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Changes in River Bed around the Fukawa Contraction Area by Floods and Channel Improvement Works in the Lower Tone River

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CHANGES IN RIVER BED AROUND THE FUKAWA CONTRACTION AREA BY FLOODS AND CHANNEL IMPROVEMENT WORKS IN THE LOWER TONE RIVER

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ABSTRACT

In the lower Tone River, channel dredging and widening have been conducted for the river improvement to respond to the flood discharge increase. Especially, the flood discharge capacity in the Fukawa contraction area has been an important problem of flood control in the lower Tone River. In the Fukawa contraction area, the river bed elevation lowered below the design bed elevation, and therefore channel dredging stopped in 1966. Nevertheless, the river bed degradation has continued until around 1998. In this study, we investigated the causes of the river bed degradation in the Fukawa contraction area in relation to flood flows, the channel dredging and widening by both observed data and analysis of flood flow and bed variation considering channel widening and dredging. Observed data demonstrated that the river bed degradation in the Fukawa contraction area has occurred due to floods, channel dredging and widening in the upstream and downstream of the Fukawa contraction area. Numerical analysis provided a good explanation for mechanics of river bed degradation and scouring during floods.

1. INTRODUCTION

In the lower Tone River, river improvement works including channel dredging and widening have been conducted to respond to the flood discharge increase. The Fukawa contraction area is located at 76km from the river mouth, and the flood discharge capacity in the Fukawa contraction area has been an important issue of flood control in the lower Tone River. Because there were many houses along the Fukawa contraction area, channel dredging had been main countermeasures for improvement works. In the Fukawa contraction area the river bed elevation lowered below the design bed elevation, and therefore channel dredging stopped in 1966. Nevertheless, the river bed degradation has continued until around 1998.

The objective of this study is to clarify the causes of the river bed degradation and scouring in the Fukawa contraction area in relation to the channel dredging, widening and flood flows. First, we investigated the causes from the observed data of the channel dredging, widening and flood flows. Secondly, we conducted the unsteady quasi 3-D flow analysis and bed variation analysis

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using observed temporal changes in water surface profiles in order to understand the bed variation in and around the Fukawa contraction area from 1981 to 1983.

2. CHANGES IN RIVER BED IN AND AROUND THE FUKAWA CONTRACTION AREA IN THE LOWER TONE RIVER

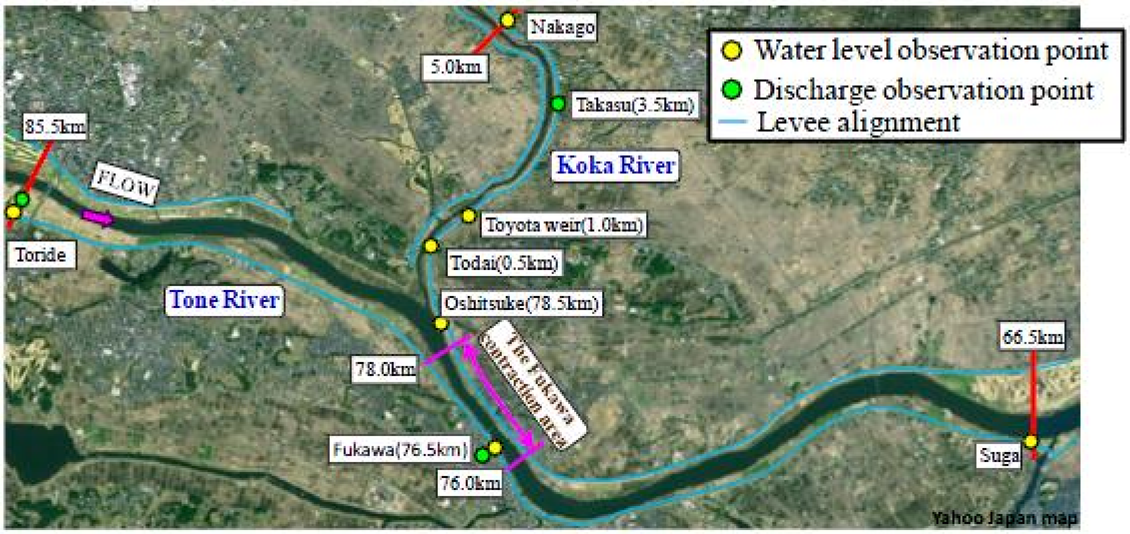


Figure 1 Study area and location of observation points in and around the Fukawa contraction area in the Lower Tone River.

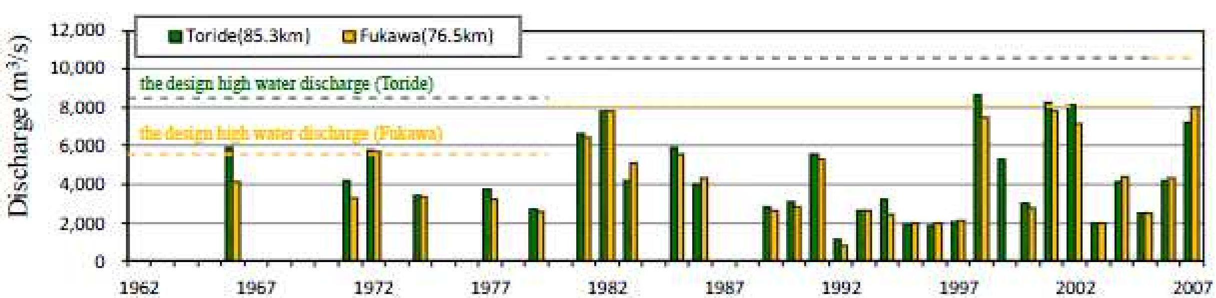


Figure 2 Maximum annual discharge.

