Advances in River Sediment Research – Fukuoka et al. (eds)
© 2013 Taylor & Francis Group, London, ISBN 978-1-138-00062-9

How the river improvement works have been conducted in the Lower Tone River and how effective they are

N. Iwaya
CTI Engineering, Co., Ltd., Saitama, Japan

S. Fukuoka
Research and Development Initiative, Chuo University, Tokyo, Japan

ABSTRACT: In the Lower Tone River, channel dredging and widening have been conducted to accommodate large flood discharge. However, the current river channel has still insufficient capacity for the design flood. It is therefore required to implement the appropriate river improvement works. However, effectiveness of the past channel dredging and widening has not been assessed so far. In the present paper, we carry out the assessment of the past improvement works in the Lower Tone River and clarify by investigating changes of channel shape and longitudinal distributions of hydraulic quantities in the river how the river improvement works have played important roles. The results of the past river improvement works demonstrated that the sediment deposition tended to vanish away at the downstream from 18.5 km and bed scouring near the outer bank in the river bends nearly disappear from 40 km to 18.5 km.

1 INTRODUCTION

In the Lower Tone River, channel dredging and widening have been conducted as one of flood control countermeasures. As a result, the discharge capacity of the river has increased year by year. However, the current river channel capacity has still insufficient for the present design flood discharge. The sediment deposition near the inner bank of river bends and the large bed scouring at outer banks tend to be marked. It is important to understand effects on changes of the river bed elevation in the past river improvement works and to make it the proper use for the present river management.

Moro et al. (2011) investigated the effects of the channel dredging from Sawara (40.0 km) to river mouth (0.0 km) in relation to changes in main channel widths and cross section areas. Iwaya & Fukuoka (2012) estimated influences of the channel dredging, widening and flood events on the changes in the river channel between 1981 and 1983 around Fukawa contraction area (from 85.5 km to 66.5 km) from the result of analyses of flood flows and bed variations. However, effects of the river improvement works have not been investigated from long-term viewpoints and also in many river sections except at Fukawa contraction area.

In this study, we investigate the past Lower Tone River improvement works and clarify how their improvement works have had effects on channel cross-sectional shape and longitudinal distributions of hydraulic quantities, such as shear velocity and relative depth (flood channel depth/main channel depth).

2 THE CHRONICLE OF THE RIVER IMPROVEMENT WORKS IN THE LOWER TONE RIVER

Figure 1 shows study area in the Lower Tone River. The river improvement works in this area have been conducted continuously from Tone River Improvement Plan made in 1900 to the basic policy for river improvement established in 2006. Figure 2 shows changes in the design flood discharge, the period, sections and sorts of the river improvement works. Figure 3 shows an aerial photo displaying river condition from 16 km to 8 km in 1948.

After the enactment of the river law in 1896, the channel dredging and widening have been conducted in the Tone River, and the embankment has been constructed in primary (1900) Tone River Improvement Plan from 40 km to 20 km and secondary (1907) from 85.5 km to 40 km (See Fig. 2b). This construction work played an essential role to lay a foundation for the current river channel.

Tone River Expansion Plan made in 1939 was reviewed by the disaster of Typhoon Kathleen in 1947. In Tone River Revised Improvement Plan, the design flood discharge was increased as shown

