River Flow 2020 – Uijttewaal et al (eds)
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Movement and discharge of sediments during the coordinated sediment flushing operation of the Dashidaira dam and the Unazuki dam

Shoji Fukuoka
Research and Development Initiative Chuo University, Tokyo, Japan

Kohei Suzuki
Graduate School of Science and Engineering, Chuo University, Tokyo, Japan

ABSTRACT: The Unazuki dam and the Dashidaira dam, which are constructed in the Kurobe River basin with a large amount of sediment yields, have conducted the coordinated sediment flushing for the purpose of maintaining the function of the dam, preventing the degradation of the downstream riverbed and reducing coastal erosion. However, riverbed degradation and shortage of sediment with large diameters have been still in progress. In this paper, we develop the riverbed variation model by floods that can reproduce the sediment movement from and in the Unazuki dam reservoir by using the cross-sectional data before and after the coordinated sediment flushing during the flood. It was clarified that considerable amounts of large sediments such as 100mm and 50mm which contributes to the stability of the downstream river channel pass through a sediment flushing gate from the coordinated sediment flushing analysis.

1 INTRODUCTION

The Kurobe River is located in Toyama Prefecture, Japan (Figure 1) and is one of the most rapid flow rivers in Japan. In addition, the Kurobe River basin is a rainy and snowy area, and a lot of sediment are yielded from the upstream mountain regions. Therefore, the comprehensive sediment control plan from the upstream to the coastal areas is being executed here. In this situation, the coordinated sediment flushing has been conducted at the Unazuki dam and the Dashidaira dam (7km upstream of the Unazuki dam) for the purpose of maintaining the function of the dams, preventing the degradation of the downstream riverbed and reducing coastal erosion. Figure 2 shows the overview of the operation of the coordinated sediment flushing in which the Unazuki dam (Ministry of Land, Infrastructure, Transport and Tourism) and the Dashidaira dam (Kansai Electric Power) conduct every event of floods. Deposited and inflowed sediments in the dams are discharged out the downstream river by the coordinated sediment flushing. However, riverbed degradation has been seen in some downstream sections due to shortage of coarse sediment from the Unazuki dam. In order to solve this problem, it is necessary to understand how the sediment yielded from the upstream is supplied to the downstream river.

Field observations and analytical studies have been carried out at the events of sediment flushing Unazuki dam and the Dashidaira dam. In the field observation, Sumi et al. (2005) and Kantoush et al. (2010) used 3D laser scanners to observe movements of sediments during the coordinated sediment flushing of the Unazuki dam reservoir. It is shown that when the drawdown of reservoir water level is done, flood flows branch off in the reservoir, and in the free-flow operation, sandbars appearing on the water surface moves slowly in the downstream direction. Minami & Fujita (2008) conducted an analysis of the one-dimensional riverbed variation in the Unazuki dam, the Dashidaira dam, and downstream rivers. It was shown that the sediment

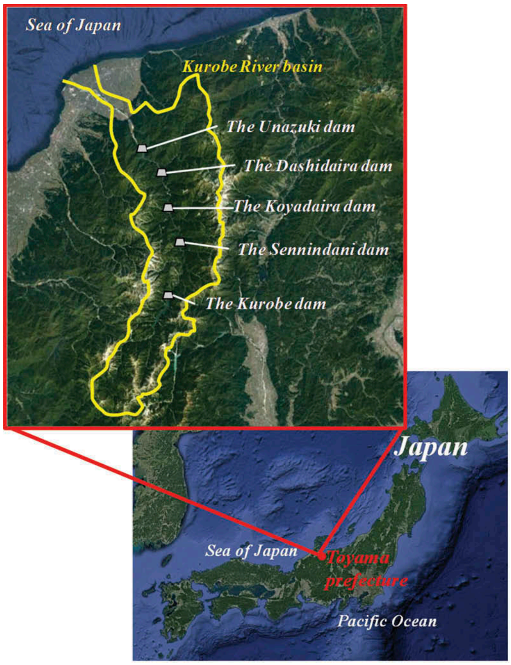


Figure 1. Location of the Kurobe River.

