River management viewed from long-term changes of the main channel in the middle reach of Tama River

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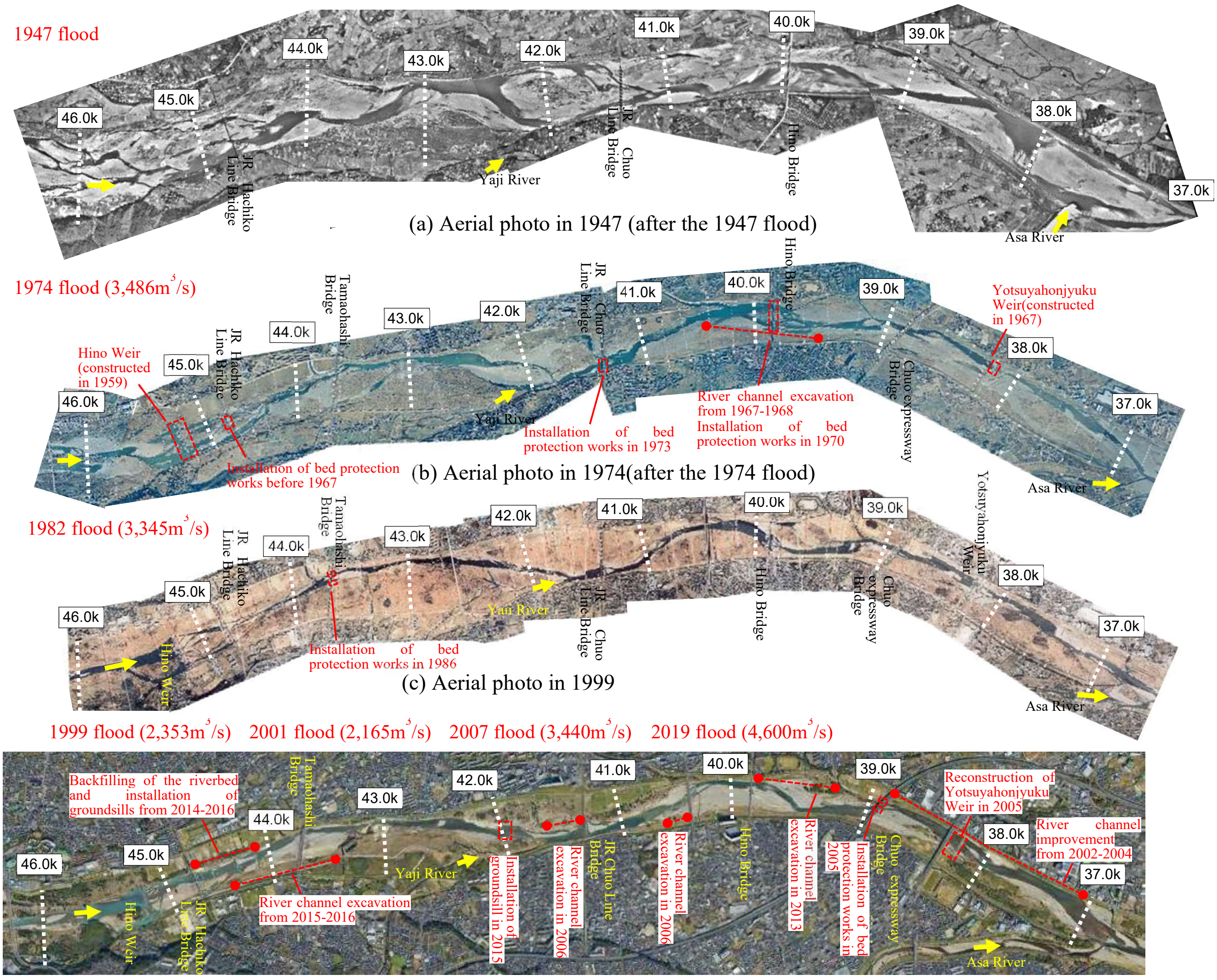
Abstract. In the middle reach of Tama River, past massive gravel-excavations and construction of fixed weirs have caused lack of sediment transport and degradation of the river bed, resulting in the reduction of channel reaches with characteristic sandbars. We investigated the long-term change in the river channel by the observed data from 1947 to 2019 and evaluated the Tama River management up to now. Analysis showed that effects of river improvement works and foundation height of cross-structures were seen in the response of the main channel to floods. The height of river bed has been maintained by the cross-structures such as bed protection works, reconstructed weirs and the groundsills installed at proper longitudinal intervals. This brought sediment supply to river bed by the increase in the main channel width, and resulted in stabilization of the main channel, recovery of channel with characteristic sandbars. Considering the main channel bed stability based on long-term river channel change leads to effective river management in harmony with flood control and river environment.