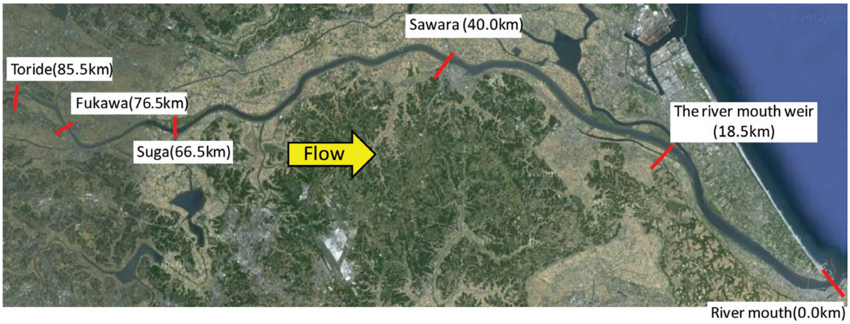
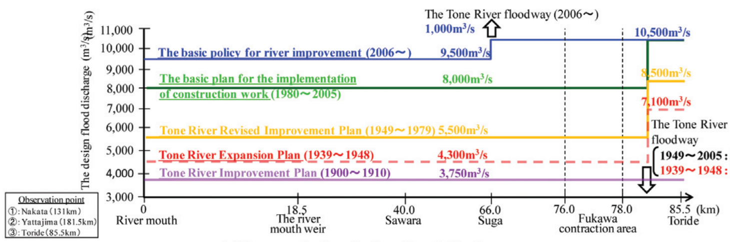
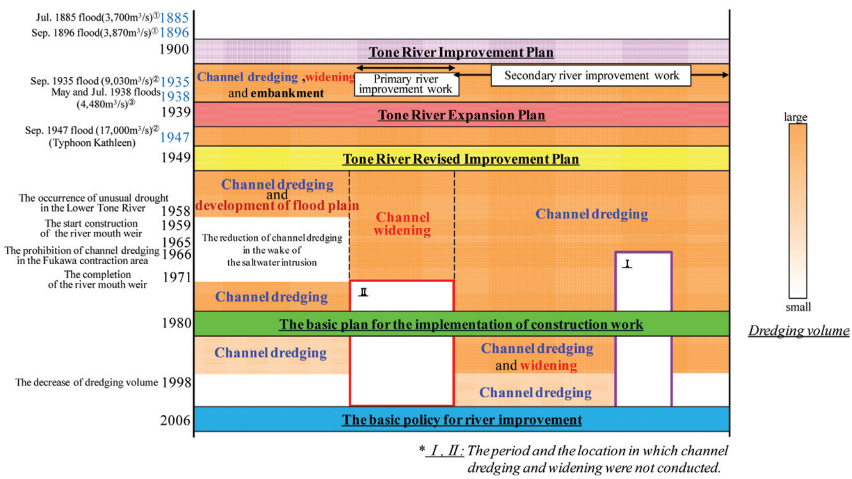


Figure 1. Study area in the Lower Tone River.



a) Changes in the design flood discharge.



b) Changes in the river improvement works.

Figure 2. Changes in the flood control plan and the river improvement works.

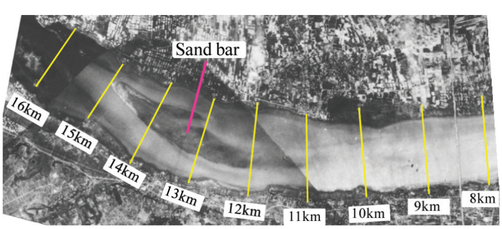


Figure 3. Aerial photo from 16 km to 8 km in 1948.

in Figure 2a. But, it was difficult to expand the Fukawa contraction area (from 78 km to 76 km) and its downstream. Accordingly, the construction of the Tone River floodway and capacity expansion of the Sugo, Inadoi and Tanaka retarding basins in the upstream of the Fukawa contraction area have been planned from Tone River Revised Improvement Plan established in 1949 to the basic plan for the implementation of construction work established in 1980. In Tone River Revised

