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Coordinated Sediment Flushing and Effect Verification of Fine Sediment Discharge Operation in Kurobe River

S. Minami, K. Noguchi & H. Otsuki
River Engineering Group NEWJEC Inc., Japan
minamish@newjec.co.jp

H. Fukuroi, N. Shimahara & J. Mizuta
Kansai Electric Power Co., Inc., Japan

M. Takeuchi
Kurobe River Work Office, Hokuriku Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism, Japan

ABSTRACT:
Dashidaira dam operated by the Kansai Electric Power Co., Inc. (KEPCO) and Unazuki dam operated by Ministry of Land, Infrastructure, Transport and Tourism (MLIT) , all located at Kurobe River have large scale sediment flushing gates at the bottom of the dams, and in case of flooding, the coordinated sediment flushing and sluicing are carried out in both of the dams. In addition, a fine sediment discharge operation on trial has been newly introduced to cope with localized torrential rain. In this report, the outlines of the sediment flushing at Dashidaira dam and the coordinated sediment flushing and sluicing is reported, and results of the fine sediment discharge operation is verified through the results of on-site observation and the numerical simulation.

Keywords: Fine sediment discharge, Coordinated sediment flushing, Numerical simulation, Sediment flushing gate, Conservation of Reservoir Environment

1. INTRODUCTION

Kurobe River located in the eastern part of Toyama prefecture is class A river in Japan. The River originates in Mount Washibadake, enters into the plain region at the Aimoto point 13km upstream of the estuary as shown in Fig.1, and finally flows into the Sea of Japan. The catchment area of the Kurobe River is 682km^2, and the length of the main river is 85km. The gradient of riverbed is 1/5 to 1/100 which means one of the steepest rivers in Japan. The geographical condition in the river basin is characterized by weathered granite and the sediment production potential is very high. The annual rainfall in the mountain area of basin is about 4,000mm, and there is great amount of sediment flowing into the reservoirs on river course (PWRI, 1993). To solve the problem of reservoir sedimentation, sediment flushing has been implemented at Dashidaira and Unazuki dams. During the flood that satisfies a stipulated standard, reservoir water levels are lowered and the inside of reservoirs are emptied to increase erosion force, and the incoming sediment and deposits in the reservoirs are flushed through sediment flushing gates to the downstream channel. The sediment flushing at the Dashidaira dam has been carried out since 1991 and the coordinated sediment flushing at the Unazuki and Dashidaira dams since 2001. After that, 21 times of coordinated sediment flushing and sluicing has been implemented by July 2011 (MLIT, HP.).

Figure 1. Location of dams in the Kurobe River basin

The coordinated sediment flushing described above is implemented on condition that there is the sufficient water flow after the flood satisfies stipulated standard and exceed the estimated flow. Nevertheless, localized torrential rain occurs frequently in various regions of Japan recently and Kurobe is no exception either; that causes a extremely peaky curve of water inflow and makes the quantity of stream flow with a gravity flow insufficient if water level of reservoirs is lowered after confirming the peak of water inflow. As a result, the sediment flushing has not been carried out adequately in such localized torrential rains in recent years and thus the incoming sediment in such occasions keeps on depositing in the reservoirs of both dams. The fine sediment discharge operation, a measure of the sediment sluicing operation without lowering the reservoir water level during the localized torrential rain, is introduced to alleviate a negative influence to the downstream environment during the next sediment flushing (MLIT&KEPCO, 2010.3).

In this paper, the outlines of the sediment flushing at Dashidaira dam and the coordinated sediment flushing are introduced and the results of verified effects of fine sediment discharge operations are reported.

2. SEDIMENT FLUSHING RECORD AND COORDINATED SEDIMENT FLUSHING PLAN

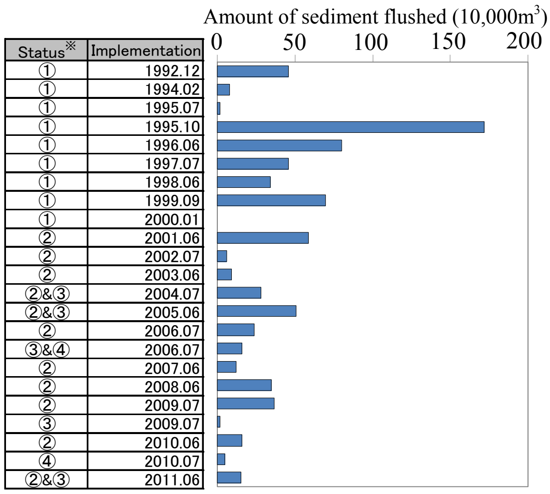
2.1 Sediment Flushing Record of Dashidaira Dam

Dashidaira dam was constructed in June 1985 with capacity of 9 million m^3. After 6 years, the first sediment flushing has been carried out in December 1991; in consequence, turbid water contained with organic matters like degraded litter was diffused to the estuary and had negative impacts on the environment.