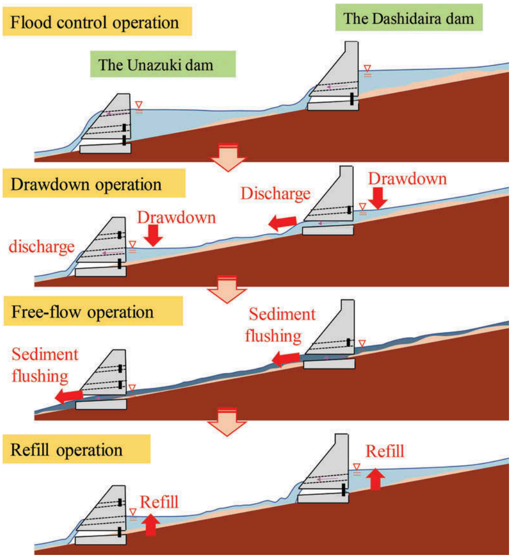


Figure 2. The coordinated sediment flushing.

characteristics differ at the just downstream of the dam and further downstream. Taymaz et al. (2017) propoced a method to improve sediment flushing efficiency of the Dashidaira dam by using a 3D flood flow and bed variation model. However, the reproducibility of the analytical model still has some issues, and it is not enough to clarify the sediment movement and sediment discharge mechanism in the reservoir.

In this paper, we developed a numerical model that can reproduce sediment movement and bed variations between two dams by the coordinated sediment flushing by using the cross-sectional data measured before and after the coordinated sediment flushing. And we clarify the sediment movement in the Unazuki dam from the sediment discharge and riverbed variation at each time zone of dam operation.

2 CONDITIONS AND METHOD OF THE ANALYSIS

2.1 *Analysis condition*

Figure 3 shows water level hydrograph, and discharge hydrograph of two dams by the coordinated flushing gate operations in 2014. The peak inflow at the Unazuki dam is about 300m³/s. The analysis is conducted from the Dashidaira dam (27.4km) to down the Unazuki dam (20.6km) as shown in Figure 4. The upstream end at the time of normal water level of the Unazuki dam reservoir is near 23.2km. The grain size distribution (Figure 4) used for the analysis is the average value of bed material collected along the downstream channel of the Unazuki dam (14.0km-20.0km). The flood flow was calculated by the quasi-three-dimensional analysis method of Takemura & Fukuoka (2019) which is suitable for steep rivers with boulders. The riverbed evolution (bed load) was calculated using the two-dimensional bed variation analysis method of Osada & Fukuoka (2012). The discharge hydrograph and the sediment graph at the Dashidaira dam are needed to understand the sediment movement in the Unazuki dam reservoir. Figure 5 shows the flow chart for the calculation of the coordinated sediment flushing.

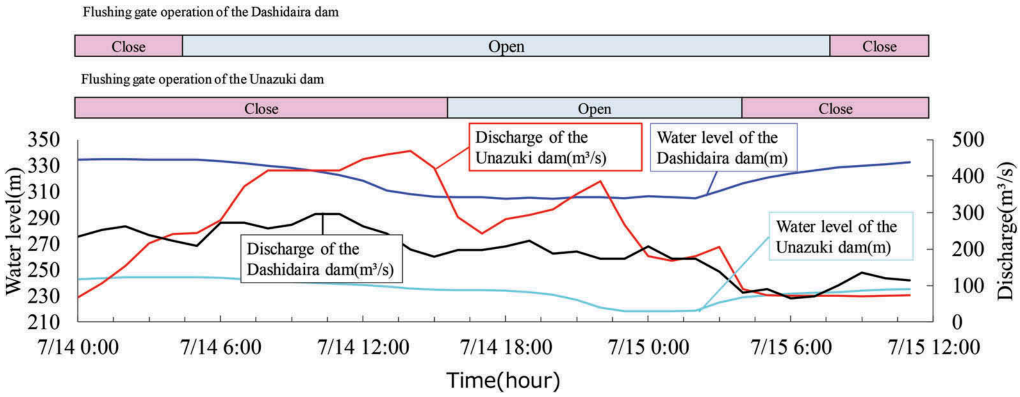


Figure 3. Operations of flushing gate, water level hydrograph, and discharge hydrograph of two dam.