1 Introduction

In Japan, floods have become more severe and more frequent due to climate change in recent years, resulting in serious flood damage and sediment disaster. In order to create safe and manageable rivers against large floods, it is important to analyse the long-term change of river channel in response to past floods and river improvement works, and to obtain technical information for the proper river management.

Figure 1 shows the annual changes of the river channel in the middle reach of Tama River. The middle reach of Tama River has a bed gradient of approximately 1/200 to 1/400, and is active in sediment transport. In the 1940s, a vast sandbar channel with a rich natural environment was formed, but sediment transport decreased due to massive gravel-excavations and construction of fixed weirs during the period of rapid economic growth (1950s to 1960s). The shortage of sediment transport rate caused river bed degradation, narrowing and deeping the main channel, resulting in the reduction in channel reaches with characteristic sandbars. In recent years, river improvement works (Shimojo et.al., 2011, Ozawa, et.al., 2013 and Ohnami et.al., 2021) has been implemented in the harmony of flood control and environment against problems such as formation of unstable channel bed, damage to river structures and forestation on sandbars.



(d) Aerial photo in 2019(after the 2019 flood)

Figure 1: Annual changes of the river channel in the middle reach of Tama River.

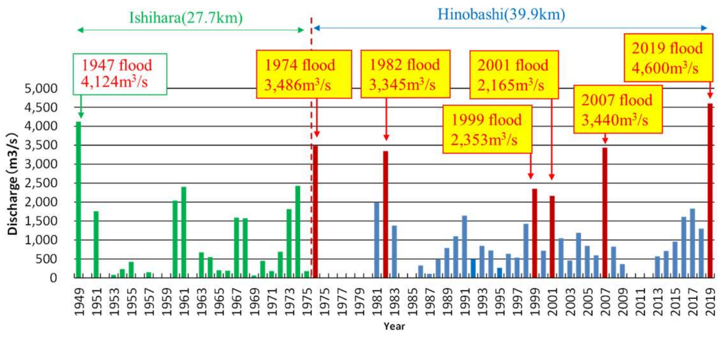


Figure 2: History of flood events in the past 73 years of the middle reach of Tama River(maximum observed flow discharge in each year).

In this study, we investigated the long-term change in the main channel response to large floods and continuous river improvement works in the middle reach of Tama River from the Hino weir (45.2km) to the confluence point of the Asa River (37.0km). We focussed on the change in bed height and width of the main channel for the proper river management. The analysis revealed that the main channel bed level has been controlled by river improvement works and foundation height of structures installed across the channel.

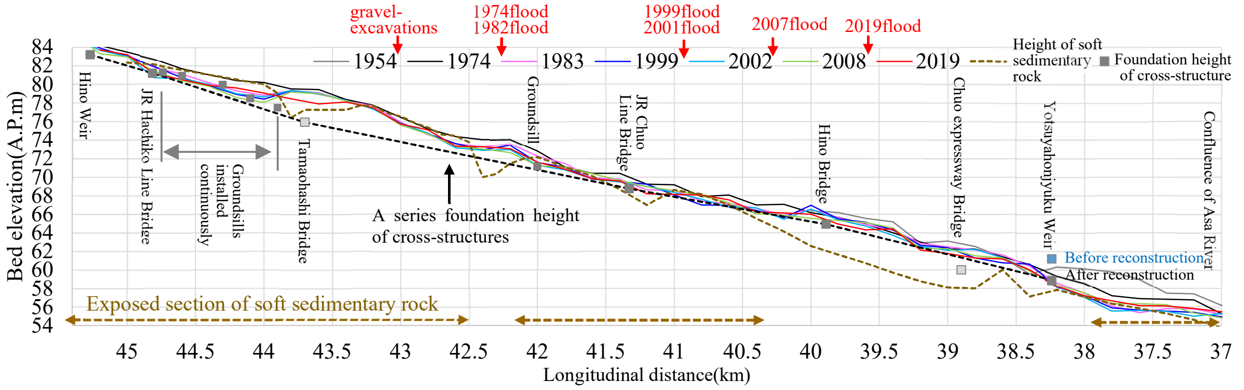


Figure 3: Changes in longitudinal distributions of the annual mean bed level of the main channel.