Improvement Plan (1949), the channel widening has also been conducted from 40 km to 18.5 km so as to increase the discharge capacity. On the other hand, the main channel was about 1200 m wide at the downstream from 18.5 km, where the sediment deposited considerably as shown in Figure 3. Thus, the channel dredging was conducted and flood plains were created by using dredged sediments. However, the channel dredging has not been conducted very so by the saltwater intrusion due to the unusual drought occurred in 1958 and 1959. To prevent saltwater intrusion, the river mouth weir was constructed at 18.5 km in 1971. Afterward, the channel dredging was resumed in the downstream of the river mouth weir. In the upstream from 40 km, the channel dredging has been continuously conducted for the river improvement and for need of the construction material. However, the river bed elevation was lowered below the design bed elevation in the Fukawa contraction area, and therefore channel dredging there stopped in 1966 (the area enclosed by purple line in Fig. 2b). In the basic plan for the implementation of construction work (1980), the design flood discharge was increased because of the progress of improvement works in the Upper Tone River as shown in Figure 2a. The channel widening and dredging have been conducted at the upstream from 40 km until around 1998, while the channel widening was not conducted at the downstream from 40 km for assuring the safety of levees (the area enclosed by red line in Fig. 2b).

The basic policy for river improvement established in 2006 determined the shift of construction location of the Tone River floodway to the downstream of the Fukawa contraction area because the floodway planned in the upstream of the Fukawa contraction area brought a large impact on the regional communities. As a result, the design flood discharge was determined 10,500 m^3/s in the upstream and 9,500 m^3/s in the downstream of the branched section of the Tone River floodway (See in Fig. 2b).

3 THE RELATIONSHIP BETWEEN RIVER IMPROVEMENT WORKS AND CHANGES IN RIVER BED ELEVATION

On this section, we investigate the chronological changes in the river bed elevations and river cross-sections by the river improvement works.

Figures 4 and 5 show water surface profiles at the peak discharge of the floods occurred in

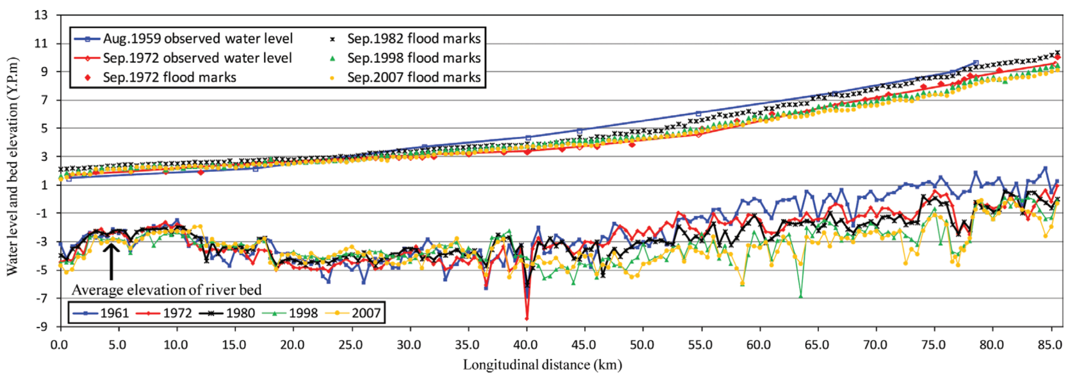


Figure 4. Water surface profiles at the peak of each flood and changes in average river bed elevation.

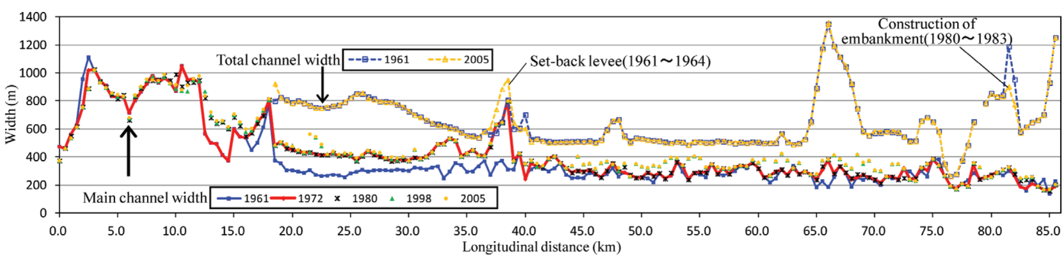


Figure 5. Changes in main channel width and total channel width.