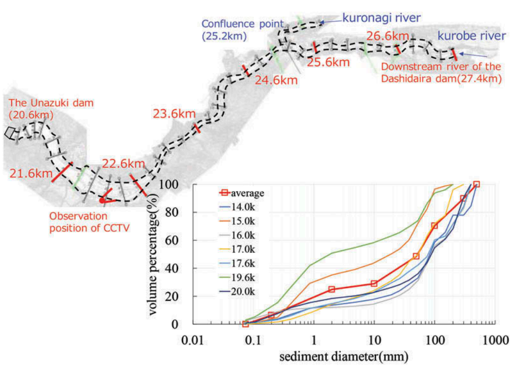


Figure 4. Analysis sections and grain size distributions.

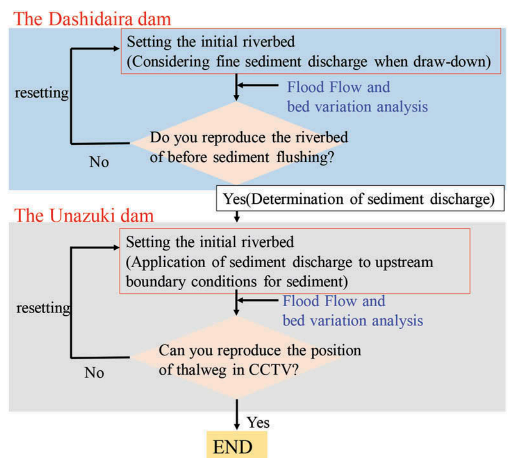


Figure 5. Flow chart of the calculation method of coordinated sediment flushing.

2.2 *How to obtain the sediment graph from the Dashidaira dam*

Figure 6(a) and 6(b) show measured shapes of cross sections about 1.3km (No.7), 0.8km (No.5) in the Dashidaira dam reservoir before and after sediment flushing and assumed bed level.

Sediment deposited in the Dashidaira dam reservoir was eroded by up to maximum 8m due to the drawdown and the free-flow operation. In order to reproduce such large erosion by analysis, grain size distributions information is necessary. However, there were only reservoir bed data before and after sediment flushing in the Dashidaira Dam reservoir. Therefore, in this study, we estimated the sediment discharge graph from the flushing gate by making the following five assumptions.

Before sediment flushing (Figure 7(a)), a large amount of deposited sediment in the Dashidaira dam reservoir is fine sediment. (2) When the draw-down ends, these fine sediments discharge out from the reservoir, and the coarser sediments were assumed to deposit on the bottom of the reservoir as shown by dotted line in Figure 6. The amount of suspended sediment outgoing from the flushing gate was calculated from the difference between the longitudinal reservoir bed elevations of before sediment flushing and at the start of the free flow. Then, suspended sediment graphs[silt (0.005mm to 0.075mm), fine sand (0.075mm to 0.25mm), medium

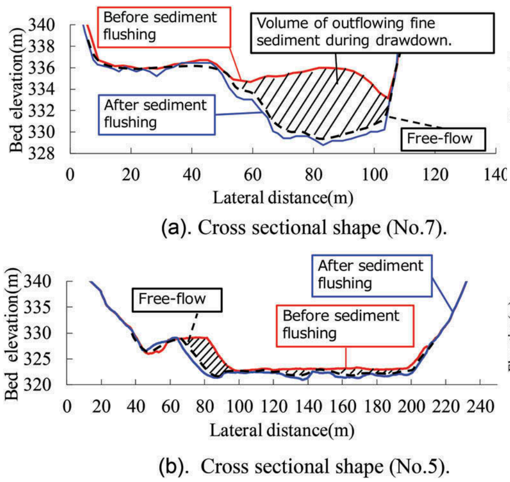


Figure 6. Cross sectional shapes in the Dashidaira dam reservoir. 6(a)Cross sectional shape (No.7) 6(b). Cross sectional shape (No.5).