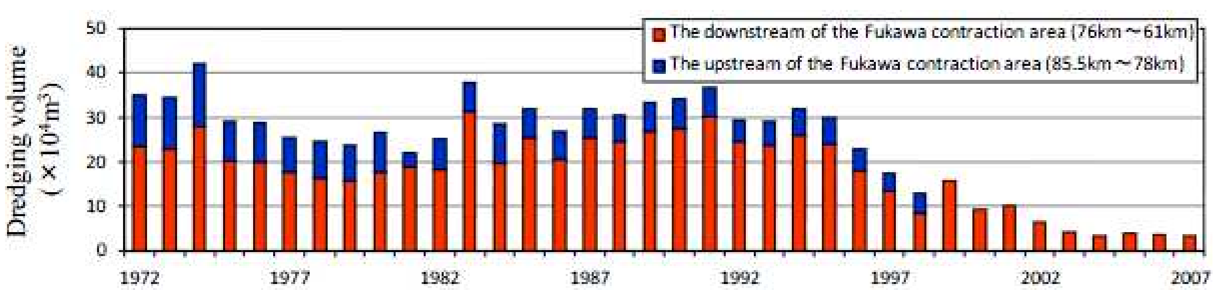


Figure 3 Dredging volumes in the upstream and downstream of the Fukawa contraction area.

Figure 1 shows study area and location of observation points in and around the Fukawa contraction area in the Lower Tone River. Figure 2 shows the maximum annual discharge at Toride (85.3km) and Fukawa (76.5km) observation point from 1962 to 2007, and the broken lines indicate the design high water discharge at the observation points. The dredging volume in the upstream and downstream of the Fukawa contraction area from 1972 to 2007 is shown in Figure 3. Since 1999, the dredging has not conducted in the upstream of the Fukawa contraction area and the dredging volume has been decreasing year by year in the downstream.

Figure 4 shows the changes in main channel width in the study area. Main channel has been widened longitudinally from 1961 to 1983 in the upstream and from 1961 to 1998 in the downstream for increasing the capacity of the river channel. In this area, large floods occurred at Sep.1983, Sep.1998 and Sep.2008. Figure 5 shows flood marks and observed maximum water level of each flood. Figure 6 and Figure 7 are the changes in average and deepest elevation of river bed in the study area. In the Fukawa contraction area, although the dredging has not conducted since 1966, the average and deepest river bed has greatly degraded from 1961 to 1983. On the other hand, from 1983 to 1998, the degradation of the river bed has caused mainly near the exit of the Fukawa contraction area (from 77.0km to 76.0km). And, the river bed elevation has not much degraded since 1998.

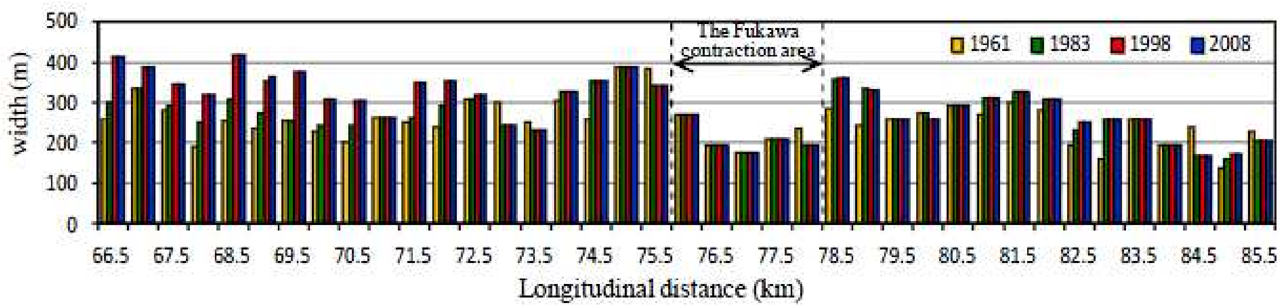


Figure 4 Changes in main channel width.

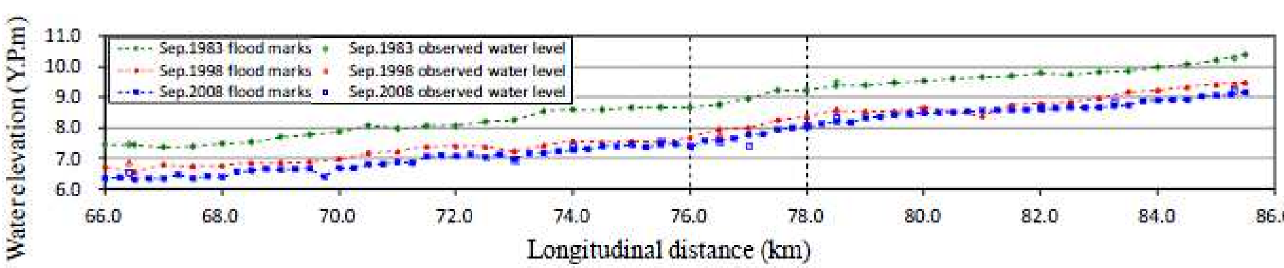


Figure 5 Flood marks and observed maximum water level of each flood.