Considering the serious impacts on the environment, “Environmental Assessment Committee on Kurobe River Dashidaira Dam Sediment Flushing” was established in September 1992, which consists of experts and relevant organizations and has been investigating and discussing the importance of sediment flushing and the low impact means of sediment flushing. In February 1994 and July 1995, a little amount of sediment was flushed experimentally for confirming the effectiveness of flushing measure. As the result, several suggestions were proposed: sediment flushing shall be implemented just at the moment it flooding, supplemental alleviations shall be taken and investigation of environmental impact shall be continued (Environmental Assessment Committee, 1995.7). After 1998, sediment flushing has been implemented just when it floods. Fig.2 represents the record of the actual amount of sediment flushed.

2.2 Coordinated Sediment Flushing Plan

Unazuki dam was constructed in 2001 with capacity of 24.7 million m^3. After 2001, coordinated sediment flushing has been carried out at Dashidaira and Unazuki dams following to the rules in Table 1 and the procedure is shown in Fig.3.



※①:Independent flushing at Dashidaira dam, ②:Coordinated sediment flushing, ③:Coordinated sediment sluicing, ④:Trial coordinated sediment sluicing

Figure 2. Actual amount of sediment flushed at Dashidaira dam

The sediment flushing is categorized into coordinated sediment flushing and sediment sluicing according to its purposes. The coordinated sediment flushing is carried out when it flood from June to August for transporting the sediment which deposit from the last sediment flushing operation in the previous year to the just before sediment flushing in the current year. On the other hand, sediment sluicing is also implemented from the same period for transporting the incoming sediment from upstream to downstream. As to the trial coordinated sediment sluicing mentioned in Fig.2 is to be carried out to alleviate impact on the downstream under the next coordinated sediment flushing and sluicing even when the flood discharge does not reach the criteria of sediment sluicing. The trial coordinated sediment sluicing is withheld since it is concluded that the expected effect would not be obtained after the result of investigation in 2010.

Table 1. Coordinated Sediment Flushing Main Plan

Item	Sediment flushing		Sediment sluicing	
	Dashidaira dam	Unazuki dam	Dashidaira dam	Unazuki dam
(1) Period	･The first flood whenever either of Dashidaira or Unazuki exceed the flood levels of 300m^3/s or 400m^3/s from June to August.		･Whenever either of Dashidaira or Unazuki exceed the flood levels of 480m^3/s or 650m^3/s from June to August after implementing the sediment flushing.	
(2) Amount of sediment flushed	･The exceed sediment for keeping the stable longitudinal profile.		･Transporting the incoming sediment from upstream to downstream under the flood flow.	
(3) Measure	･Gravity flow		the same as on the left	
(4) Hour	･The hour required for flushing the exceed sediment for keeping the stable longitudinal profile.		･Within implementing gravity flow at Unazuki.	･Within 12 hours after the gravity flow.
(5) Post-treatment after flushing & sluicing operation	･The withdrawal for power generation is stopped for 24 hours after sediment flushing; discharge the entire flow entering the dam downstream.	･Entire flow is discharged from the dam and Unazuki power station for 24 hours after sediment flushing.	･Flush at the dams and the power station located on the downstream for 12 hours after sediment sluicing.	

