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CHARACTERISTICS OF FINE SEDIMENT DISCHARGE DURING SEDIMENT FLUSHING OF UNAZUKI DAM

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SYNOPSIS

In the Kurobe River, coordinated sediment flushing operations of Dashidaira and Unazuki dams have been executed since 2001. From the viewpoint of the comprehensive sediment management in a sediment routing system, monitoring the quantity and the quality of sediment transport during periods of flushing in rivers and reservoirs is very important. This paper discusses the results of field data obtained during the flushing and the sluicing operations of the Unazuki dam in 2005. Suspended sediment concentration measured by means of manual samplings and SMDP (Suspended Sediment Concentration Measuring System with Differential Pressure Transmitter), turbidity measured by a turbidimeter for high sediment concentrations and grain size distribution are discussed. Based on these data, the movement of the suspended load discharged from Unazuki dam during floods, flushing and sluicing periods can be clarified. The difference between the turbidity and the SS values is also examined from the viewpoint of the sediment grain size distribution.

INTRODUCTION

The Unazuki dam, completed in 2001 by the Ministry of Land, Infrastructure and Transport, and the Dashidaira dam, completed in 1985 by the Kansai electric power co. are both located in the downstream of the Kurobe river basin were the first dams to be constructed with large-scale sediment scouring gates in Japan. Coordinated sediment flushing and sediment sluicing of these dams have been performed since 2001. In "Sediment flushing", the reservoir water level is drawn down in the first flood period of the year and deposited sediment is discharged into the downstream by the tractive force of the river in a free flow state. In "Sediment sluicing", the sediment that flows into the dam during additional flood periods after sediment flushing is discharged into the downstream in order to prevent sediment deposits from accumulating. From the viewpoint of the comprehensive sediment management in the sediment routing system, monitoring the quantity and the quality of sediment transport during these periods in rivers and reservoirs is very important.

Generally, both continuous turbidity measuring and bottle sampling have been used for suspended-sediment concentration (SS) measurement in rivers or reservoirs. Since the probable turbidity range during sediment flushing operations is expected to exceed the upper limit of the conventional turbidimeters, manual bottle sampling is the only practical monitoring technique at this time. Here, we have developed a new suspended sediment concentration measuring system with a differential pressure transmitter (hereafter, we call *SMDP*) (Sumi and Morita et al. (1), (2), (3)). This system was introduced in the Kurobe river in order to monitor suspended sediment concentration during sediment flushing operations (Sumi and Baiyinbaoligao (4)).

In this study, the characteristics of the suspended sediment transport during the sediment flushing operation in 2005 were examined based on the data obtained by these monitor techniques. The grain size change of the bottled samples is also analyzed, and then the movement of the suspended load discharged from Unazuki dam during each period of flood, flushing and sluicing that continued for a whole week is clarified. Finally, the relation between the turbidity and the SS values is also discussed from the viewpoint of the sediment grain size distribution.

MEASUREMENT METHOD

Table 1 and Fig. 1 show an outline of the measurement to monitor the suspended load discharged from Unazuki dam during the sediment flushing operation. SMDP and COMPACT-HTW (Miniature Super-High Turbidity Data Logger with Wiper) were installed for sediment monitoring in the river. Furthermore, river water samples were taken constantly to calibrate these monitoring systems and to obtain grain size distributions of the suspended load.

Table 1 Measurement method

Measurement item	Measurement place	Measurement method	Measurement interval
	Downstream of Unazuki dam	Bottle sampling	1hr
SS	Downstream of Unazuki dam	Water circulation type SMDP	2sec
	Aimoto	Submergible type SMDP	2sec
Turbidity	Downstream of Unazuki dam	Bottle sampling	1hr
	Downstream of Unazuki dam	COMPACT-HTW	10min
Grain size distribution	Downstream of Unazuki dam	Bottle sampling	Not specified

Note : River water samples were taken from water surface, and SMDP and COMPACT-HTW were installed at about 100cm from the river bed.

