Characteristics of SS Transportation during Floods of the Saru River

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ABSTRACT: Recent river management problems include a decrease in water storage capacity of the dam reservoir due to sedimentation and a lack of continuity in sediment movement from the upper to lower reaches. To clarify the characteristics of substance transport during flooding, we conducted observations and sampling at the Saru River in Hokkaido, Japan, a Class-A river with a reservoir at its middle reaches.
We then examined theose observations and the sampled data. Due to the presence of the reservoir, SS is not transported from the upper reaches during the early phase of flooding. Using this phenomenon, we clarified the behavior of SS and the effects of the tributary during the flood.

1. Introduction

Basin-wide sediment management has been recognized as being important for effective river management. Onsite surveys have recently been conducted on substance transport during flooding at many sites, and the Civil Engineering Research Institute of Hokkaido has been conducting such research on the Mukawa River, a Class-A river. The research has focused on the behavior of suspended solids (SS) and nutrient salts at the middle and lower reaches[1, 2, 3]. We have found that the SS load from the basin undergoes repeated accumulation and traction near the riverbank in several floods before reaching the mouth and flowing into the sea. It can therefore be assumed that the SS load and its accompanying nutrient salts considerably affect the natural environment of the river and its basin, especially the riverbank.

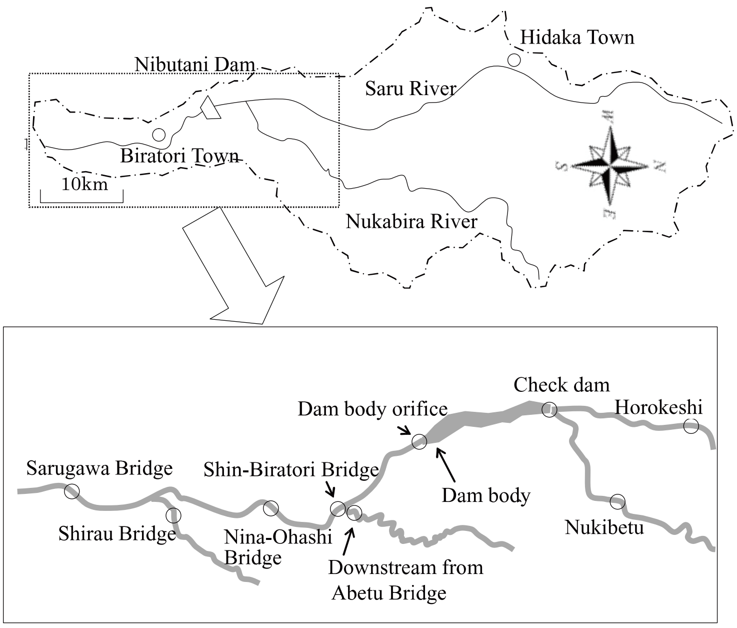

Figure 1. Drainage basin and observation sites

Recent river management problems include a decrease in water storage capacity of the dam reservoir due to sedimentation and a lack of continuity in sediment movement from the upper to lower reaches. To clarify the characteristics of substance transport during flooding, we conducted observations and sampling at the Saru River in Hokkaido, Japan, which is a Class-A river with a reservoir at its middle reaches. This paper examines those observations and sampled data.

2. Summer 2001 Floods and the Drainage Basin

The Saru River drainage basin measures 1,350 km^2 and the river's main stream length is 104 km. Mountainous terrain accounts for 87% of the basin area. Most of the plains are downstream of Nibutani Dam, which is located approximately 21 km from the mouth. The land in this area is used for agriculture, including racehorse pastures.