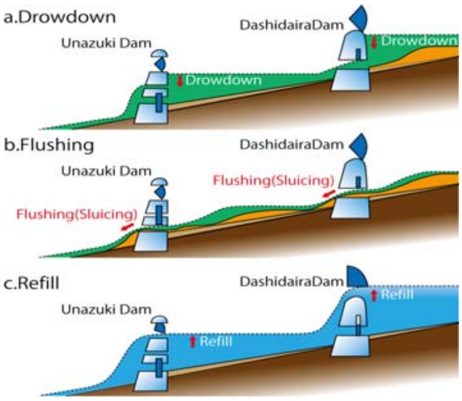


Figure 3. Outline of coordinated sediment flushing

As implementing the sediment flushing, prior consultation is conducted with fisherman's cooperative association and other relevant organizations, and then a sediment flushing plan is made. The plan contains the time schedule and the water flow criteria of sediment flushing and other related matters. Thereafter, "Kurobe River Dam Sediment Flushing Evaluation Committee" which consists of those people who have relevant knowledge and experience evaluates its flushing measure and environmental survey and after that, brings up the plan at "Consultative Committee on Kurobe River Sediment Flushing Management" consists of the representatives of the relevant executive branches; then flushing plan is completed after the consensus of the local residents. Up to now, both the Committee and Consultative Committee have evaluated the past plans that there certainly exists the temporary impacts on the environment, however, no serious matters would not be occurred throughout the flushing. Furthermore, they remark that the plans have been revised to achieve the flushing and sluicing operations conducted with near-nature conditions; thus it is concluded that the current flushing operations has a little impact on the downstream environment.

3.EFFECTS VERIFICATION OF FINE SEDIMENT DISCHARGE OPERATION

3.1 Method and Results of Fine Sediment Discharge Operation

The aim of fine sediment discharge operation is to alleviate the negative impact on the downstream in the next flushing operation following to: 1.the transportation of the incoming sediment to the downstream and not deposit them in the reservoirs as far as possible and in the meanwhile, 2.the control of oxygen supply by inducing current near the reservoir bottom and prevent the bottom material from deteriorating by operating the gate in the lower side of the dams. The fine sediment discharge operation is regarded as the alternative measure to the trial coordinated sediment sluicing with low environmental load.

The fine sediment discharge operation is carried out opening the sediment flushing gate set at the lower side of Dashidaira dam and the gate for water-level lowering set at the middle of Unazuki dam respectively in floods flowing after implementing the sediment flushing from June to August. This does not involve the decline of reservoir water level and keeps the normal water level. Once the amount of water flow or the turbidity of the water is reduced, the operation is closed. The outline is described in Fig.4. Fine sediment discharge operation has been carried out once in August 2010 and 6 times in 2011 already, as shown in Table.2.

Table 2. Implementation of Fine Sediment Discharge Operation

	The Peak of water income		Opening hours of gate	
	Dashidaira (m^3/s)	Unazuki (m^3/s)	Dashidaira	Unazuki
2010/8/12	313.7	436.0	6h37m	6h39m
2011/6/28	331.6	360.0	4h2m	7h2m
2011/6/29	321.1	348.0	11h8m	11h53m
2011/7/4	370.0	456.6	2h	6h29m
2011/7/8	314.4	457.5	4h2m	4h26m
2011/7/28	351.4	391.4	8h2m	10h20m
2011/7/29	314.0	346.7	4h5m	6h58m

3.2 Validation Methods of Effect

The effect is validated according to the following measures. First the suspended solid concentrations (SS) in the 2 cases whether the fine sediment discharge operation is implemented or not at both 2 dams are compared by the simulation. This aims to confirm its effect that the operation increases fine sediment discharge. The data of water flow in August 2010 is applied; furthermore its effect is verified based on the 2-D numerical simulation model. Fig.5 shows the fine sediment discharge operation in August 2010.

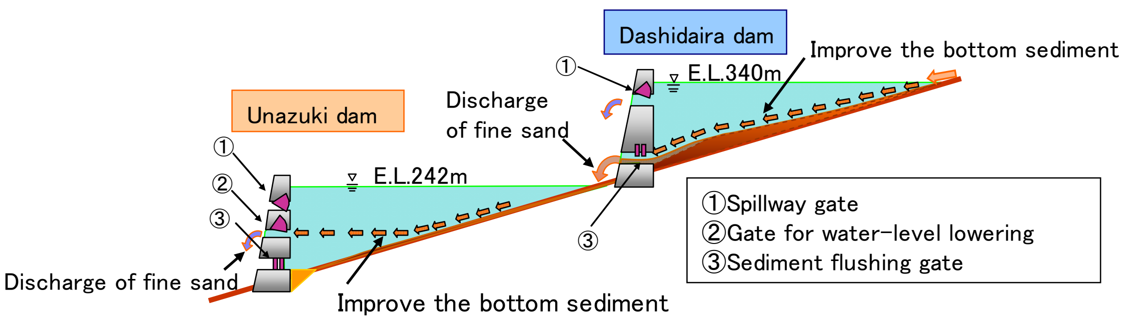


Figure 4. Outline of fine sediment discharge (MLIT&KEPCO, 2010.3)