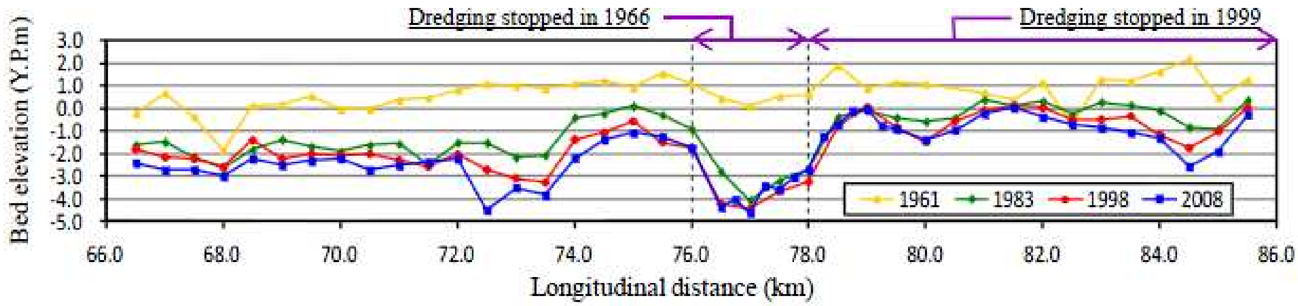


Figure 6 Changes in average elevation of river beds

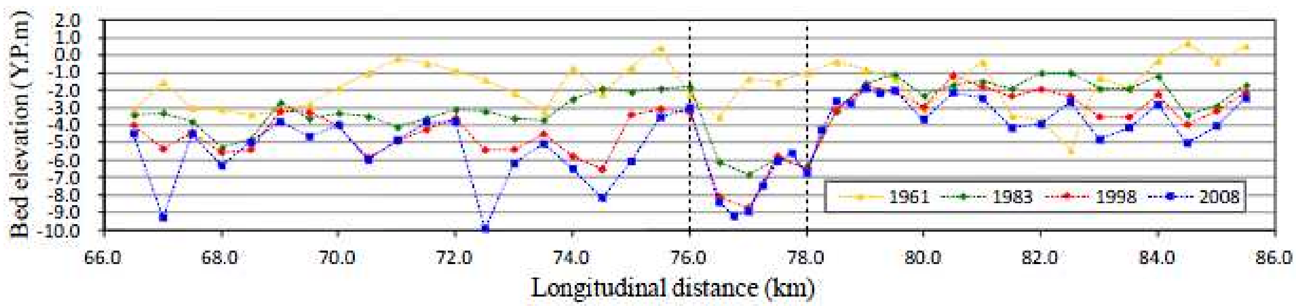


Figure 7 Changes in deepest elevation of river bed.

From 1961 to 1983, the dredging has been conducted actively in the upstream and downstream of the Fukawa contraction area. And, the amount of sediment from the upstream has reduced due to the erosion and sediment control management and the construction of dams in the upper Tone River in the 1960s. Therefore, the average and deepest elevation of river bed has degraded severely in the upstream and downstream of the Fukawa contraction area (See Figure 6 and Figure 7). And, the river bed elevation in the Fukawa contraction area has also lowered due to flood flows and the river bed degradation in the upstream and downstream of the Fukawa contraction area from 1961 to 1983.

From 1983 to 1998, the dredging has continued in the upstream and downstream as shown in Figure 3. And, the amount of the river bed degradation in the downstream is greater than in the upstream (See Figure 6 and Figure 7). Figure 8 shows cross sectional form at 76.5km after Sep.1983 and Sep.1998 flood, and broken lines indicate the peak water levels of the floods. Table 1 indicates the cross section area at the peak water levels. As shown in Figure 8 and Table 1, the water level in Sep.1998 flood is lower than in Sep.1983 flood. However, the cross section area in Sep.1998 flood is almost as large as in Sep.1983 flood. In the downstream of the Fukawa contraction area, because the river bed elevation decreased more greatly than in the upstream and the main channel has been widened, the water level has degraded. It is supposed that the scouring near the exit of the Fukawa contraction area progressed to get the almost same cross section area of Sep.1983 flood. From the above discussions, the dredging and widening in the downstream of the Fukawa contraction area are closely related to the river bed degradation near the exit of the Fukawa contraction area from 1983 to 1998.

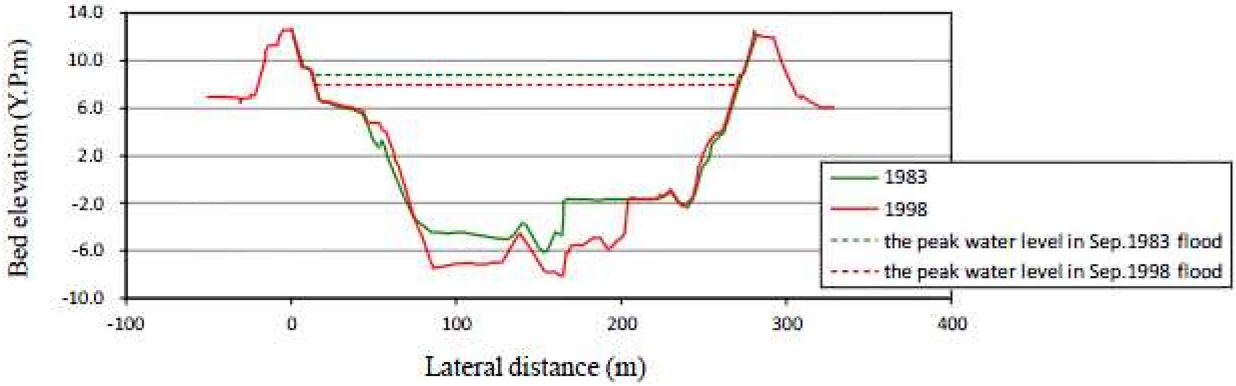


Figure 8 Peak water levels and cross sectional form at 76.5km.

Table 1 Cross section area at peak water levels.