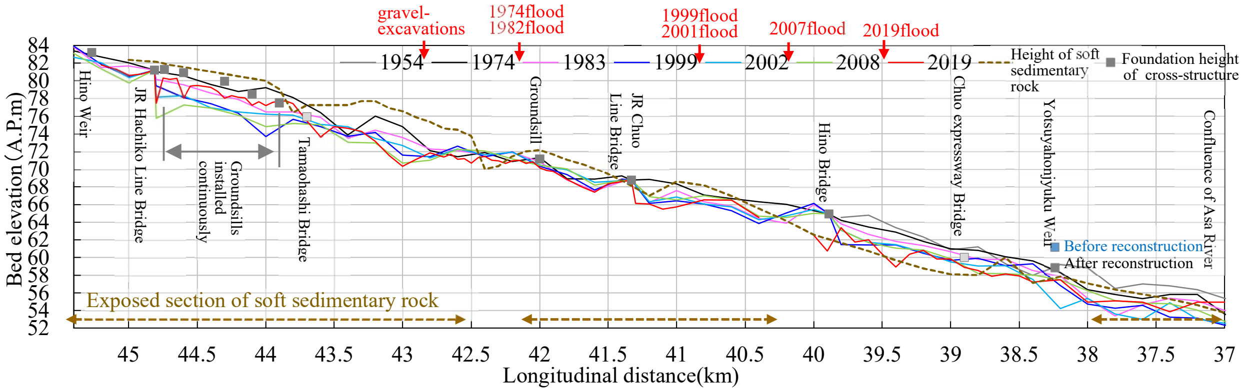


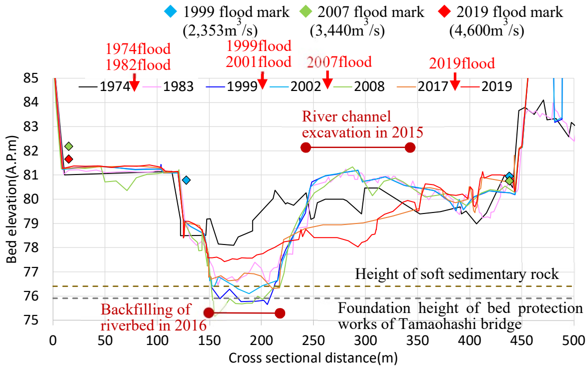
Figure 4: Changes in longitudinal distributions of annual the deepest bed level.

2 Long-term river channel change and mechanism of bed stabilization of the main channel

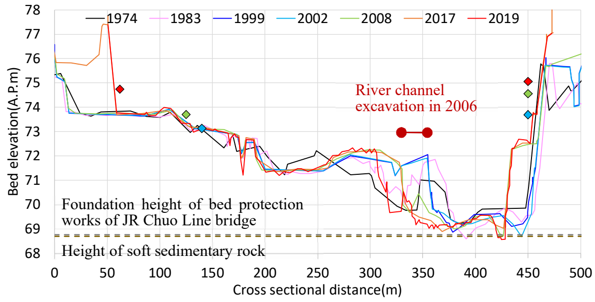
We investigated the long-term river channel change using floods and channel data in the middle reach of Tama River. Figure 2 shows the flood history of the Tama River. In the Tama River, floods exceeding 2,000m^3/s have occurred six times in the past 46 years from 1974 to 2019. No large floods occurred between 1983 and 1999, and the frequency of large floods has increased afetr 1999. Figure 3 and Figure 4 show changes in longitudinal distributions of the annual mean bed level and annual the deepest bed level of the main channel, respectively. Figure 5 shows the annual changes of the cross-sectional profiles. Figure 6 shows the longitudinal distribution of sediment deposition and erosion in the bed and bank of the main channel and flood channel bed due to 1974 flood and 2019 flood obtained from cross-sectional survey before and after the floods.