Table 1. Distance from river mouth

site (km)	Sarugawa Bridge	Confluence with the Shirau	Nina-Ohashi Bridge	Shin-Biratori Bridge	Confluence with the Abetu	Dam body	Check dam	Horokeshi	Nukibetu
Distance from river mouth	2. 8	6. 6	12. 5	16. 1	16. 4	21. 4	27. 1	34. 3	33. 4

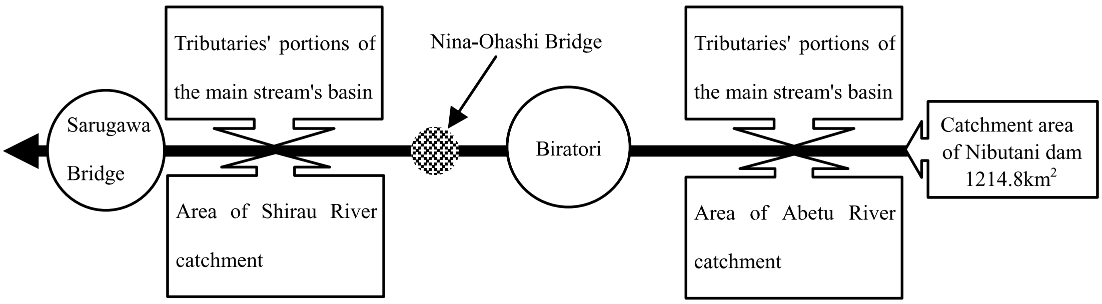

Figure 2. Tributaries, their portions of the main stream's basin and observation sites

The catchment of Nibutani Dam measures 1,215 km^2 and its reservoir is 4.3 km^2. In addition, the Saru River has three relatively large tributaries: the Nukabira, Abetsu and Shirau rivers (Figure 1). The Nukabira's confluence with the Saru is immediately upstream from the dam reservoir. The Abetsu's and Shirau's confluences with the Saru are approximately 5 and 15 km, respectively, downstream from the dam body. The Abetsu River drainage basin area measures 24.0 km^2 and the river's channel length is 7.0 km. The Shirau River drainage basin area measures 11.4 km^2 and the river's channel length is 6.3 km.

Observations were made during two floods in 2001: a medium-scale flood from August 22 to 24, and a large-scale flood from September 11 to 13. The August flood was slightly smaller in scale than the average of yearly largest-scale floods of years for which data were available. The September flood was the largest in scale in the past 20 years. Most of the time during these two floods, dam gate control was the same as that during normal times, with inflow and outflow maintained at equal volumes. Only when the inflow volume exceeded 1900 m^3/s, during the September flood, was floodgate control executed.

3. Outline of the Survey Sites

Observations were performed at the sites shown in Figure 1, whose distances from the mouth are shown in Table 1. To understand the effects of tributaries, the observations were conducted near the Abetsu's and the Shirau's confluences with the Saru. These two tributaries have relatively large catchments downstream from the dam. The Abetsu's confluence with the Saru is between the dam and Shin-Biratori Bridge. The Saru's basin between the dam and Shin-Biratori Bridge measures 38.2 km^2. The Abetsu's basin measures 24.0 km^2, approximately 63% of the area of the Saru's basin between the dam and Shin-Biratori Bridge. The Shirau's confluence with the Saru is between Sarugawa Bridge and Nina-Ohashi Bridge. The area of the Saru's basin between these two bridges was unknown, but it was known that the Shirau's catchment area was 11.40 km^2, or 16% of the portion of the Saru basin area between Shin-Biratori Bridge and Sarugawa Bridge (70 km^2) (Figure 2). Since this number is small, consideration of it may be problematic. In the following analysis, the results obtained at the observation sites on the Abetsu and Shirau rivers, which are immediately upstream from their confluences with the Saru, were regarded as the representative values for their respective basins. At the