Aug. 1959, Sep. 1972, Sep. 1983, Sep. 1998 and Sep. 2007 as well as changes in the average river bed elevation and changes in main channel width and total channel width, respectively. Figures 6 and 7 show river bed elevation contour in 1961 and 2007 before and after the river improvement works and changes in the lowest bed elevation, respectively. Large bed scourings are seen at the places indicated by red color in Figure 6 and the area shaded by green color in Figure 7. Here, we define "large bed scouring" as the bed scouring near the bank and places of relatively low elevation of river bed seen in the longitudinal profiles of the lowest bed elevation in Figure 7. Plan shape of the Lower Tone River has changed markedly between 1961 and 2007 as shown in Figure 6.

Okada et al. (2002) showed the characteristic diagram of plan shape of the meandering compound channel in Figure 8, in which the meandering channel is assumed to be described by sine generated curves in Figure 9. Here, b_{mc}, A_{mp} and L are main channel width, meander amplitude and

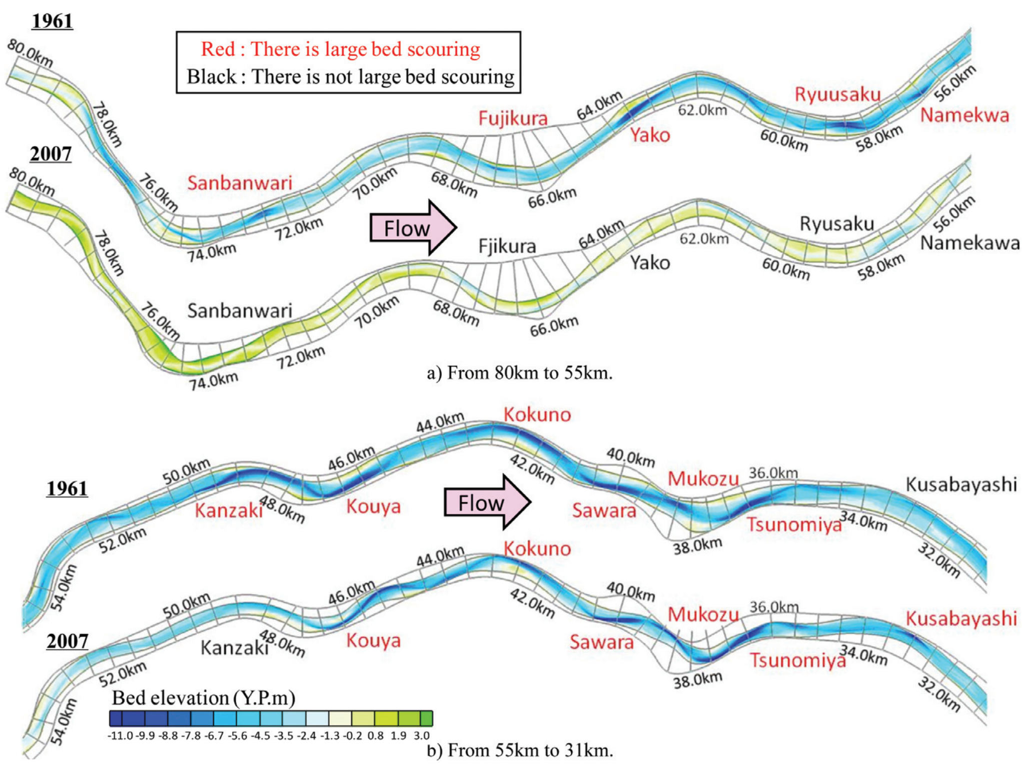


Figure 6. River bed elevation contour in 1961 and 2007 in the Lower Tone River (from 80 km to 31 km).