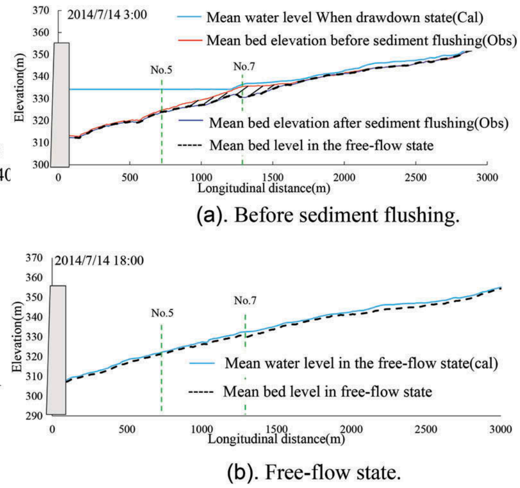


Figure 7. Observed and calculated water surface and riverbed profiles. 7(a). Before sediment flushing. 7(b). Free-flow state.

sand (0.25mm to 0.85mm)] are determined to match the total amount of fine sediment, based on the distribution of the suspended sediment concentration graph observed at the just downstream of the Dashidaira dam during the flood. (3) During the time of free-flow operation (Figure 7(b)), coarser sediments are scoured and transported, making the reservoir bed elevation formed after sediment flushing. Flood flow and bed variation analysis are performed so as to take the initial reservoir bed topography at the start of free-flow operation. (4) Compare the analysis with measured data and calculate by the correction of the initial reservoir bed elevation until it almost matches the measured elevation. (5) The graphs of bed load and suspended sediment from the flushing gate obtained by the analysis are used as the upstream boundary conditions for the analysis of sediment movement of the Unazuki Dam.

Figure 8 (a) and 8(b) show the analysis results of the sediment graphs that passed through the Dashidaira dam flushing gate. The sediment discharged is 50mm, and the sediments with maximum diameter are 300mm. When the water level is high, suspended sediment discharged are not much. When the flow become in the a free-flow state and an open channel flow in the flushing gates, suspended sediments reach a peak value.

2.3 *Sediment transport characteristics of the Unazuki Dam*

Figure 9 shows CCTV (closed-circuit television) image at around 22.2km at 4:40 minutes on July 15, 2014 flood. This CCTV image shows the flow in the free-flow states in the Unazuki

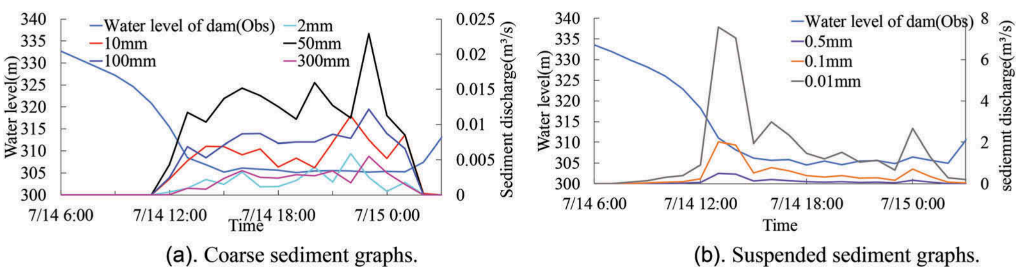


Figure 8. Calculated sediment graph that passed through the Dashidaira dam flushing gate. 8(a). Coarse sediment graphs 8(b). Suspended sediment graphs.