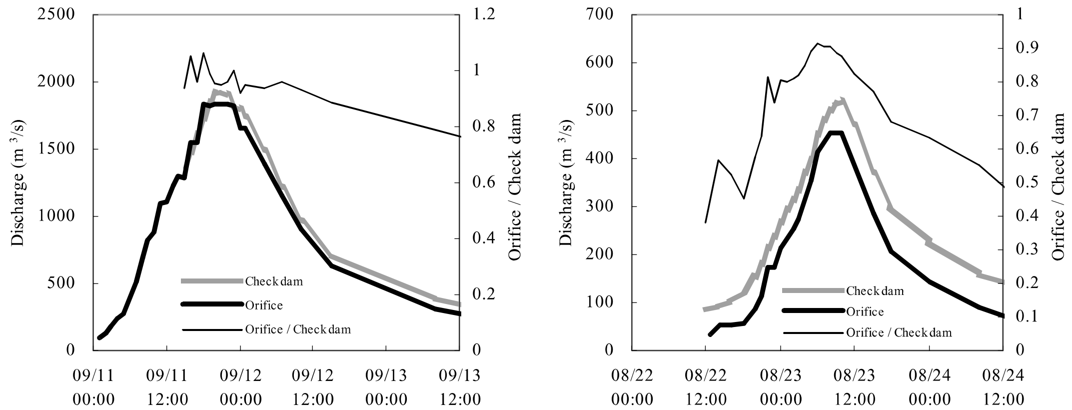

Figure 3. Discharge at the upstream and downstream ends of the dam reservoir

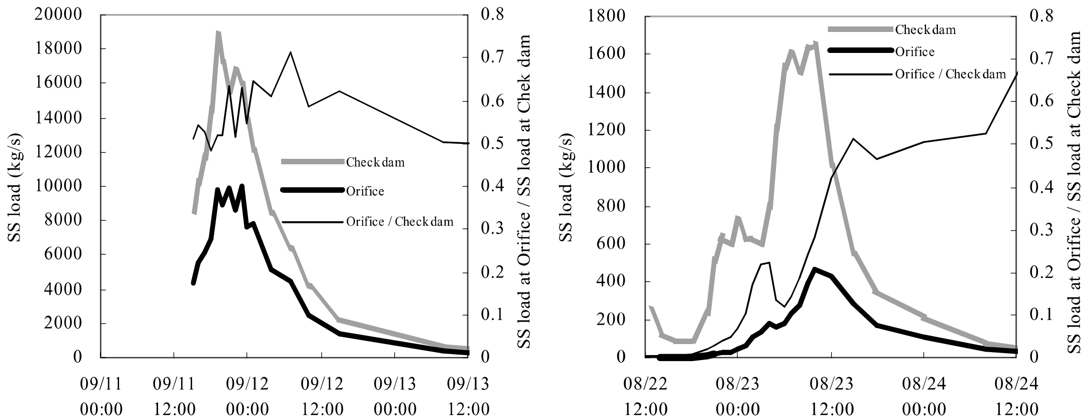

Figure 4. Inflow of SS load and outflow of SS load at the reservoir

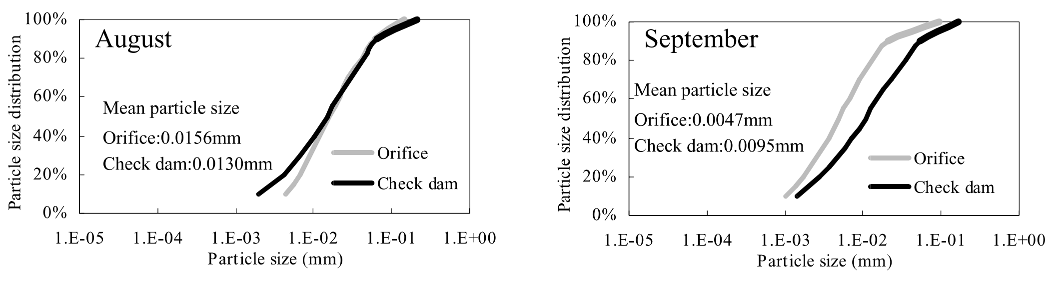

Figure 5. Averaged particle size distribution of SS during the observation period at the dam reservoir

observation sites other than at the dam body orifice, surface water was sampled, and discharge was observed. At the dam body orifice, outflow was sampled. River water was sampled in the center of the river channel at the observation site downstream from Shirau Bridge on the Shirau River and at the site downstream from Abetsu Bridge on the Abetsu River. At the observation stations along the river other than these two sites, river water was sampled not only in the center of the river channel, but also near the right and left riverbanks. An observation site for the check dam is located immediately downstream from the dam as well as at the center in the direction traversing the flow section. Buckets were used to collect water, and the SS concentration of the collected samples was analyzed using the GFP filtration method. Discharge was not observed at the observation site downstream from Abetsu Bridge during the August flood.