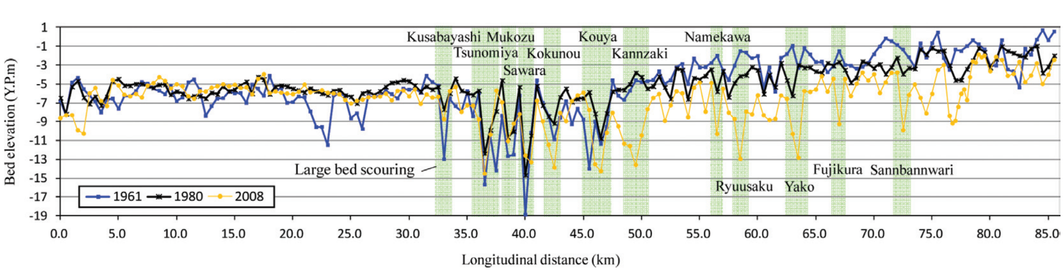


Figure 7. Changes in the lowest bed elevation.

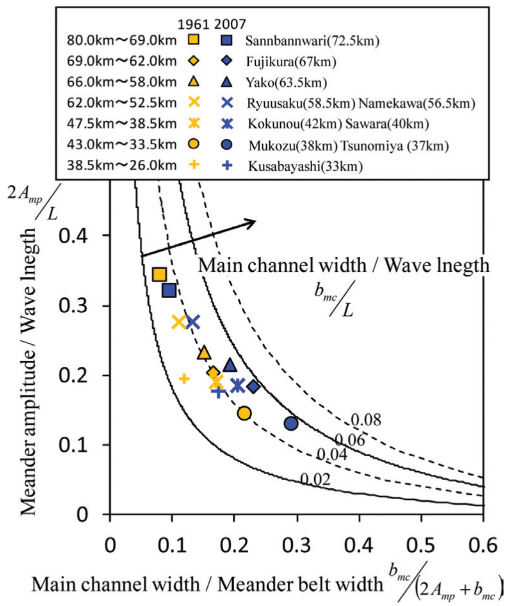


Figure 8. Changes in non-dimensional plan shape parameters before and after river improvement works.

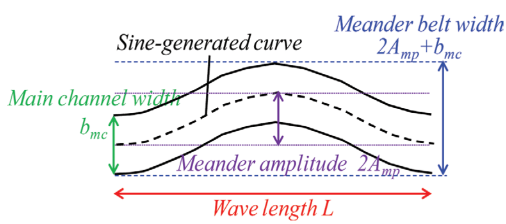


Figure 9. Definition of plan shape parameters.

wave length, respectively. Figure 8 shows that three parameters $2A_{mp}/L$, $b_{mc}/(2A_{mp} + b_{mc})$ and b_{mc}/L are important to express plan shape of meandering channels. The higher the horizontal axis $b_{mc}/(2A_{mp} + b_{mc})$ is, the more features of flood flow approach features in the straight channel. Thus, both abscissa values $b_{mc}/(2A_{mp} + b_{mc})$ and curved lines b_{mc}/L vary with the main channel width b_{mc}. Table 1 shows physical quantities of plan shapes in 1961 and 2007. The values of b_{mc}/L in 1961 and 2007 shown in Table 1 are found to correspond with the values of a family of curved lines b_{mc}/L shown in Figure 8. We can evaluate changes in plan shape of the Lower Tone River by using Figure 8.

Figure 10 shows maximum annual discharges at Toride (85.3 km) and Fukawa (76.5 km) observation points from 1959 to 2007, and the broken lines indicate the design flood discharge at the observation points. In this area, large floods occurred in Aug. 1959, Sep. 1972, Sep. 1983, Sep. 1998 and Sep. 2007. In order to clarify the interrelationship between the river improvement works and changes in river bed elevation, we investigate longitudinal distributions of cross section area, shear velocity and relative depth Dr (flood channel depth/main channel depth) in the peak flood level of large floods.