Figure 9. CCTV image taken at 22.2km (4:40 on July 15th).

dam reservoir, where the river is wide, and large sandbars are seen. During the period from the free-flow state to the refill state, riverbed structures do not change much because of sand bars hardly change and flow rate are relatively low. For this reason, the position of the thalweg during free flow operation is almost similar to the cross-section surveyed often the coordinated sediment flushing. In this study, the initial riverbed shape was set using the planar position of the thalweg seen from CCTV images and the cross-sectional shape measured after coordinated sediment flushing. The other cross sections used those measured at intervals of 200m before the coordinated sediment flushing. In the downstream of the Dashidaira dam, the maximum suspended sediment diameter was observed between 0.25mm and 0.85mm. Therefore, the sediments with diameter of 0.85mm or less is assumed to be suspended sediment and were calculated by the depth integrated two-dimensional advection diffusion equation. However, further study about diameters dividing suspended load and bed load must be investigated.

The sediment discharge is greatly influenced, depending on the reservoir water level and the gate operation time of the two dams. Therefore, the gate operations were divided into three times zones (Figure 3): ①The Dashidaira dam and the Unazuki dam are in the drawdown state ②The Dashidaira dam is in the free-flow state, and the Unazuki dam is in the drawdown state ③The Dashidaira dam and the Unazuki dam are in the free-flow state.

3 CALCULATATION RESULTS AND CONSIDERATION

3.1 *Dashidaira dam: Drawdown state, Unazuki dam: drawdown state*

Figure 10 shows calculated results of longitudinal distributions of bed load in the Unazuki dam. During the period of ①, There is almost no sediment discharge from the dam. But there is large discharge from the dam, the riverbed at the downstream of the Dashidaira dam is scoured and transported. The maximum sediments with size of 300 mm are deposited around 22.6 km in the Unazuki dam reservoir. From this, it is considered that in the time zone ①, the bed load that was deposited in downstream of the Dashidaira dam before present coordinated sediment flushing is transported further downstream.

3.2 *Dashidaira dam: Free-flow state, Unazuki dam: drawdown state*

Figure 11 shows calculated profiles of the water surface and riverbed in the Unazuki dam. Figure 12 shows the calculated longitudinal distributions of the coarse sediment (bed load). Similar amount of sediment transport discharged from the dam are seen in the upstream river channel, too. It is considered that the sediment from the Dashidaira dam is provided to the Unazuki dam reservoir by the coordinated sediment flushing.

Figure 13 shows calculated longitudinal distributions of the suspended sediments of different sizes from the Dashidaira dam. Suspended sediment of 0.01mm passes through the Unazuki dam while depositing in the river channel between Dashidaira dam and Unazuki dam. However, the larger suspended sediment (0.1mm,0.5mm) deposit in the river channel area and

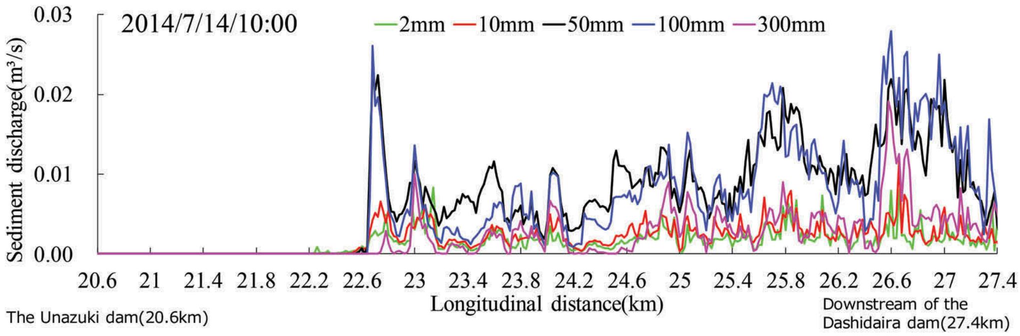


Figure 10. Calculated longitudinal distributions of the bed load.