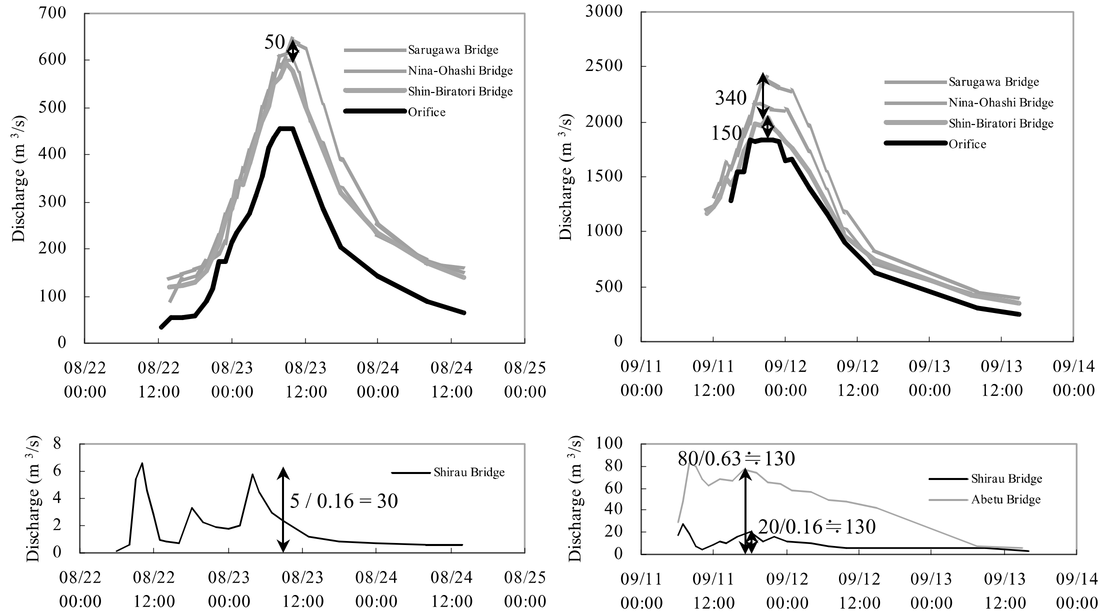

Figure 6. Temporal changes in discharge downstream from the dam and discharge of tributaries