	Peak dischrge (m^3/s)	Cross section area (m^2)
Sep.1982 flood	7700	2500
Sep.1998 flood	7600	2550

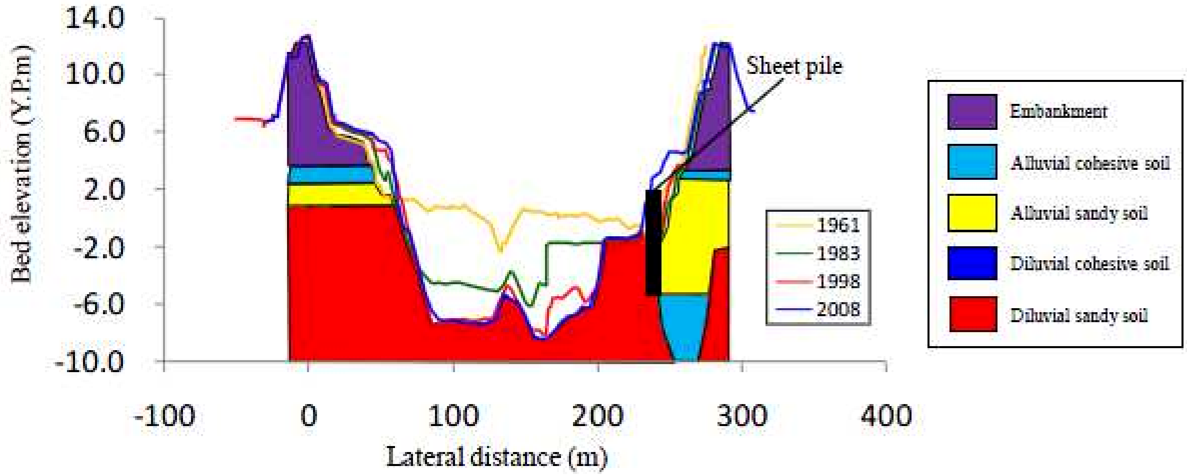


Figure 9 Geologic cross section at 76.5km.

After 1998, although the floods comparable to the design high water discharge have occurred (See Figure 2), the river bed elevation has not much degraded as shown by Figure 6 and Figure 7. There are two reasons for this. One is the decrease of dredging volume and the other is the geological factor in the Fukawa contraction area. Figure 9 shows the geologic cross section at 76.5km. The geologic cross section indicates that the river bed surface has been covered with the diluvial sandy soil since 1998, which is more difficult to erosion than alluvium. For this reasons, it is considered that the river bed degradation near the exit of the Fukawa contraction area almost stopped.

3. BED VARIATION ANALYSIS CONSIDERING THE CHANNEL DREDGING AND WIDENING DURING THE FLOODS

3.1 Analysis Method

The foregoing section showed that flood flows, channel dredging and widening had an effect on change in the river bed in and around the Fukawa contraction area. But, flood flows and bed variation in the study area during the floods is not discussed. Okamura, Fukuoka et al. (2010) clarified bed variation and flood flows in the Tone River mouth during the flood by analysis method using time series of the observed water surface profiles. The analysis is conducted based on the idea that the effects of river conditions and bed variation during flood appear in time series of the water surface profiles. We conducted the numerical analysis of flood flow and bed variation using observed temporal changes in the water surface profiles for the five large floods in Aug. 1981, Aug. and Sep. 1982 and Aug. and Sep. 1983. In this period, the river bed elevation in the Fukawa contraction area lowered severely.

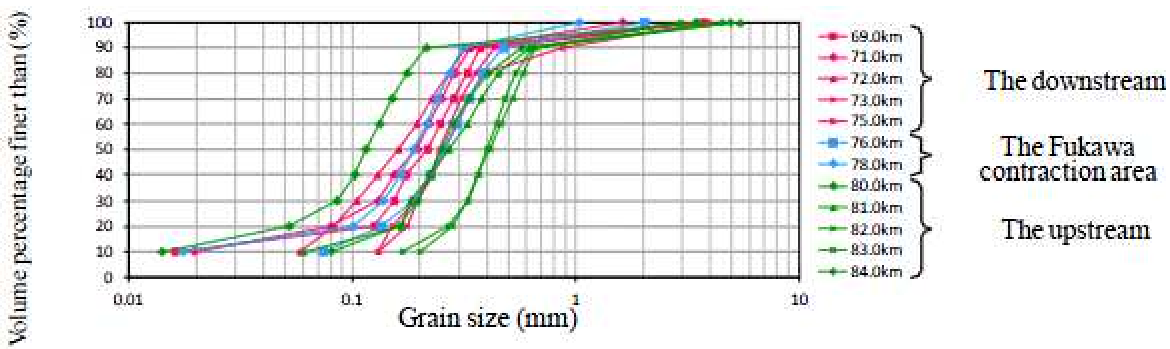


Figure 10 Grain size distribution in 1996.