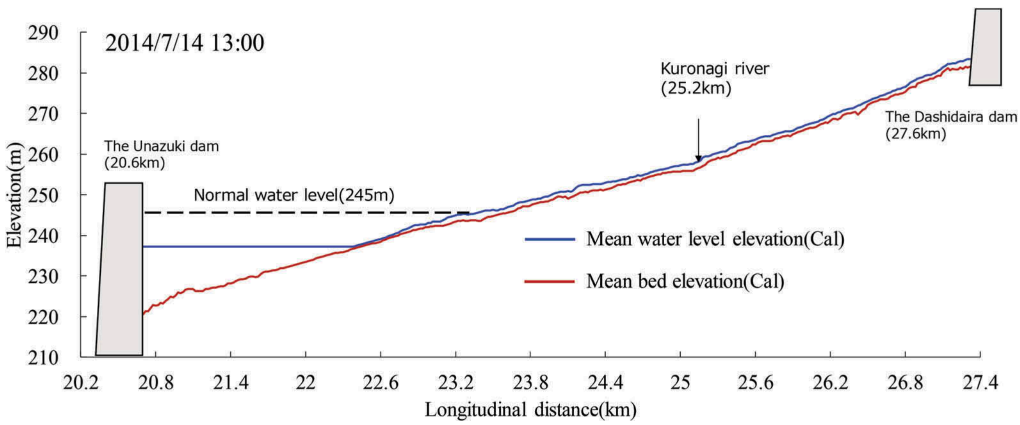


Figure 11. Calculated water surface profiles and riverbed profiles in the Unazuki dam.

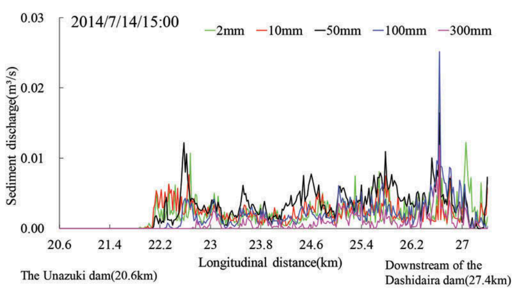


Figure 12. Calculated longitudinal distributions of the bed load.

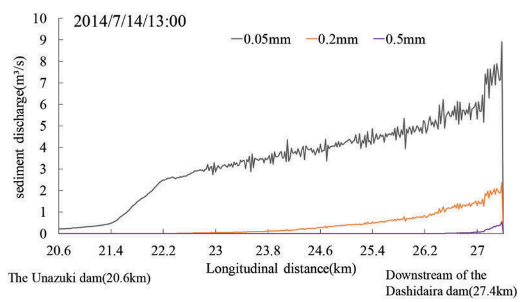


Figure 13. Calculated longitudinal distributions of the suspended sediment.

does not reach the reservoir. This is because fine sediments are not included the initial riverbed material of the Unazuki dam. The result of bedload analysis shows that the 2 mm and 10 mm particle sizes are moving as shown in Figure 12. Therefore, it is considered that the 0.1 mm and 0.5 mm grain sizes are transported not only by suspended load motion but also by bed load motion. The analysis accuracy is controlled by the initial grain size distribution and the moving mode of sediments.