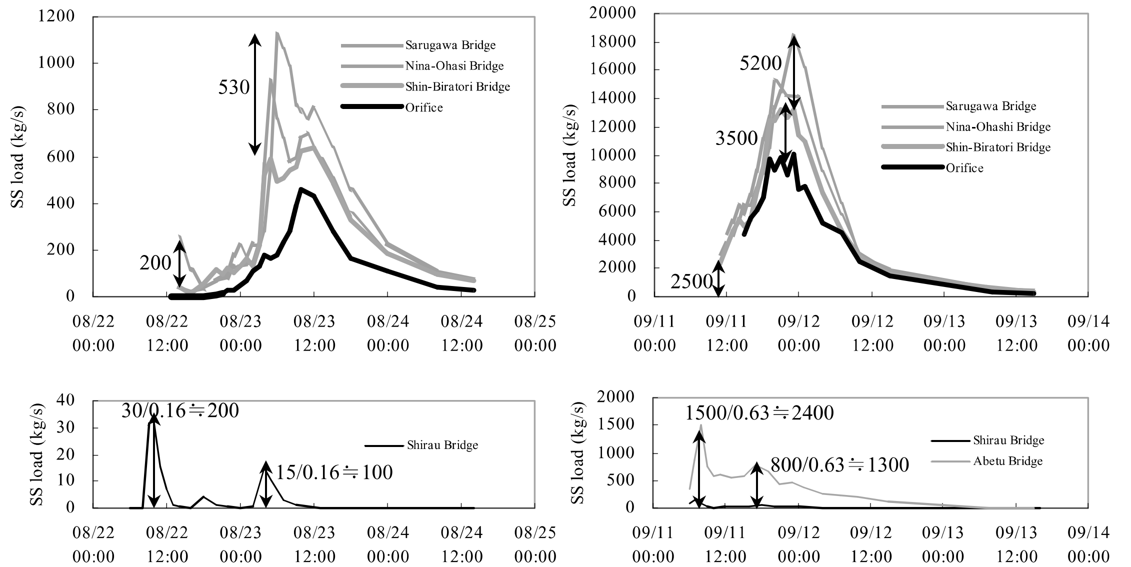

Figure 7. Temporal changes in SS load downstream from the dam and runoff of tributaries

4. Observation Results and Analysis

4.1 Dam reservoir SS inflow and outflow

The volume of water stored in the dam reservoir can be determined by comparing the discharge and passing SS load at the upstream end (check dam) to those at the downstream end (dam body orifice). Figure 3 shows the discharge, and Figure 4 indicates the SS load, which was found by multiplying the flow rate by SS concentration. The hourly average of discharge at the outflow point as a percentage of that at the inflow point was 70% during the August flood and 92% during the September flood. The hourly average SS load at the outflow point as a

Table 2. Relationship between the discharge (m^3/s) at the two observation points, the increase in SS load (kg/s) and the discharge and SS load in the tributary

Item	target section	caliculation method	early phase of August flood	peak of August flood	early phase of September flood	peak of September flood
increase in Discharge	Shin-Biratori Bridge	based on measurement at the main stream				150
	--Orifice	based on measurement at the Abetu River				130
	Sarugawa Bridge	based on measurement at the main stream	60	50		340
	--Shin-Biratori Bridge	based on measurement at the Shirau River	40	30		130
increase in SS load	Shin-Biratori Bridge	based on measurement at the main stream			2500	3500
	--Orifice	based on measurement at the Abetu River			2400	1300
	Sarugawa Bridge	based on measurement at the main stream	200	530		5200
	--Shin-Biratori Bridge	based on measurement at the Shirau River	200	100		0

percentage of that at the inflow point was 21% during the August flood and 56% during the September flood. If the time required for the reservoir to return to the pre-flooding water level is regarded as the flood duration, the volumes of inflow and outflow during the flood should roughly agree. Based on this assumption, the floodwater stays in the reservoir for a long period of time, so the duration of the flood is very long. This means that the two observation periods were not long enough and did not cover the early and late phases of flooding. Approximately half the volume of the SS that flowed into the reservoir during the observation periods did not pass through, but rather stayed there. The late phases of flooding, which did not fall within the observation periods, were long, but the SS load was largely unchanged throughout these durations because the SS load showed negligible changes during the late phases. As Figure 4 clearly demonstrates, the SS load of the water that flowed out of the reservoir was nearly zero at the early phase of the flood duration, even when the SS load of the floodwater flowing into the upstream end of the reservoir was large. The reason for this is that before flooding, the reservoir stored water that did not contain SS. The mechanism of SS transport downstream from the reservoir is markedly different from that of rivers without a dam reservoir. Figure 5 shows the particle size distribution which were averaged during the observation period and mean particle size of SS during the observation period. The perticle size distribution was nearly equivalent at the check dam and the dam body orifice during the August flood. During the September flood, however, the particle size of SS was finer at the dam body orifice than at the check dam.