2.1 Change in channel bed due to gravel-excavation and bed foundations of cross-structures

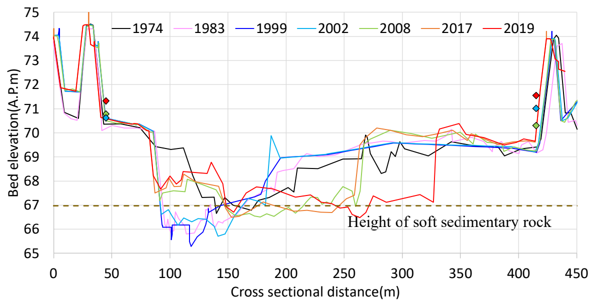
The 1947 river channel as in Figure 1(a) was a simple vast channel with characteristic sandbars because there were no cross-structures. During the 1950s and 1960s, massive gravel-excavations were conducted, and the Hino weir (45.2km) and the Yotsuyahonjyuku weir (38.2km) were constructed for the water use across the river. These channel improvement works reduced the rate of sediment transport, resulting in the river bed degradation. The river bed degradation progressed as flood flows become concentrated in the main channel formed by gravel-excavation, and the river channel became monotonous, as shown in Figure 1(b). In the 1960s and 1970s, bed protection works around the bridge were conducted to protect against scouring around bridge piers.



(a) 43.8km(directly upstream of the Tamaohashi bridge)

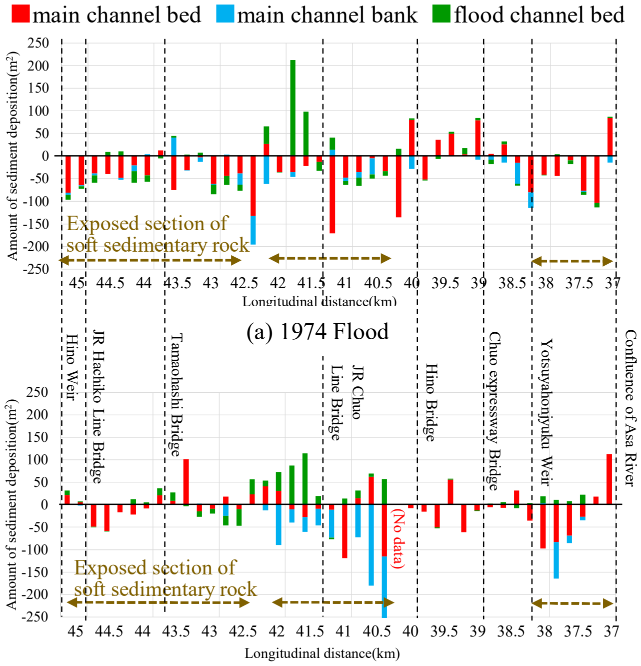


(b) 41.4km(directly upstream of the JR Chuo Line bridge)



(c) 40.6km(upstream of Hino bridge)

Figure 5: Annual changes in cross-sectional profiles.



(a) 1974 Flood

(b) 2019 Flood

Figure 6: Longitudinal distribution of sediment deposition and erosion due to floods.

2.2 Loss of characteristic sandbars in the channel

Figure 4 shows that after gravel-excavation in 1974, the river bed in the main channel degraded and soft sedimentary rock shown by the brown dotted line was exposed in the main channel. The soft sedimentary rock is easily worn away by gravel movement on it and makes it difficult for sands and gravels to be deposited (Tadatsu et.al., 2009). Therefore, Figure 3 and Figure 6(a) show that the river bed degradation due to 1974 flood (3,486m^3/s) and 1982 flood (3,345m^3/s) was significantly larger in the exposed soft rock section than in the unexposed section. Figure 5 shows that those floods caused the degradation of the main channel bed and deposition of sediment on sandbars between 1974 and 1983, and the elevation difference between bed height of the main channel and sandbar increased. After 1982 flood, there were no floods exceeding 2,000m^3/s until 1999, so the sandbars were hardly flooded. As a result, flood flows were concentrated in the main channel, causing further bed degradation of the main channel. The 1999 river channel shown in Figure 1(c) has lost characteristic morphological structures of the river with sandbars due to narrowing and deeping the main channel and brought forestation on immobilized sandbars.