3.3 *Dashidaira dam: Free-flow state, Unazuki dam: free-flow state-refill state*

Figure 14 shows calculated water surface profiles and riverbed profiles in the Unazuki dam. It can be seen that the Unazuki dam reservoir behaves like a river in the time of free flow gate operation. Figure 15 shows the calculated bed topography and depth-average velocity vector in the Unazuki dam reservoir at 23:00 on July 14th. It is seen that the main flow velocity increased due to reduced cross-sectional areas by sandbars appearing on the water surface. Figure 16 shows the calculated longitudinal distributions of the bed load during free-flow state of the Unazuki dam. In the wide cross-section area(22.6km-22.2km), the finer sediment group in the bed load was hardly deposited, and the sediment discharge 100mm and over decreases in this section. This is due to the fact that the depth-average velocity is about 2.5m/s, which is slower than that of the upstream river channel. Figure 17 shows the calculated sediment graphs for particles of each diameter that passed through a sediment flushing gate of the Unazuki dam for 10 minutes. About 12 particles with a maximum diameter of 300mm pass through the Unazuki dam for 10 minutes in free-flow state. It can be seen that 50mm passes 10,000 and 100mm passes about 1,000. There are considerable sediment discharges of 100mm and 50mm. In addition, there is a time difference in the sediment discharge of 300mm, 100mm and 50mm. From a result of the grain size distribution collected at just downstream of the the Unazuki dam, particles of 100 mm on the average and the maximum 200 mm were observed. These particles almost correspond to particles the calculated maximum sediment diameter.

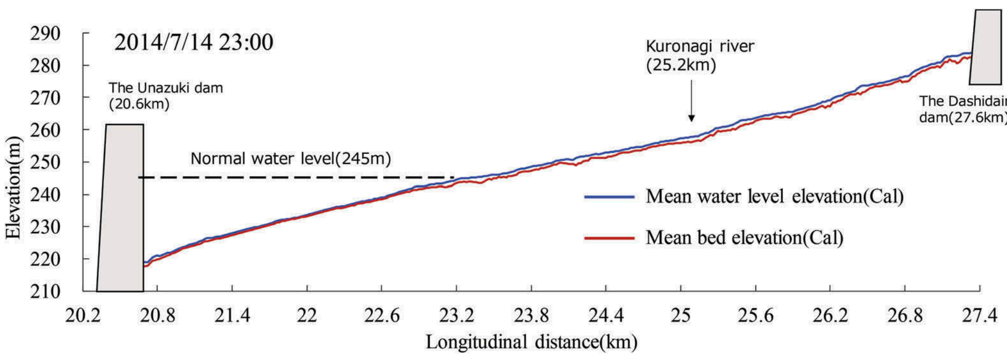


Figure 14. Calculated water surface profiles and riverbed profiles in the Unazuki dam.

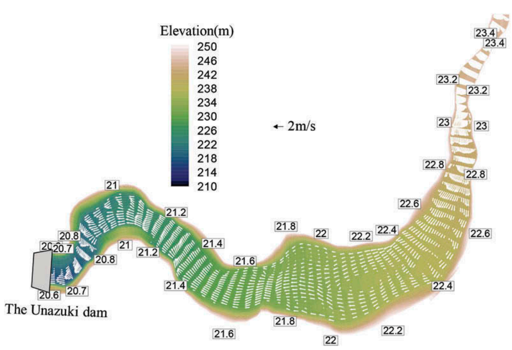


Figure 15. Calculated bed topography and water depth-average velocity vector in the Unazuki dam reservoir at 23:00 on July 14th.

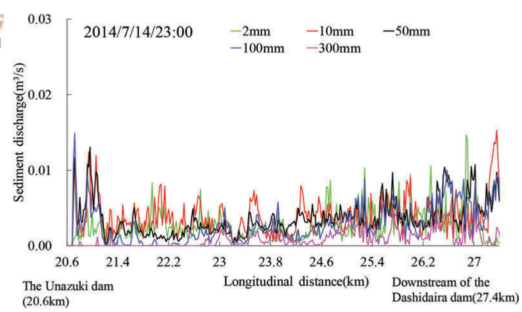
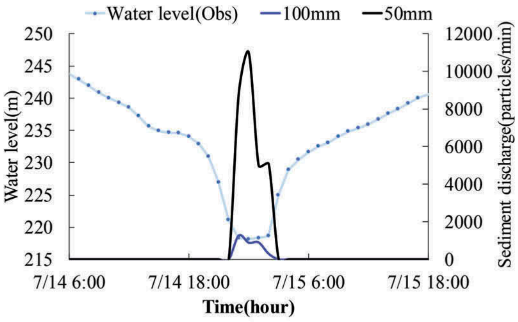
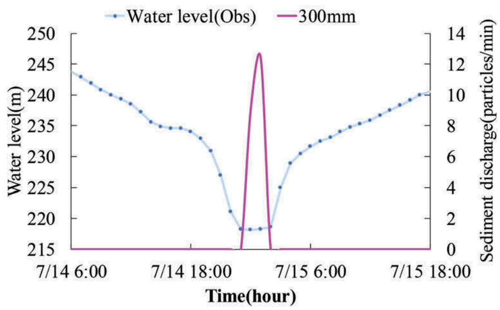