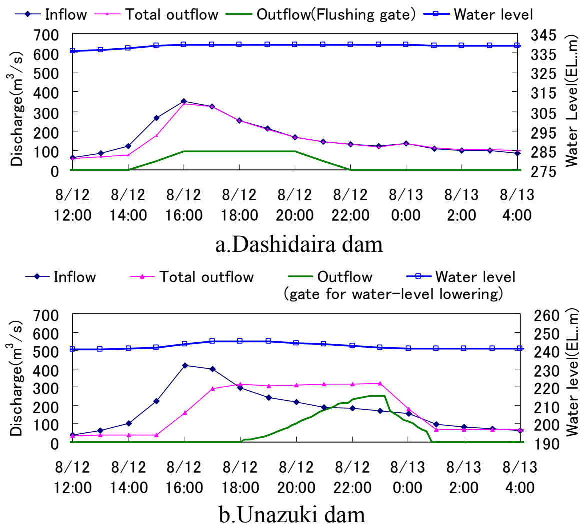


Figure 5. Fine sediment discharge operation in August 2010

Through the investigation of the surface layers of sediment at the bottom of the reservoirs from the designated points before and after the fine sediment discharge operation in August 2010, changes of some parameters are analyzed and then the effect of fine sediment discharge for preventing the deterioration of sediment is evaluated. COD, ORP, Ignition Loss, T-N, T-P and particle size distribution are chosen as the parameters evaluated here.

3.3 Verification of Simulation Model

3.3.1 Outline of model

Two dimensional numerical turbidity simulation model is applied for the analytical model. The basic formulas of the model are shown below; Equation of water continuity Eq.1, Conservation of momentum Eq.2 and 3, and Convection diffusion equation of water temperature Eq.4 and turbidity concentration Eq.5.

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{1}$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+\frac{\partial}{\partial x}(A_x\frac{\partial u}{\partial x})+\frac{\partial}{\partial y}(A_y\frac{\partial u}{\partial y}) \tag{2}$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-g-\frac{1}{\rho}\frac{\partial p}{\partial y}+\frac{\partial}{\partial x}(A_x\frac{\partial v}{\partial x})+\frac{\partial}{\partial y}(A_y\frac{\partial v}{\partial y}) \tag{3}$$

$$\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{\partial}{\partial x}(D_x\frac{\partial T}{\partial x})+\frac{\partial}{\partial y}(D_y\frac{\partial T}{\partial y})+\frac{H}{\rho C_W} \tag{4}$$

$$\frac{\partial c}{\partial t}+u\frac{\partial c}{\partial x}+v\frac{\partial c}{\partial y}=\frac{\partial}{\partial x}(D_x\frac{\partial c}{\partial x})+\frac{\partial}{\partial y}(D_y\frac{\partial c}{\partial y})+S \tag{5}$$

The symbols in the above formulas represent; x and y for coordinates of flow and vertical directions, u and v for flow velocities against x and y directions (m/s), ρ for water density (t/m^3), A_x and A_y for coefficient of eddy viscosity against x and y directions (m^2/s), g for gravitational acceleration (m/s^2), p for pressure (N/ m^2), T for water temperature (℃), D_x and D_y for diffusion coefficient against x and y directions (m^2/s), H for heat fluxes absorbed within water surface (kcal/m^2/hr), C_w for specific heat of water (cal・$g^{-1}K^{-1}$), c for turbidity concentration (mg/l), S for occurrence and disappearance concentration of turbidity (mg/l).

3.3.2 Conditions of calculations

Mesh division is conducted based on the result of reservoir cross-sectional surveying before implementation of fine sediment discharge operation. The survey is carried out with about 100m spacing at Dashidaira dam and 200m spacing at Unazuki dam. As carrying out the survey, the reservoir is divided with spacing of traverse lines against longitudinal direction and 0.5m against vertical direction.