From 1961 to 1980, the channel dredging has been conducted at the upstream from 40 km. The amount of sediment transported from the upstream area has reduced due to the erosion and sediment control and the construction of dams in the Upper Tone River in the 1960s. Therefore, river bed degradation occurred as shown in Figure 4. The channel widening was conducted from 40 km to 18.5 km in Figure 5. As a result, the peak water level in the Sep. 1972 flood (peak discharge: 6300 m^3/s) was lower than that in the Aug. 1959

Table 1. Physical quantities of plan shapes in 1961 and 2007.

	1961				2007				
	L (m)	$2A_{mp}$ (m)	b_{mc} (m)	b_{mc}/L	L (m)	$2A_{mp}$ (m)	b_{mc} (m)	b_{mc}/L	Location of large bed scouring
80.0 km~69.0 km	8830	3040	260	0.029	8830	2850	290	0.033	Sannbannwari (72.5 km)
69.0 km~62.0 km	6500	1330	260	0.040	6500	1200	360	0.055	Fujikura (67.0 km)
66.0 km~58.0 km	6750	1580	280	0.041	6750	1460	350	0.052	Yako (63.5 km)
62.0 km~52.5 km	8500	2350	290	0.034	8500	2350	360	0.042	Ryusaku (58.5 km), Namekawa (56.5 km)
47.5 km~38.5 km	7670	1460	300	0.039	7670	1420	370	0.048	Kokuno (42.0 km), Sawara (40.0 km)
43.0 km~33.5 km	8200	1200	330	0.040	8200	1080	440	0.054	Mukozu (38.0 km), Tsunomiya (37.0 km)
38.5 km~26.0 km	12000	2340	320	0.027	12000	2130	450	0.038	Kusabayashi (33.0 km)

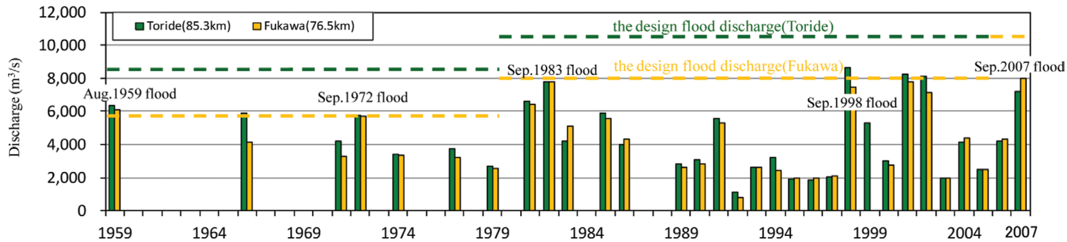


Figure 10. Maximum annual discharges.

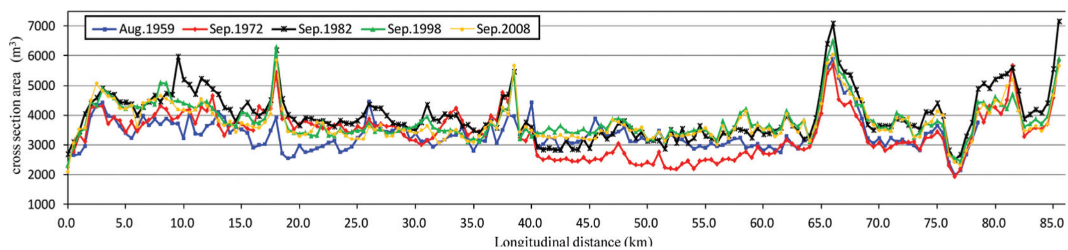


Figure 11. Changes in cross section area.