Figure 16. Calculated longitudinal distributions of the bed load sediment discharge during free-flow state.



(a). 100mm,50mm.



(b). 300mm.

Figure 17. Calculated sediment graph of bed load of the number of particles that passed through the Unazuki dam flushing gate in 10 minutes. 17(a). 100mm,50mm. 17(b). 300mm.

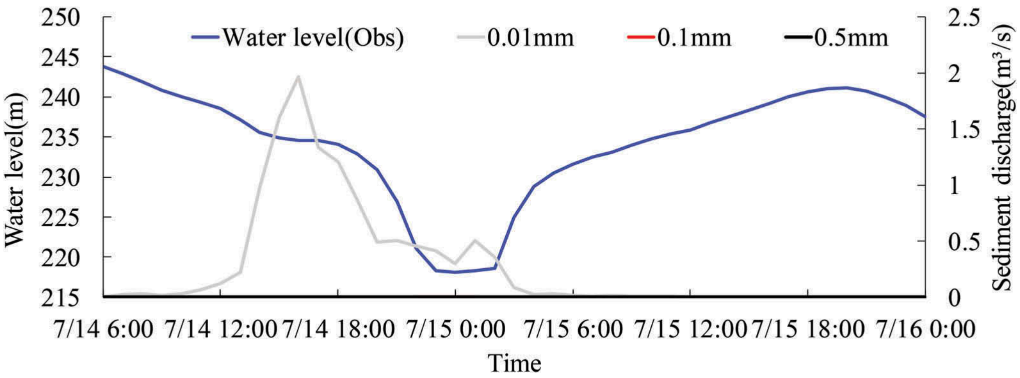


Figure 18. Calculated suspended sediment graph that passed through the Unazuki dam flushing gate.

Figure 18 shows the calculated result of the time graph of suspended sediment that passed through the Unazuki dam sediment flushing gate. The peak of suspended sediment discharge passing through the Unazuki dam appears at the time near the peak sediment discharge (7/14 13:00) of the Dashidaira dam. In the time of the draw-down operation, suspended sediments from the Dashidaira dam are considered to pass through the Unazuki dam.

4 CONCLUSIONS

Characteristics of sediment movement in each time zone were investigated based on numerical analysis and field observation results. The main conclusions and future works are given as follows.

(1) we developed a numerical model that can reproduce sediment movement and bed variations by the coordinated sediment flushing.
(2) Different of characteristic sediment transport have been seen under each gate operation of the Dashidaira dam. When the drawdown of stored water was performed, the sediment deposited downstream of the Dashidaira dam is transported. Most of the 0.01mm passes through the Unazuki dam while depositing in the river channel during free-flow state. And, coarse sediment from the Dashidaira dam is provided to the Unazuki dam reservoir by the coordinated sediment flushing.

(3) The sediment movement in the Unazuki dam reservoir were examined by the numerical model using the flood hydrograph and sediment graph from the Dashidaira dam as boundary conditions. It was clarified from the coordinated sediment flushing analysis, that the maximum particle size with 300mm diameter passed through the sediment flushing gate at the event of relatively small flood flow. In addition, bed load, such as 100mm and 50mm, which contributes to the stability of the downstream river channel, passed a lot downstream of the Unazuki dam.

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