4.2 Temporal changes in discharge and SS downstream from the dam reservoir

Figures 5 and 6 show temporal changes in discharge and SS load, which was found by multiplying the flow rate by SS concentration at the center of the stream, at the observation sites downstream from the reservoir along the Saru main stream and its tributaries. The Abetsu River merges into the main stream in the section between the dam body and Shin-Biratori Bridge, and the Shirau River merges into the main stream in the section between Sarugawa Bridge and Nina-Ohashi Bridge. Thus, increases in the discharge and SS load in these two sections are compared with the discharge and SS load supplied from tributaries and their catchments. It was hypothesized that the discharge and SS load from an area of the basin between two points on the main stream could be represented by measurements at the tributary. The discharge and SS load measured at the tributary divided by the ratio of the area of the tributary's catchment to the area of the main stream's basin between those two points (the confluences of the two tributaries with the Saru) is considered to be the supplied discharge and SS load from the tributary and its portion of the main stream's basin. If differences in the measurements between the two observation points on the main stream are attributed to the supply from the tributaries, they should be equal to the measured values of supplied discharge and SS load. Table 2 shows the measured values.

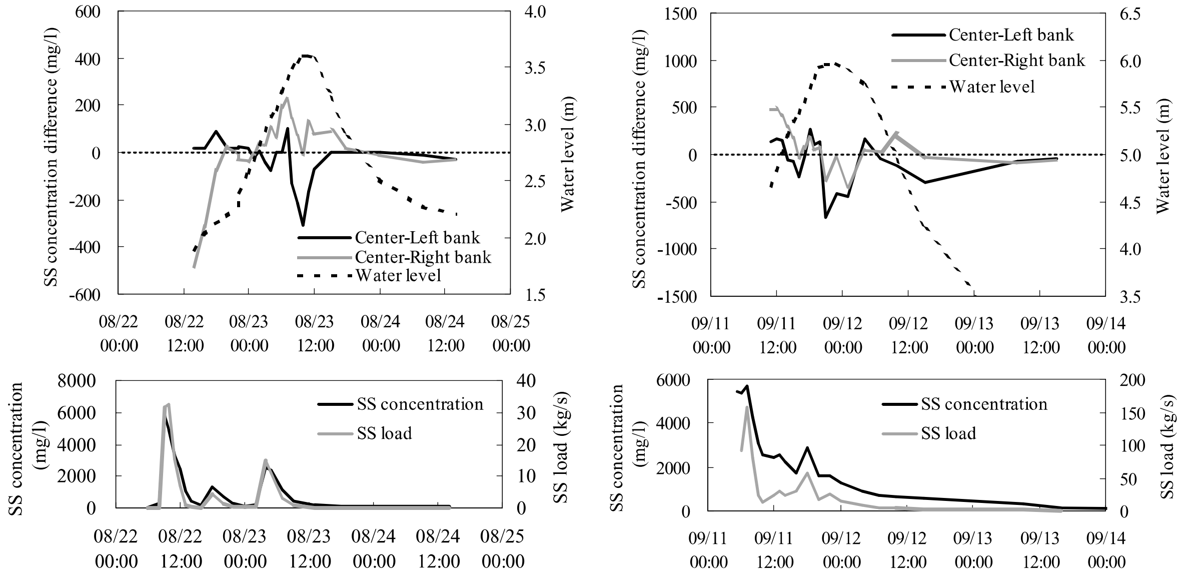

Figure 8. Difference in SS concentration between the center of the stream and the riverbank, and SS concentration and SS load from the Shirau River

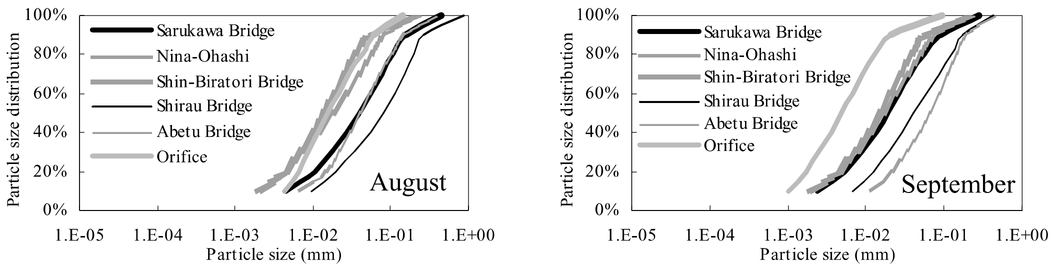

Figure 8. Averaged particle size distribution of SS during the observation period downstream from the dam