Fig. 1 Unazuki and Dashidaira dams, and SMDP installations in the Kurobe river

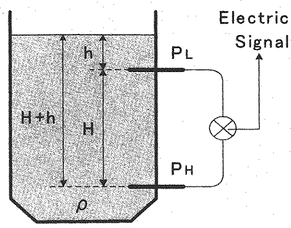

Fig. 2 Schematic diagram of SMDP

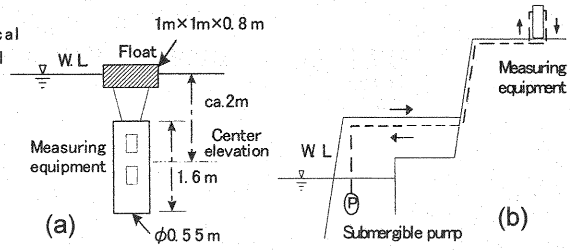

Fig. 3 Submergible type (a) and water circulation type (b) SMDP

SMDP is a suspended sediment concentration measuring system with a differential pressure transmitter. We developed the system in 2001 and carried out laboratory and field tests for the purpose of calibration. COMPACT-HTW is a new turbidimeter developed for a high turbidity measurement up to 70,000ppm by the ALEC Electronics Co., Ltd.

The schematic diagram of SMDP is shown in Fig. 2. Two pressure detectors were placed vertically with the interval H=1,000mm and connected by small pipes filled up with water to the differential pressure transmitter mounted at the center of the system. We have developed two different units to measure water with suspended sediments based on different measuring situations. One is the submersible type (Fig. 3 (a)) and the other is the water circulation type (Fig. 3 (b)). In the submersible type, the main measuring equipment is placed in the measuring water directly. The advantages of this type of unit are that has a simple structure and is easy to maintain. On the other hand, it needs enough water depth of at least over 2.0 m to maintain almost equal velocities between high and low pressure detectors in order to measure static pressure. It is also necessary to protect the measuring equipment by floating debris. We have solved these problems by shielding the equipment with the shell type cylinder. This submergible type is applicable for measuring in places such as reservoirs.

On the other hand, adopting the submergible type becomes difficult in the case where the water depth changes to a great extent depend on time such as a natural river. We also developed the water circulation type. The main measuring equipment is installed in a water tank that is placed in land and two pipes are connected. One pipe is to intake water from the river using a submergible pump installed just above the river bed and another is to drain from the tank. This type can be applied anywhere, if the minimum water depth for intake is secured, and is safer than the submersible one during the flood. On the other hand, a pump operation is needed for continuous measurement. The system has an electromagnetic flow meter to measure the quantity of water and the accumulated sediment can be discharged from the valve installed at the bottom of the tank.

MEASUREMENT RESULTS

Outline of the sediment flushing in 2005

A coordinated sediment flushing and sluicing in 2005 were executed from June 27th through July 5th. The flushing and sluicing operations were extended to a long term since a big flood occurred at each drawdown stage because of the stagnation of the "Rainy front". Hydrologic data during these operations is shown in Figs. 4 (a) and (b). These operation periods can be divided into the "Flood period" (6/27 12:00 - 6/28 22:00), the "Flushing period" (6/28 22:00 – 6/30 5:00) and the "Sluicing period" (6/27 12:00 - 6/28 22:00) as shown in Fig. 4 (b).

SS and turbidity changes during flushing and sluicing operations

Figs. 4 (c) and (d) show SS and turbidity during flushing and sluicing operations measured at the downstream of Unazuki dam (Yamabiko bridge is located 600m downstream), respectively. Figs. 4 (e) and (f) show the median diameter (d_{50}) and the SS/Turbidity ratio during the operation, respectively, and Fig. 4 (g) shows SS at Aimoto that is located about 7,000m downstream from Unazuki dam. The water circulation type SMDP could have measured a density of SS 30,000mg/l or more but there were some data missing because of the clogging of a pipe caused by very high sediment concentration. On the other hand, the submergible type yielded fairly good data which almost corresponded to the time variation of manual water samples. It was confirmed that SMDP is a powerful technique of the SS continuous observation. As for COMPACT-HTW, data was obtained continuously and observed turbidities almost coincided with the manual samples.