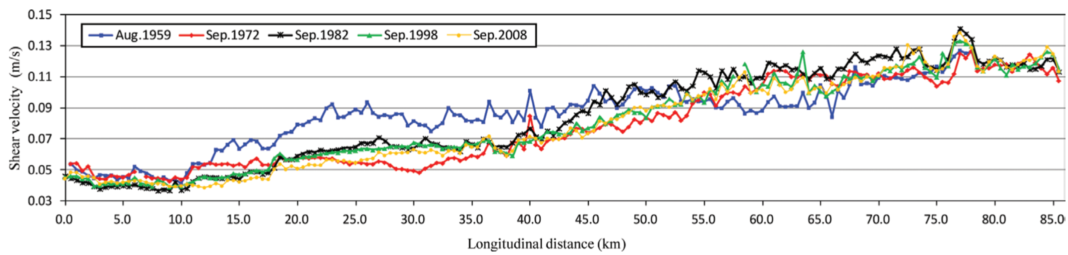


Figure 12. Changes in shear velocity.

flood (peak discharge: 5800 m³/s) at the upstream from 20 km as shown in Figure 4.

Figure 8 shows that characteristic values vary greatly by the channel widening from 1961 to 2007 in each meandering section of Mukozu (38 km), Tsunomiya (37 km) and Kusabayashi (33 km). Especially, $b_{mc}/(2A_{mp} + b_{mc})$ vary more greatly than $2A_{mp}/L$. In the downstream of 40 km, difference of the river bed elevation between 1961 and 1972 is small. Local bed scouring is mostly dependent on plan shape. In the meandering section which $b_{mc}/(2A_{mp} + b_{mc})$ vary greatly, the plan shape of main channel changed as indicated in Figure 6, and the flood flows have behaved like flows in the straight channel. From this reason, it is considered that bed scouring near the outer bank in the river bend nearly disappeared in the downstream from 40 km because of the decrease of the secondary flow intensity. Figures 11 and 12 show longitudinal distributions of cross section area and shear velocities at peak water level of the each flood, respectively. The cross section area of the Aug. 1959 flood was different between upstream and downstream of 20 km. At the downstream from 18.5 km before 1961, the sediment deposition was considerable as shown in Figure 3. Because of channel widening from 18.5 km to 40 km after Aug. 1959 flood, the difference of cross section area between upstream and downstream of 20 km has reduced in Sep. 1972. The distribution of shear velocities has become uniform at the downstream from 40 km. Therefore, it is considered that the sediment deposition tended to reduce at the downstream from 18.5 km after 1961 (See Fig. 4). On the other hand, the difference of main channel width between upstream and downstream of

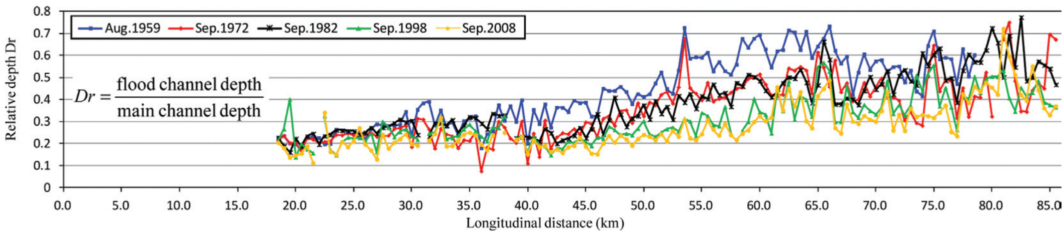


Figure 13. Changes in relative depth (flood channel depth/main channel depth).

40 km has increased in 1972 by the channel widening from 40 km to 18.5 km. Accordingly, shear velocities at the upstream from 40 km have been greater than at the downstream. For this reason, it is considered that the river bed aggradation occurred from 40 km to 18.5 km since 1972.

From 1980 to 1998, the river bed degradation occurred and main channel width widened at the upstream from 40 km by the river improvement works. Since 1998, the variations of river bed elevation and main channel width are relatively small (See Figs. 4 and 5). Consequently, the peak water level in the Sep. 1998 flood (peak discharge: 8600 m^3/s) was lower than that in the Sep. 1983 flood (peak discharge: 7800 m^3/s). On the other hand, it was much the same as the peak water level in the Sep. 2007 flood (peak discharge: 7200 m^3/s) as shown in Figure 4. Due to channel widening at the upstream from 40 km, the difference of the main channel width between upstream and downstream of 40 km disappeared in 1998. As a result, longitudinal distribution of cross section area has become nearly uniform in the Lower Tone River since the Sep. 1998 flood, and longitudinal variation of shear velocities has become smaller.