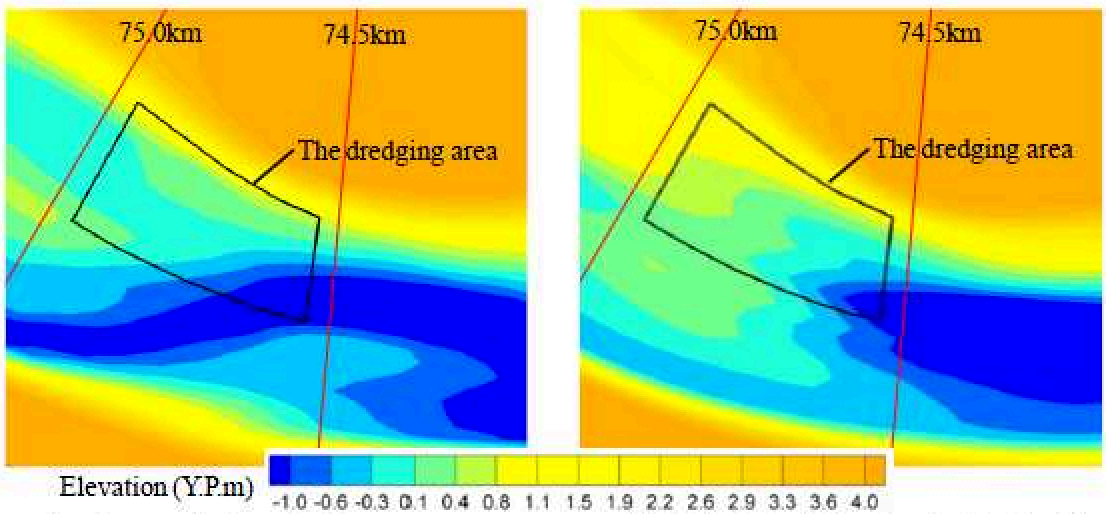
The analysis consists the unsteady quasi 3-D flow (Uchida and Fukuoka, 2011) and bed variation analysis. The bed variation analysis was considered both bed load and suspended load because the grain diameter is relatively so small as shown in Figure 10 that the amount of suspended load is not negligible. The rate of bed load transport was calculated by Ashida and Michiue formula (Ashida and Michiue, 1972). The vertical distribution of suspended load concentration, fall velocity and amount of suspended load were calculated by using Lane-Kalinske formula (Lane and Kalinske, 1941), Rubey formula (Rubey, 1933) and Kishi-Itakura formula (Itakura and Kishi, 1980), respectively. The suspended load concentration was calculated by depth averaged planar 2-D convective diffusion equation.

The initial bed forms were measured in 1980. The upstream and downstream boundary conditions were given by the time series data of observed water level at Toride (85.3km), Suga (66.5km) observation point in the lower Tone River and Nakago (5.0km) observation point in the Kokai river (See Figure 1). The mean grain diameter is 0.25mm in the study area. In the Fukawa contraction area, we assumed the river bed degradation does not occur at the place of diluvium in the analysis. Manning's roughness coefficients were set to 0.020 for the main channel and 0.038 for the flood channel.

In this calculation, flood flows and bed variation were calculated during the 5 floods continuously. The channel dredging and widening have been conducted in the study area after Aug. 1981 flood, Sep. 1982 flood and Sep. 1983 flood, respectively. So, the bed variation analysis considered channel dredging and widening after each flood in the following manner. In this study, we defined dredging as excavation of river bed and widening as extension of main channel width.

Table 2 Dredging range,volume and implementation year.

1981		1982		1983	
dredging location	(m^3)	dredging location	(m^3)	dredging location	(m^3)
81.25k right bank	30,465	81.5k right bank	32,535	81.0k right bank	41,460
78.75k left bank	6,850	74.5k left bank	37,119	75.0k left bank	43,440
74.5k right & left bank	21,844	73.75k left bank	12,321	73.5k left bank	19,446
74.0k left bank	18,800	71.5k right bank	17,100	69.5k left bank	5,020
68.5k right & left bank	35,060	68.0k right bank	24,560	69.0k right bank	49,740
68.0k right bank	35,830	68.75k right bank	35,229	68.0k right bank	40,550



a) Observed river bed in 1983 b) Calculated river bed after the floods

Figure 11 Observed river bed contour in 1983 and calculated river bed contour after the floods.

Table 2 shows dredging range, dredging volume and implementation year. But, there was no data of dredging depth and area of each dredging location. We determined the dredging depth and area so that calculated bed profiles after the floods reproduce the observed bed profiles. Concretely, Figure 11 shows the observed river bed contour in 1983 and the calculated river bed contour after the floods and the area enclosed by black line indicates the determined channel dredging area. The channel dredging depth and area is estimated to correspond with the dredging volume in the location which the calculated river bed elevation is higher than the observed river bed elevation. If the calculated bed profiles after the floods do not sufficiently reproduce the observed bed profiles, we adjust the channel dredging depth and area by trial and error so that the calculated bed profiles reproduce the observed bed profiles.

Table 3 Widening place name, kilometer post and implementation year.

1981	1982	1983
Toride	Toride	72.0km
Inba	Inba	79.0km
	79.0km	

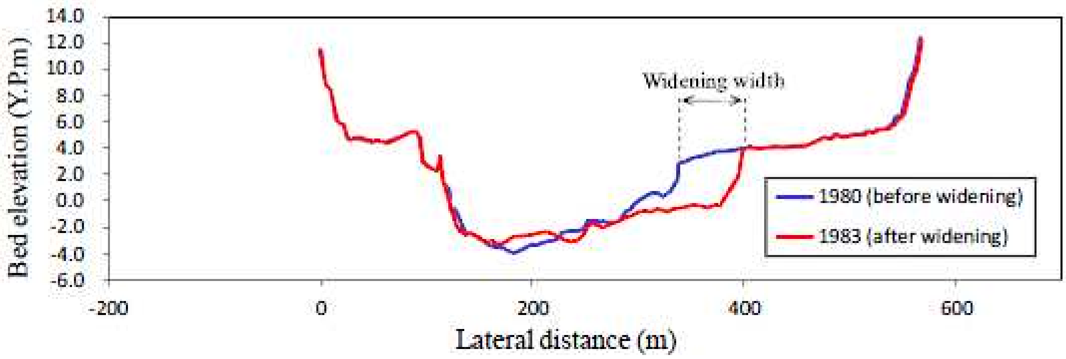


Figure 12 Cross sectional form before and after the river widening at 72.5km.