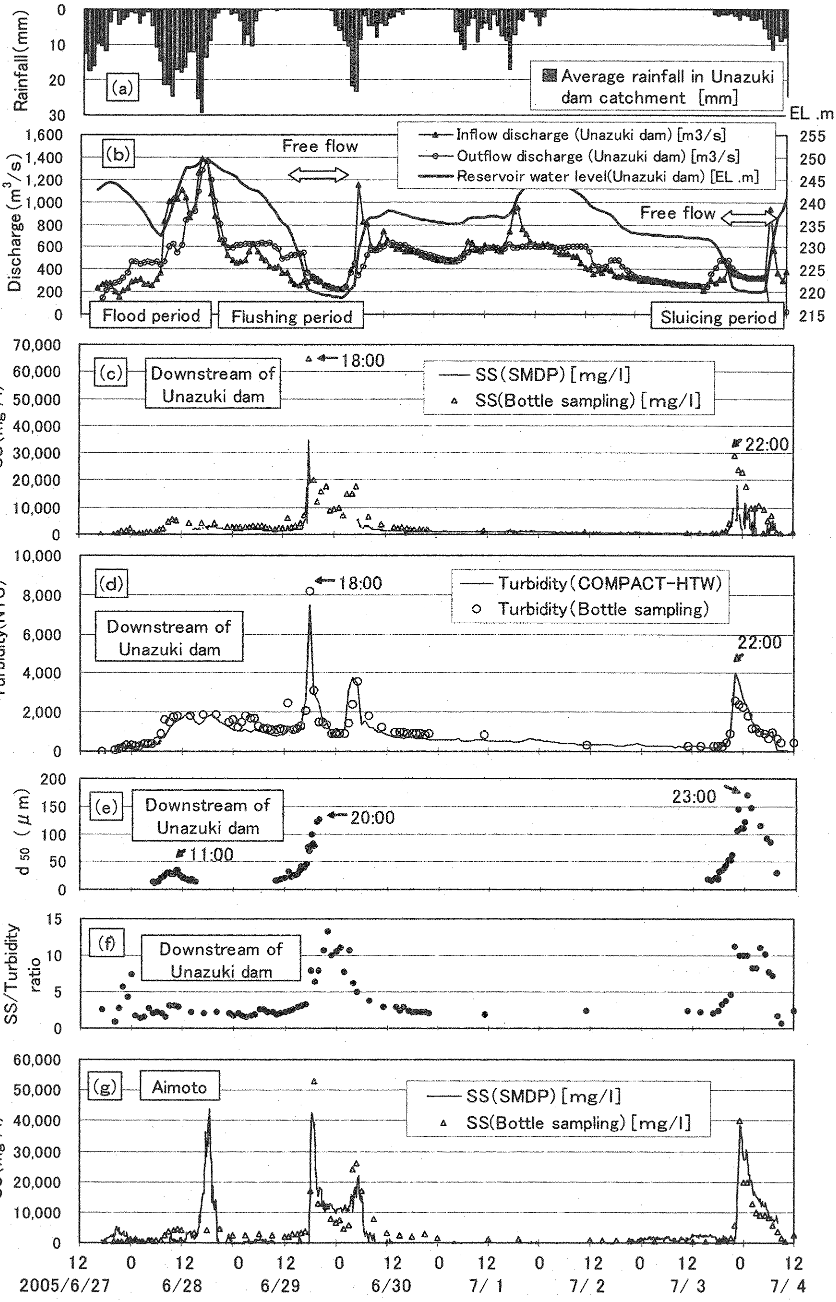

Fig. 4 Outline of sediment flushing and sluicing of Unazuki dam in 2005 and measurement results
(a) Average rainfall in the catchment, (b) Inflow, outflow and water level of Unazuki dam, (c) SS (Unazuki dam (600m downstream)), (d) Turbidity (Unazuki dam (ditto)), (e) d_{50} of SS (Unazuki dam (ditto)), (f) SS and Turbidity ratio (Unazuki dam (ditto)), (g) SS (Aimoto)

Characteristics of fine sediment discharge from Unazuki dam during each period

a) Flood period

Inflow and outflow SS are shown in Fig. 5 (a). In the flood period, the maximum outflow SS decreased to 5,000 mg/l about 1/5 of the maximum inflow SS, 25,000 mg/l. During this period, median diameter (d_{50}) of SS that passed the dam rose up with an increase of the flood discharge, and reached up to 35μm at 11:00, 6/28 as shown in Fig. 4 (e). We expected these sediments to be transported to the dam without depositing in the reservoir and to be discharged from the overflow crests, flood discharge outlets and an outlet for water level drawdown.