The characteristic values at the upstream from 40 km indicated in Figure 8 do not vary so much except for the meandering section of Fujikura (67 km) because the widening width at the upstream from 40 km is smaller than that at the downstream from 40 km. From this, it is supposed that change in plan shape hardly has an effect on flows. But, the bed scouring progressed greatly at the upstream from 40 km since 1980 as shown in Figure 7. This reason is discussed as follows. Figure 13 indicates longitudinal distribution of relative depth Dr of each flood. Here, Dr is defined as the ratio of flood channel depth to main channel depth. As a result of channel dredging and widening at the upstream from 40 km, relative depth Dr gradually decreased and is distributed around 0.3 since Sep. 1998 flood. This means that the simple meandering channel flow became dominant at the upstream from 40 km (Fukuoka, 2005). And, the ratio of main channel width to total channel width increased as shown in Figure 5. For this reasons, the sediment transport rate increased as the flood discharge in the main channel increased, and therefore it is considered that the large bed scouring occurred at the upstream from 40 km (Okada et al., 2002). Additionally, the large bed scouring in the meandering section of Fujikura (67 km) occurred near the inner bank of the river bend because the feature of flood flow has approached that in the straight channel as $b_{mc}/(2A_{mp} + b_{mc})$ increases (See Fig. 8).

4 CONCLUSIONS

In this study, we investigated the chronological changes of the river improvement works in the Lower Tone River and clarified how the river improvement works have given effects on changes in the river bed elevation by investigating the changes of channel shape and longitudinal distributions of hydraulic quantities.

Main conclusions were drawn as follows.

1. From 1961 to 1980, the channel widening has been conducted between 18.5 km and 40 km. As a result, distributions of cross section area and shear velocities have become almost uniform at the downstream from 40 km. There is a clear distinction of cross section area and shear velocities between upstream and downstream of 40 km. Therefore, the aggradation disappeared at the downstream from 18.5 km and occurred from 40 km to 18.5 km.
2. In the meandering section downstream from 40 km, the flood flow features have approached those in the straight channel due to the channel widening. Bed scouring near the outer bank in the river bends nearly disappeared as the secondary flow intensity decreased.
3. From 1980 to 1998, the channel widening and dredging have been conducted at the upstream from 40 km. The sediment transport rate increased as the flood discharge in the main channel increased because the relative depth

decreased and the ratio of main channel width to total channel width increased. For this reason, the bed scouring progressed greatly upstream from 40 km.

REFERENCES

Fukuoka, S. 2005. *Flood Hydraulics and Channel Design*, Tokyo: Morikita Publishing Company.

Iwaya, N. & Fukuoka, S. 2012. Changes in river bed around the Fukawa contraction area by floods and channel improvement works in the Lower Tone River, *Advances in Hydro-Science and Engineering*, ICHE, Vol. 10.

Ministry of Construction, Kanto Regional Construction Bureau. 1987. *100 Year's History of the Tone River*.

Moro, Y., Kazama, S. & Fukuoka, S. 2011. Change of river improvement works of the Lower Tone River and effectiveness of channel dredging, *Advance in River Engineering*, JSCE, Vol. 17, pp. 101–106.

Okada, S. & Fukuoka, S. 2002. Characteristics of flood flow, sediment discharge and bed topography in compound rivers, *Proceedings of JSCE*, JSCE, No. 754, pp. 19–31.

Shirai, K. & Fukuoka, S. 2011. Changes of Tonegawa River channel by river improvement since the Meiji era and hydroscience and hydraulic engineering analysis on its factor, *Advance in River Engineering*, JSCE, Vol. 12, pp. 217–222.