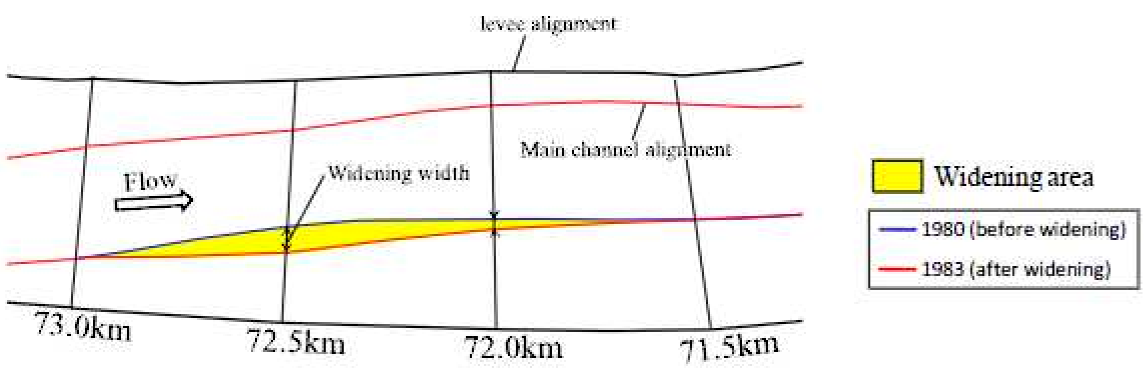


Figure 13 Planar change in main channel width from 1981 to 1983.

In the study area, the widening place name, kilometer post and implementation year have been recorded as shown in Table 3. But, widening area has not been recorded. In order to determine the widening area, we used the observed cross sectional form before and after the floods and the data shown in Table 3. First, we set the widening depth by comparing the cross sectional forms every point which cross-sectional leveling was conducted (e.g., Figure 12). From this, the planar area of channel widening is determined as indicated in Figure 13.

Conclusively, we set the planar area of channel dredging and widening of each year as shown in Figure 14.

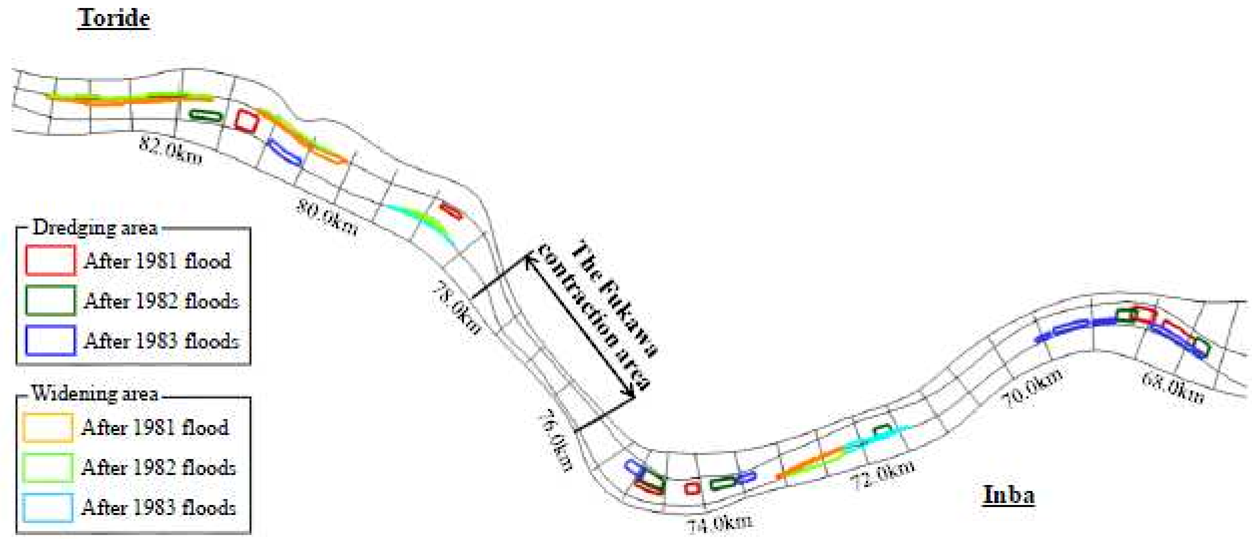


Figure 14 Planar area of channel dredging and widening each year

3.2 Analysis Results

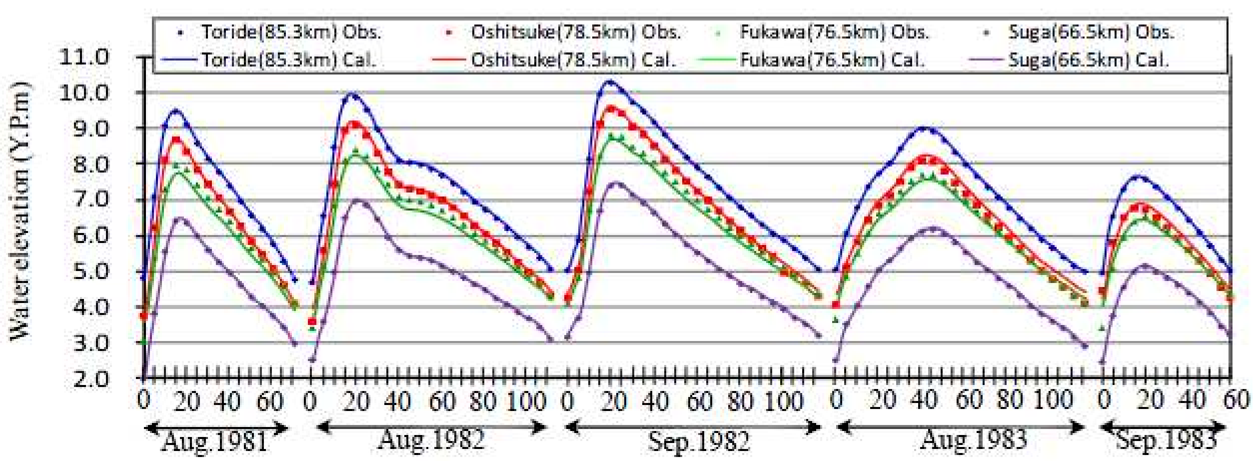


Figure 15 Comparison between observed and calculated water level hydrographs of the flood in the Tone River.