b) Flushing period

Inflow and outflow SS are shown in Fig. 5 (b). In the flushing period, the maximum outflow SS increased to 65,000 mg/l whereas the maximum inflow SS was 20,000 mg/l. With the reservoir drawdown, the upstream of the reservoir gradually shifted into the natural free flow state. Then, the increased tractive force of the river started to erode the deposited sediments and transported them to the dam. These sediments were discharged through sediment scouring gates and the peak sediment concentration occurred 18:00 immediately before completion of the drawdown. During this period, the median diameter (d_{50}) of SS that passed the dam also rose quickly with the reservoir drawdown, and the maximum value 127μm was recorded in 20:00, two hours after the peak SS. It is thought that this value should correspond to the time lag until the relatively coarse sediments were transported through the reservoir to the sediment scouring gates.

c) Sluicing period

Inflow and outflow SS are shown in Fig. 5 (c). In the sluicing period, the maximum outflow SS was 29,000 mg/l lower than the maximum inflow SS 60,000 mg/l. This is because discharged sediments from Dashidaira dam contained relatively coarse materials and almost all of them deposited in the Unazuki dam. During this period, the maximum value of d_{50} was 164μm at the almost same time of the peak SS.

Sediment budget of respective grain diameter

a) Flood period

The ratio of the respective grain size of outflow SS during the flood period obtained by the laser scattering particle size distribution analyzer (HORIBA-LA300) is shown in Fig. 6 (a). Converted SS related to the respective grain size that is obtained by multiplying by SS and each ratio of the respective grain diameter is shown in Fig. 6 (b).

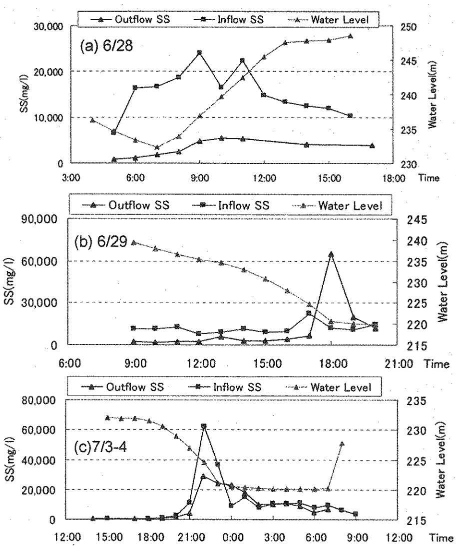

Fig. 5 Inflow and outflow SS during (a)flood, (b)flushing and (c)sluicing periods in Unazuki dam

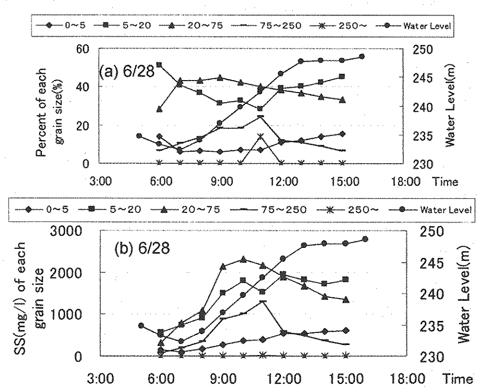

Fig. 6 Respective grain size (μm) of outflow SS during flood period and converted SS of each grain size

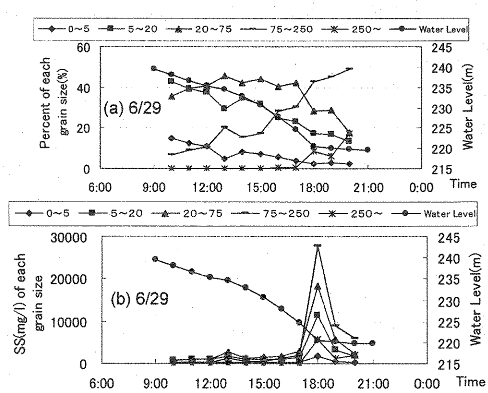

Fig. 7 Respective grain size (μm) of outflow SS during flushing period and converted SS of each grain size

The ratio of the grain size of 5-75μm has accounted for 70-80% of the whole overall for this period.

b) Flushing period

As shown in Figs. 7 (a) and (b), the ratio of the finer grain part of 20μm or less decreased and the coarse grain part of 75μm or more increased with the reservoir drawdown and the free flow start. In particular, ratios of 75-250μm and 250μm or more rose up to about 50% and 17% respectively.

c) Sluicing period

In addition to the flushing period, the ratio of the finer grain part of 20μm or less decreased and the coarse grain part of 75μm or more increased with the reservoir drawdown and the free flow start as shown in Figs. 8 (a) and (b). In particular, ratios of 75-250μm and 250μm or more rose up to about 60% and 19% respectively.