The actual data of the amount of inflow and outflow from every gate of water is given for calculation. In addition, the initial water temperature distribution in reservoir is referred to the actual data and applied the data with fixed value to all mesh of each reservoir, and then the water temperature and SS at the inlet section of both dams are determined on the basis of the measured value. At the upstream of Unazuki reservoir, the water temperature and the turbidity are observed continuously; the water temperature is applied with the actual data and SS is calculated from the actual data of turbidity. The SS value at Dashidaira dam is based on the actual data, and the water temperature is set at the estimated value from the air temperature. The grain size is categorized in to 5 types by its grain size of 2.5, 9.2, 25, 36.9 and 66μm based on the actual data; the fall velocity is set by the Stokes' law. The climate data is provided from Toyama meteorological observatory.

3.3.3 Verification of model

In the consequence of the calculation, the actual and the calculated values of SS on the just downstream of each dam are described in Fig.6. The figure shows that some parts have gap to some extent however, both values correspond to each other for the most part; therefore it is concluded that this model is reasonable.

3.4 Validation Method of the Effect

3.4.1 Verification by numerical simulation (MLIT&KEPCO, 2011.3)

Fig.7 shows the comparison of calculated values of SS under fine sediment discharge operation and the ordinal flooding operation at the 2 dams based on the rules in August 2010. It is confirmed that the SS value under the fine sediment discharge operation is higher at both dams. Fig.8 describes the SS distribution contour figure in the case whether fine sediment discharge operation is implemented or not at Dashidaira dam on 19:00 and Unazuki dam on 22:00 of 12th August. It is confirmed that the SS materials are swallowed into the sediment flushing gate of Dashidaira dam and the gate for water-level lowering of Unazuki dam under the fine

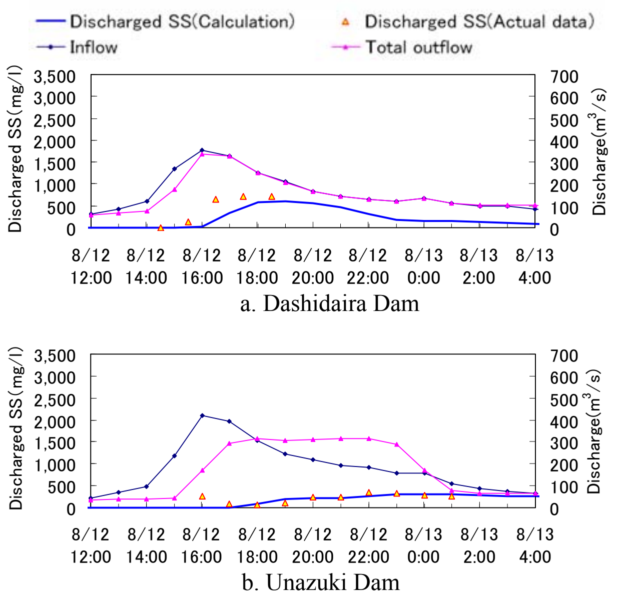


Figure 6. Comparisons of calculated and actual SS values

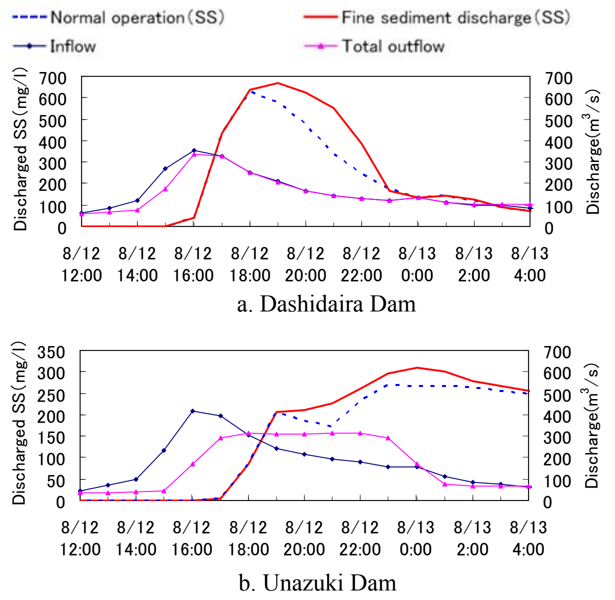


Figure 7. Comparison of predicted SS values

sediment discharge operation; this means that the water current is formed around the elevation of those gates. It is considered that the water flows toward the intake of power generation are also formed in Dashidaira dam. To sum up the above mentioned, it comes to be cleared that the discharged SS is increased and water current is formed around the opened gates through the fine sediment discharge operation.