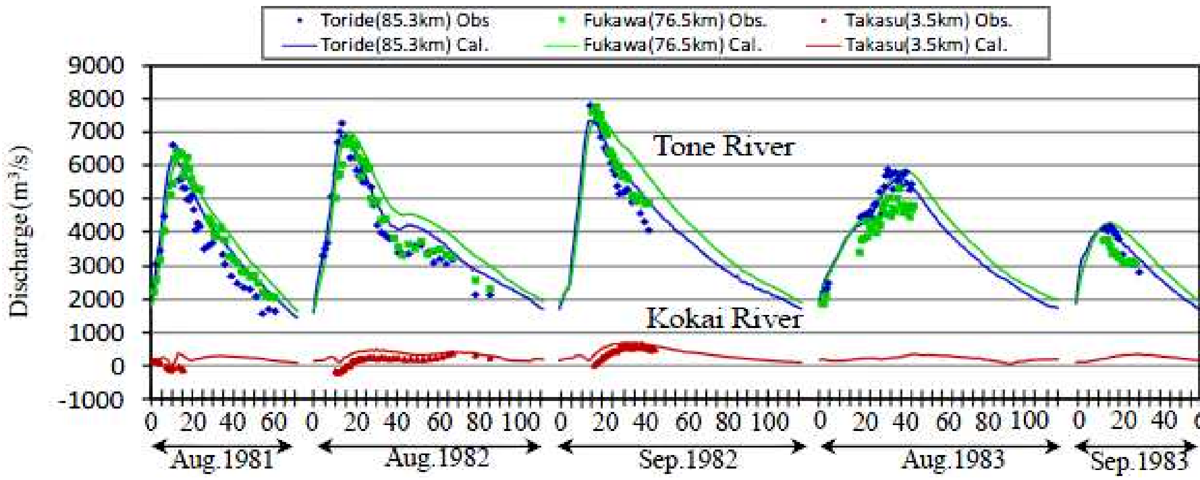


Figure 16 Comparison between observed and calculated discharge hydrographs of the floods in the Tone River and the Kokai River.

Figure 15 shows the comparison between observed and calculated water level hydrographs of the flood in Tone River. Figure 16 shows the comparison between observed and calculated discharge hydrographs of the floods in the Tone River and the Kokai River. The calculated water level and discharge hydrographs correspond well with the observed water level and discharge hydrographs.

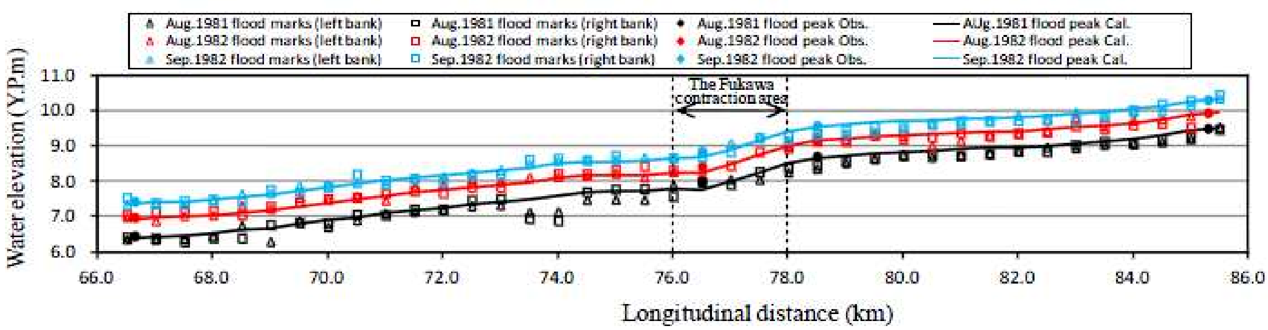


Figure 17 Comparison between observed and calculated water surface profiles at the peak of each flood.

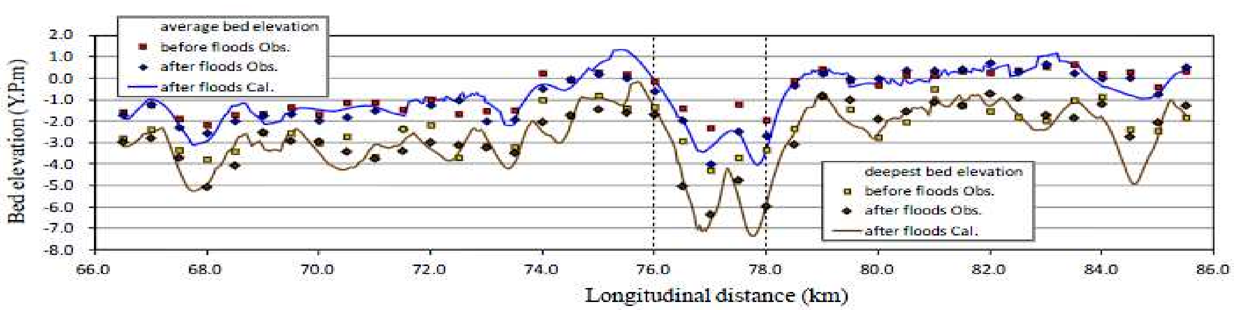


Figure 18 Comparison between observed and calculated river bed elevation before and after the floods.