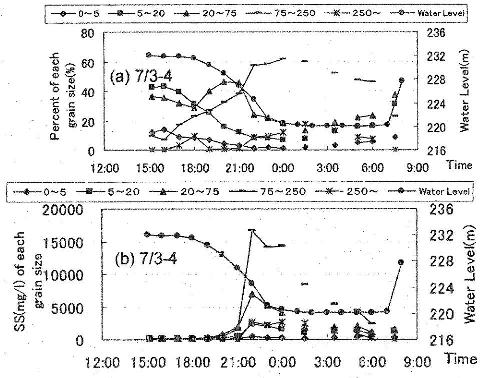

Fig. 8 Respective grain size (μm) of outflow SS during sluicing period and converted SS of each grain size

Table 2 Ratio of the amount of the respective grain size sediments in each period

Grain size (μm)	0~5	5~20	20~75	75~250	250~
Flood period (%)	10.36	37.77	38.42	13.42	0.03
Flushing period (%)	3.80	20.65	31.89	37.11	6.55
Sluicing period (%)	2.28	9.72	22.55	55.32	10.13

Table 2 shows the ratio of the amount of the respective grain size suspended load in each period based on the above-mentioned respective grain size ratio of SS. The ratio of 5-75μm accounts for 76% of the whole in the flood period, and the ratio of 20-250μm accounts for 69% and 78% of each whole in the flushing period and the sluicing period, respectively. Moreover, the grain size of especially 250μm or more increased from 0.03% in the flood period to 10.13% in the sluicing period. This indicates that a large amount of coarse sediment was supplied to the downstream by the flushing and the sluicing operations.

Correlation of turbidity and SS at the sediment flushing

In general, it is thought that there is a constant correlation between SS and the turbidity in rivers. The correlation can be satisfied only when diameter, shape, and the tone etc. of the fine grain sediments contained in turbid water are roughly invariable. However, this may not be true in the case of a different river or in the case where the element of the fine sediments may change depending on the seasonal variation etc. even in the same river. In particular, the problem becomes a very serious matter when the grain size in SS changes greatly during the sediment flushing operations as discussed in the above section.

We studied the correlation between SS (Fig. 4 (c)) and turbidity (Fig. 4 (d)) considering the grain size distribution (Fig. 4 (e)) during the flushing operations in Unazuki dam. As shown in Fig. 4 (f), SS/Turbidity ratio has changed greatly from 2 to about 14, and so we concluded that this tendency agrees very well with the change in the median diameter of Fig. 4(e).

Fig. 9 shows the relation of SS and turbidity in each period separately. As for the flood period, the correlation is very high and the ratio of SS/Turbidity is small, and the ratio is increasing in the flushing and the sluicing periods as can be surmised from Fig. 4 (f). These linear regression formulas are shown in Fig. 9 and the SS/Turbidity ratio in the flushing and the sluicing periods are estimated roughly to be 6 and 10, respectively.

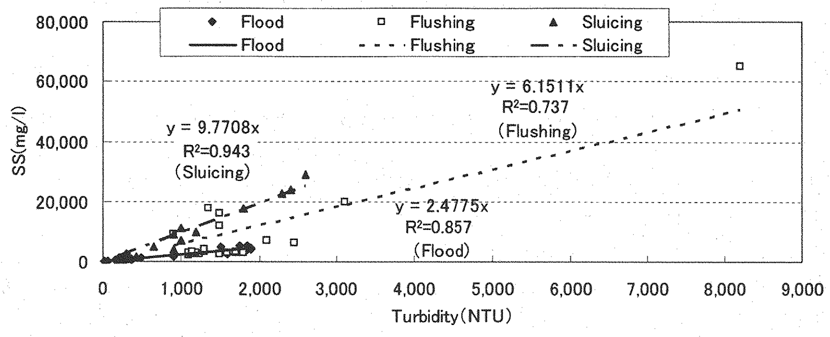

Fig. 9 Relation of SS and turbidity during flood, flushing and sluicing periods in Unazuki dam