3.4.2 Verification of effect based on the result of sediment investigation (MLIT&KEPCO, 2011.1)

Fig.9 describes the observation point of investigation, the period, the status of implementing the sediment flushing and sluicing, the period of flood occurred and the change of sediment parameters at the 2 dams in 2008 and 2010, the years the fine sediment discharge operation is implemented or not. The sediment parameters at the 2 dams take very similar changes to each other; that is to say, the values of the parameters at the point close to the body of dams (No.1&20.8k) get larger in May, before the season of implementation of sediment flushing, according to the sedimentation of organic matters. After that the values get smaller following to the implementation of sediment flushing and sluicing. In September 2008, the year fine sediment discharge operation has not been implemented, the value gotten larger and then in 2010, the year fine sediment discharge operation has been implemented the value gotten smaller. It is assumed that the fine sediment discharge operation induces water current at lower to middle level of reservoir hence the deterioration of the sediment is prevented. In contrast at other points (No.3&21.8k), there is no obvious difference on the sediment parameters.

4. CONCLUSION

The coordinated sediment flushing and sluicing

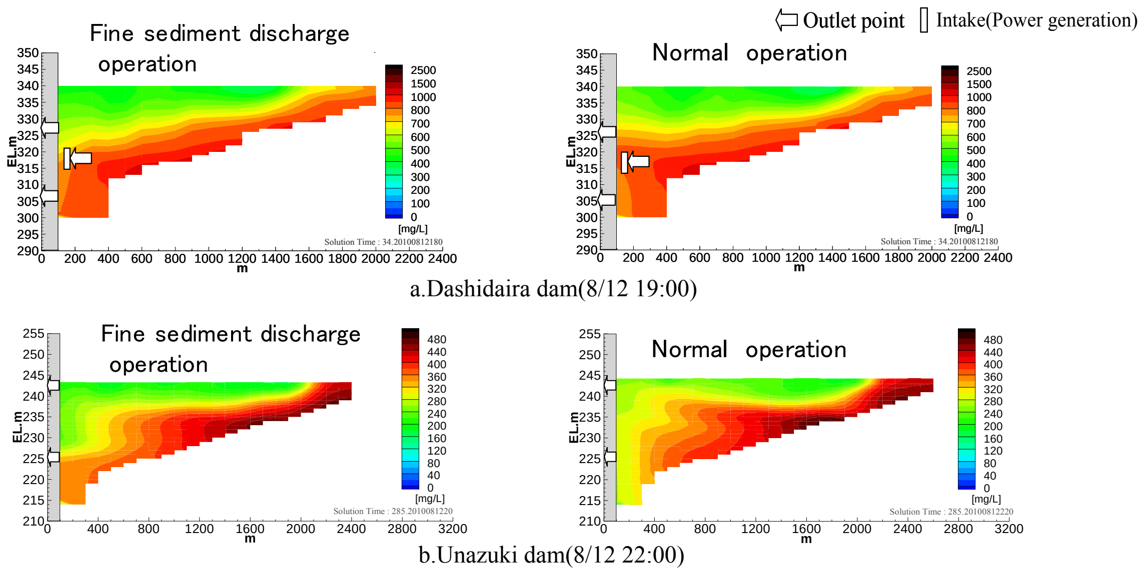


Figure 8. Calculated results of SS distribution in the reservoir

operations at Dashidaira and Unazuki dams are very essential for achieving the balanced sediment transportation through solving and preventing those problems of sedimentation, riverbed degradation at downstream and coastal erosion. However those operations normally accompany temporal, physical and biotic influences on the downstream. While the negative influences should be continuously examined, it is expected that ideal condition of sediment transport in each dam shall be achieved with the sediment management operations as mentioned in this paper.

It is necessary that the environmental impact assessment should be carried out continuously as implementing the sediment flushing and in the meanwhile, a consultation to the related bodies and ideas exchange with them should be organized to meet a final consensus. In addition, it is considered that by introducing the sediment flushing and sluicing as described above and other effective methods closer to a natural way is one of the important points to get the social recognition and the reliability growth against the sediment flushing.