The calculations are provided in Figures 6 and 7. The increase in discharge in the main channel and that in the tributary are in general agreement, with the exception of the section between Sarugawa Bridge and Shin-Biratori Bridge. The above hypothesis may therefore be considered valid. Also, the increase in the SS load measured in the main stream and the SS load measured in the tributary are roughly equal for the early phases of the floods, but the difference widens at the flood peaks. At the early phase, the SS load from the basin is included in the measurement taken at the tributary. However, around the peak period, the tributary's portion of the basin of the main stream may have provided SS load that cannot be included in the measurement. As the results of the survey on the Mukawa River indicated, the supply of SS from the riverbank, induced by a rise in the water level, was likely to be added to the supply from the tributary and its portion of the basin of the main stream.

Here we will discuss these two hypotheses in detail. Figure 8 shows the three-hour moving average of SS concentrations at the center of the stream and the riverbank at Sarugawa Bridge as well as SS concentration and SS load of the water from the Shirau River during the August and September floods. The distance between Sarugawa Bridge and the Shirau's confluence with the Saru is approximately 4 km, and the time for water to travel between these two points is short. In addition, the Shirau merges with the main stream from the left bank. Therefore, the SS volume supplied from the tributary (the Shirau) and the SS concentration at Sarugawa Bridge during the two floods might be more or less related to each other at the times indicated by the dashed arrows. However, it is difficult to conclude that they are closely related overall. At Sarugawa Bridge, the SS

Table 3. Mean particle size (mm) during the observation period

Month \ Point	Sarukawa Bridge	Nina-Ohashi Bridge	Shin-Biratori Bridge	Abetu Bridge	Shirau Bridge
August	0.0307	0.0149	0.0117	0.0333	0.0588
September	0.0164	0.0144	0.0125	0.0507	0.0358

concentration at the center of the stream is greater than that at the riverbank before the peak of the water level, and vice versa at the peak. Making a judgment based only on concentration is too rough, but we can say that SS is supplied from the riverbank to the center of the stream. In the tributary's portion of the main stream basin, the main channel is shorter than that of the Abetsu River channel or the Shirau River channel and the time of concentration is short. If the target basin is assumed to have supplied greater SS load than the tributary did around the peak, this assumption invalidates the hypothesis that at the early phase of the flood the SS load supplied from the basin can be included in the measurement at the tributary. Therefore, further research is needed in the future. The increase in SS between Sarugawa Bridge and the Shirau's confluence with the Saru around the peak of the flood can be largely attributed not only to supply from the tributary and its basin, but also to supply from the riverbank. Figure 9 shows the particle size distribution which were averaged during the observation flood, and Table 3 presents the mean particle size during the observation period. It can be seen that particle size distribution tended to become coarse as the river flowed downstream. Since the particle size distribution of the merging tributaries was coarser than that of the Saru, it was presumed that its tributaries and basin also affected the particle size distribution of the river. At the peak time, the riverbanks may also affect the particle size distribution of the river. Detailed examination of this issue, including the results of the survey for particle size distribution at the riverbanks, will be necessary in future.

5. Conclusions

We studied the results of a survey on the behavior of SS load in a river with a dam reservoir at its middle reaches. Due to the presence of the reservoir, SS is not transported from the upper reaches during the early phase of flooding. Using this phenomenon, we clarified the behavior of SS and the effects of the tributary during the flood. This research employed SS measurements at large-scale tributaries. We had no data on SS behavior in small-scale tributaries nor their portions of the main stream's basin. Such behavior remains to be elucidated.

References

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