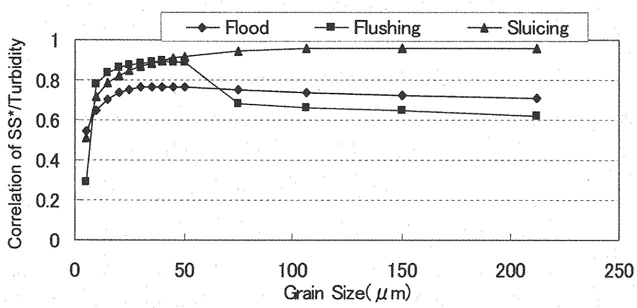

Fig. 10 Correlation of the modified SS (SS*) of each grain size and turbidity

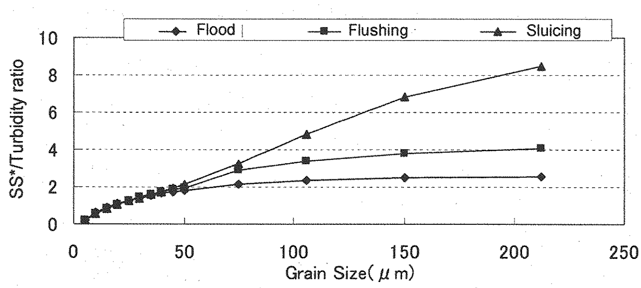

Fig. 11 Ratio of the modified SS (SS*) of each grain size and turbidity

Fig. 10 shows the linear correlation coefficient of the turbidity and the modified SS (SS*) that is calculated by summing up to each grain size separately for 17 classes of 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 75, 106, 150, 212, 300, 425, and 600μm. Generally, each period has the appropriate grain size that yields the maximum correlation coefficient. These are 45μm for the flood period (0.768) and the flushing period (0.893), and 150μm for the sluicing period (0.959). If we include larger grain sizes, each correlation coefficient will decrease. Usually, an optical turbidimeter is calibrated with standard clay such as China clays, and therefore it is thought that the error becomes larger as the content of the coarse sediments increases though a good correlation is maintained for the fine sediments.

Fig. 11 shows the ratio of the modified SS (SS*) of each grain size and the turbidity. In fact, the ratios of the SS* less than 50μm and turbidity are almost the same in each period. For example, SS*/Turbidity is approximately equal to one for less than 20μm and two for less than 50μm. On the other hand, the ratio of SS* and the turbidity does not coincide if larger grain seizes are included. Therefore, it is thought that the direct measurement of SS and the turbidity measurement that reacts to the ratio of fine sediments are indispensable for the SS monitoring including the grain size larger than 50μm during the sediment flushing.

CONCLUSIONS

The conclusions of this study are as follows:

1) The outflow SS from Unazuki dam and its grain size distribution differ greatly between the flood period, and the flushing or the sluicing periods. For the flood period, outflow SS rises and larger grain sizes can be discharged according to the flood discharge increase and the discharge level drawdown from the dam. During the flushing or the sluicing periods, outflow SS rises and larger grain sizes can be discharged according to the reservoir water level drawdown.

2) Peaks of the outflow SS in the flushing and the sluicing periods occur immediately before the completion of the reservoir drawdown and the time when the maximum discharge grain size occurs is delayed several hours behind the SS peak that flows in the reservoir.

3) As for the sediment budget of the respective grain size, the grain size discharged from Unazuki dam increased gradually to the extent that 75μm or more forms 45% and 65% of the total sediment during the flushing and the sluicing periods while 75μm or less forms 80% or more for the flood period.

4) Concerning the relationship between the outflow SS and the turbidity during the sediment flushing operations, the ratios of the modified SS* were calculated by summing up each grain size less than 50μm. We found that turbidity was almost the same in each period and that it may has increased up to about twice depending on the increase of the grain size. Finally, it is thought that direct measurement of SS is indispensable for the SS monitoring including the grain sizes larger than 50μm during sediment flushing.

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