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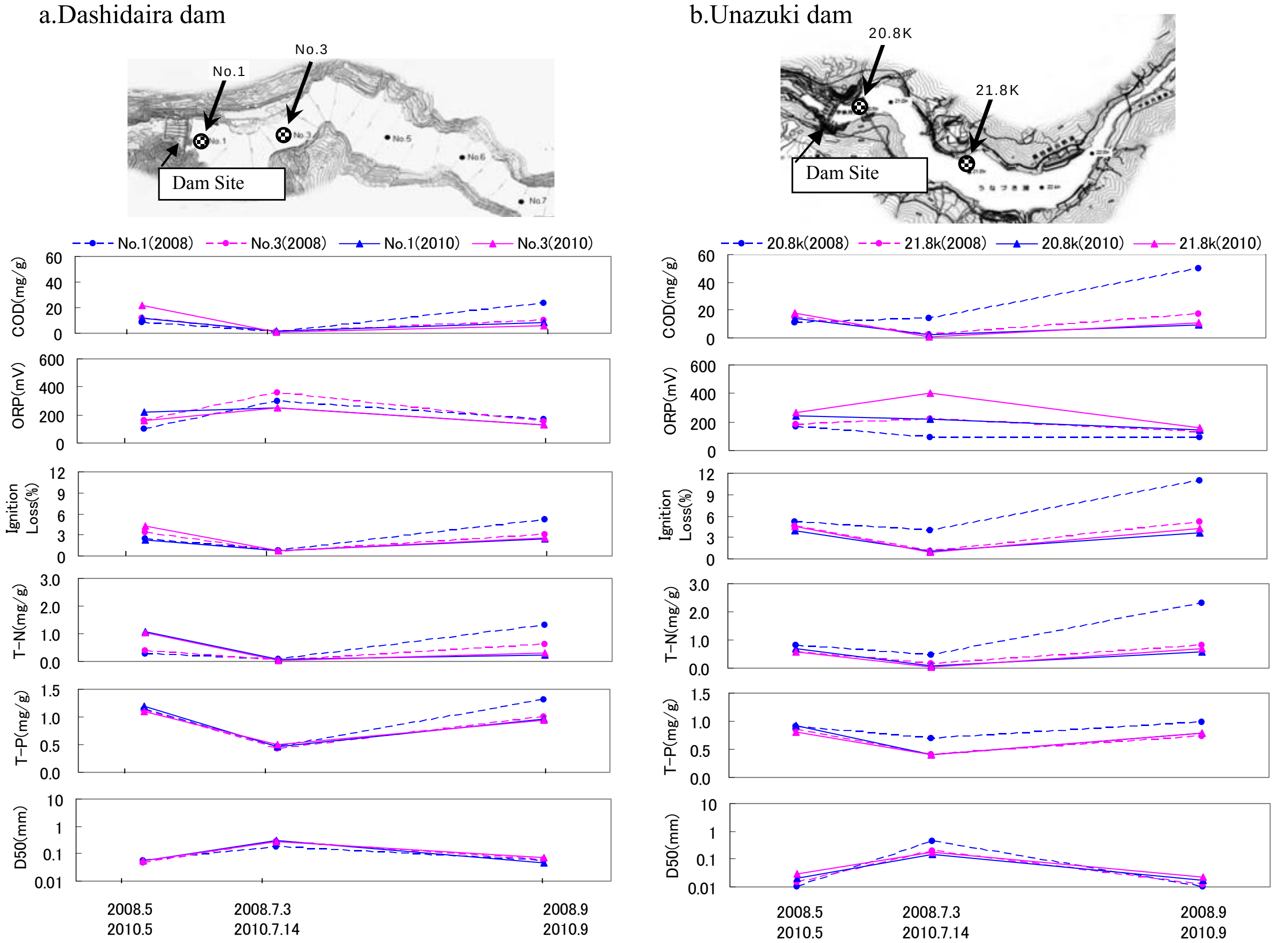

Year	May	June	July	August	September
2008	◆	▲	◆(7/3) ○	○ ○	◆
2010	◆	▲	▲◆(7/14)	●	◆

◆ : Sediment investigation ▲ : Coordinated sediment flushing/sluicing ○ : Flood(no implementation of fine sediment discharge) ● : Flood(implementation of fine sediment discharge)

Figure 9. Comparison of sediment data at Dashidaira dam and Unazuki dam