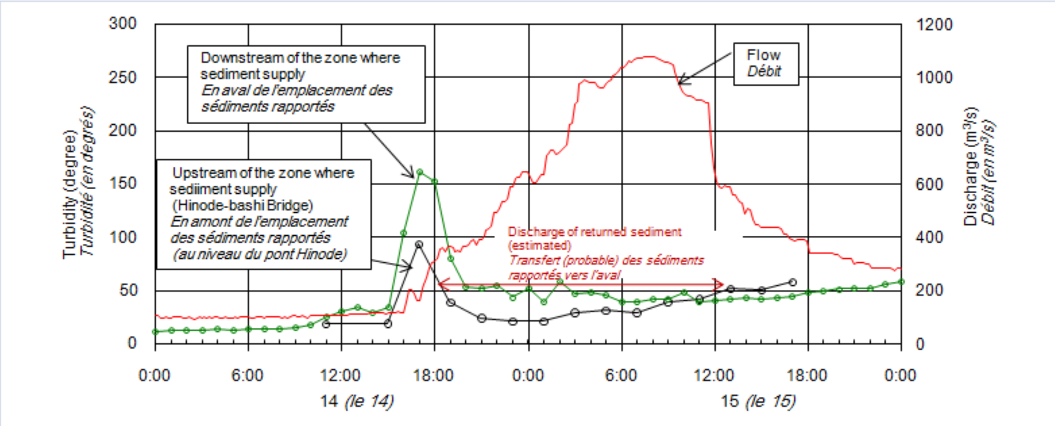
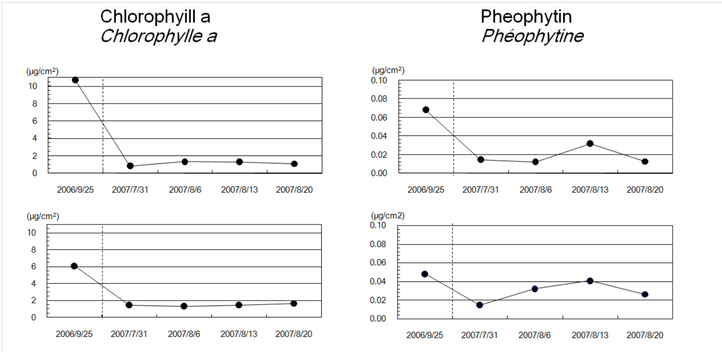


Fig. 19
Changes in turbidity in the upstream and downstream
of the zone where sediment supply
Variation de la turbidité du cours d'eau en amont et en aval
de l'emplacement des apports de sédiments

(5) Changes in attached algae

Chlorophyll a and pheophytine, which were measured as an index of attached algae, detached during the flood. They did not restore in one month. The same trend was observed in both the up and downstream of the points of sediment supplying, the detachment and non-recovery were attributable not to the sediment supply but to the intense flood.



C-3
Upstream of the zone where sediment was supplyed
En amont de l'emplacement des apports de sédiments

I-1
Downstream of the zone where sediment was supplyed*En aval de l'emplacement des apports de sédiments*

Fig. 20
Changes in chlorophyll a and pheophytin of attached algae
Évolution de l'abondance de chlorophylle a et de phéophytine du péripyton algal

(6) Stream invertebrates and fish

Effects of the sediment supply could not be understood this time. Thus, effects should be further monitored.

CONCLUSIONS

The suction system is an appropriate permanent sediment control measure in Yahagi Dam. However, the technology is new. Thus, measures against assignment should be urgently investigated, and the reliability of the system should be raised by conducting verification tests. Sediment supplying for checking the effects of sediment flushing to river environments were insufficient for predicting long-term effects because the amount of sediment to be return is small. Thus, long-term effects of massive sediment supply from a permanent facility were predicted by conducting a simulation analysis on riverbed changes.

Use of predicted changes in physical situation by riverbed fluctuation calculations for assessing impacts on living organisms has been little understood as effects of changes in physical conditions (sand size, turbidity, etc.) on biological environments and organisms have been scarcely investigated [3]. Effects of changes in physical situations on biological environment and organisms should be further investigated by monitoring.

REFERENCES

[1] Water Resources Environment Technology Center, Fiscal 2007 Yahagi Dam Improvement Project Investigation Report (in Japanese), 2008

[2] Water Resources Environment Technology Center, Survey Manual of Environmental Impact due to Sediment Supply to River (first draft) (in Japanese), 2005

[3] TSUKAHARA, Koichi: Present states of environmental measures in dam projects and acts to be taken (in Japanese), Journal of Kasen, No. 713, pp. 12-17, 2005

SUMMARY

In order to ensure and keep the flood control capacity (of the Yahagi Dam), sediments must be urgently removed by excavation. As a subsequent and permanent measure, sediment bypass and a suction system were comparatively investigated. The suction method was decided to be used since it was found during the operation of the dam that the method was efficient, the sediment contained much sand, and there were sites that were prone to sand accumulation. The facility for sucking sediment was decided to be constructed near the shoulder of a delta (4.0 km from the dam) in the reservoir, to discharge 250,000 m^3 of sediments, which is equivalent to the mean annual sediment inflow, to the downstream of the dam through a bypass at the maximum rate of 100 m^3/s and a concentration of 2%.

Possible impacts by sediment flushing were investigated by preparing an impact-response diagram on changes in physical situations in the lower reaches and impacts to facilities and biological situations, based on which a plan for surveying impacts was drawn up and the survey was conducted. Impacts were estimated and assessed by conducting a simulation analysis on linear riverbed changes to predict changes in physical situations (riverbed elevation, materials, and flux) caused by sediment flushing and surveying the water quality (MES and concentration) and biological situations (fish species, stream invertebrates, and attached algae). After a large flood, a survey was conducted to examine the effects of sediment flushing. However, the effects could not be confirmed because the flood was too large (five-year probability).

RÉSUMÉ

Afin d’assurer et de maintenir la capacité de contrôle de la crue (du barrage Yahagi), les sédiments doivent immédiatement être enlevés par excavation. Un

système de dérivation de sédiments et un système à succion ont été évalués comparativement comme mesure ultérieure et permanente. La méthode par succion a été retenue après avoir démontré son efficacité lors de l'exploitation du barrage, les sédiments comportant une quantité importante de sable, et plusieurs sites étant prônes à l'accumulation de sable. L'installation de succion des sédiments a été mise en place à proximité d'un bras de delta dans le réservoir (à 4,0 km du barrage), pour passer 250 000 m^3 de sédiments, l'équivalent du débit entrant annuel moyen, et les évacuer à l'aval du barrage à travers une dérivation d'un débit maximal de 100 m^3/s et à une concentration de 2 %.

Basé sur la relation impact – réponse, établie en supposant des impacts du dessablement sur l'environnement physique du lit aval et sur les ouvrages et l'environnement biologique, un projet d'étude d'impact a été élaboré et réalisé. En vue de la prévision et de l'évaluation des impacts, une simulation unidimensionnelle de la modification du lit de la rivière a été effectuée pour estimer la modification de l'environnement physique (niveau du fond, matériaux du lit, flux). Ont été également menées une étude d'environnement physique à l'aide de rechargement en sédiments, une évaluation de la qualité de l'eau et une étude d'environnement biologique (poisson, benthos, périphyton algal). Une étude conduite après la crue n'a pu détecter les conséquences du rechargement en sédiments à cause de l'ampleur de la crue (une crue quinquennale).