Figure 17 is the comparison between observed and calculated water surface profiles at the peak of each flood. The calculation coincides with observed water surface profiles. Figure 18 shows the comparison between observed and calculated river bed elevation before and after the floods. The numerical computation provided a good explanation for the observed bed elevation after the floods.

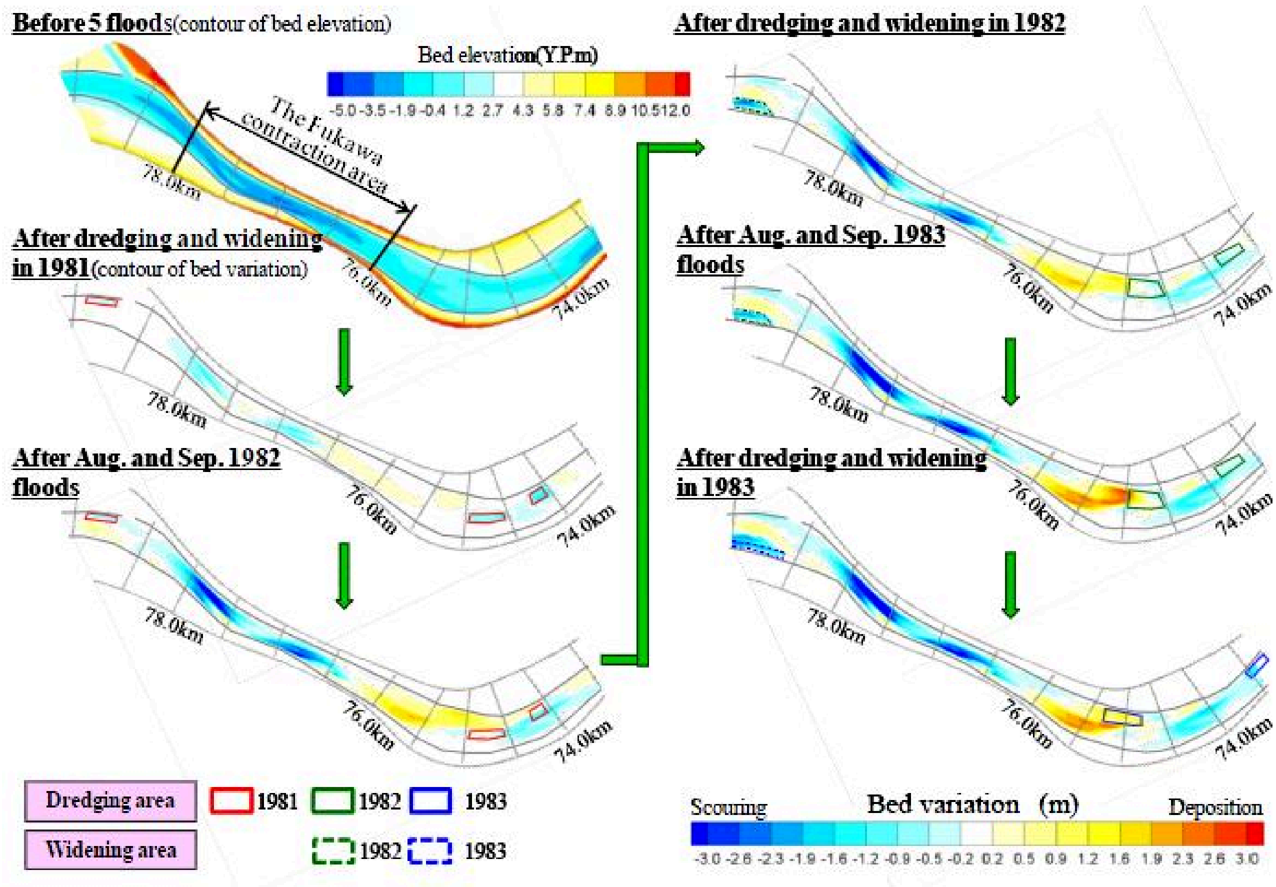


Figure 19 Calculated bed variation contour in and around the Fukawa contraction area from 1981 to 1983.

As a result, we reproduced the bed variation in and around the Fukawa contraction area from 1981 to 1983 by using numerical analysis as shown in Figure 19. The more the floods occurred, the more bed scouring progressed at the Fukawa contraction area and sediment deposition became noticeable at the exit of the Fukawa contraction area. Channel dredging was conducted around the location in which sediment deposition was considerable at the end of the contraction area. However, sediment deposition occurred again at the dredging location after the flood, in each year. In this way, we think that respective influences of channel dredging, widening and flood flows on change in river channel morphology can be analyzed by this method.

4. CONCLUSION

1. Observed data shows that river bed degradation and scouring in the Fukawa contraction area have occurred due to flood flows, channel dredging and widening in the upstream and downstream of Fukawa contraction area.
2. We estimated dredging area, depth and widening area so that calculated water surface profiles and bed profiles reproduced the observed water surface profiles and bed profiles by using dredging volume, implementation year and the cross sectional form before and after the floods, and the analysis result provided a good explanation for the observed results of bed variation in and around the Fukawa contraction area.
3. We evaluated the respective influences of channel dredging, widening and flood flows on change in the river channel from the result of the analysis.

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