2.3 Channel bed stabilization and recovery of channel with sandbars due to occurrence of large floods and proper river improvement works

After 1999, many large floods such as 1999 flood (2,353m^3/s), 2001 flood (2,165m^3/s), 2007 flood (3,440m^3/s) and 2019 flood (4,600m^3/s) occurred, and the effects of large floods and river improvement works became apparent, resulting in bed stabilization of the main channel. The mechanism of bed stabilization of the main channel is described below.

In the section between the upper reaches of the JR Chuo Line bridge and the Yotsuyahonjyuku weir (42.2 to 38.2km), the river bed degradation in the main channel has been controlled since 1999, as shown in Figure 3. This is because bed protection works were installed around the Hino bridge (39.9km) and the JR Chuo Line bridge (41.35km), and mean bed level of the main channel upstream of these bridges has been almost maintained at the foundation height of the bed protection works installed by a certain interval. In addition, the Yotsuyahonjyuku weir (38.2km) was damaged by 2001 flood, so the groundsill was constructed for lowering the foundation height of the weir to improve flow capacity and sediment transport rate in the main channel (Shimojo et.al., 2009). Figure 3 shows that the longitudinal river bed profile of the main channel has been controlled by the foundation height of the cross-structures and maintained mainly by a series of foundation heights shown by the black dotted line. The bed protection work of the JR Chuo Line bridge (installed in 1973) and that of the Hino bridge (installed in 1970) were installed before 1974 flood which caused the river bed degradation significantly. The section between those (41.2 to 40.0km) is stable now with a gentle riverbed slope around the 1970s.

The maintenance of the main channel bed level brought riverain erosion consisting of the sandbar banks due to the occurrence of frequent large floods since 1999, as shown in Figure 5(b) and (c). This enlarged the main channel width and stabilized the main channel bed level by sediment supplied from the sandbar banks. In 2019 large flood, which was the largest flood in the past, the main channel banks formed by sandbars were significantly scoured in the section upstream and downstream of the JR Chuo Line bridge (42.2 to 40.4km), as shown in Figure 6(b). Most of the scoured sandbar banks are composed of sediments deposited after 1974 flood, and recovery of the river morphological structure has become visible in the middle reach of Tama River.

On the other hand, from the JR Hachiko line bridge to Tamaohashi bridge section (44.8 to 43.8km), river bed in the main channel continued gradually to decline after 2007 flood, as shown in Figure 3. The bed protection works of the Tamaohashi bridge (installed in 1986) was installed later than that of the JR Hachiko Line bridge (installed before 1967), and the elevation difference between the two bed protection works has been increasing, so the river bed has continued to decline, as shown by the black dotted line in Figure 3. As shown in Figure 5(a), the immobilized sandbar in this reach was hardly flooded even in the 1999 flood exceeding 2000m^3/s, indicating that flood flows were concentrated in the main channel, and the lack of sediment supplied from the sandbar banks affected to the river bed degradation.

Therefore, river improvement works has been implemented in the section upstream and downstream of the Tamaohashi bridge (44.8 to 43.4km) from 2014 to 2016, including backfilling of gravels to the degradation reach, excavation of immobilized sandbars, and installation of groundsills at the certain interval to maintain the river bed level (Ozawa et.al., 2013 and Ohnami et.al., 2021). In 2019 large flood, the concentration of flood flows to the main channel was alleviated and the main channel bed level between groundsills is mostly free from the degradation as in Figure 3. These works created the stable main channel and contributed to recover the channel with sandbars around 1970s as in Figure 1(d) and Figure 5(a), which was the main target of river improvement works of the Tama River.

3. River management considering long-term change of the main channel

In the middle reach of Tama River, long-term data of bed changes showed that river improvement works in the past were implemented towards the bed stabilization. The bed protection works of river cross-structures are functioning to stabilize the longitudinal bed profile of the main channel, and the desirable channel with characteristic sandbars is recovering as the main channel bed is stabilized and the main channel width extends. In river channel with a stable bed level, the elevation difference between bed height of the main channel and sandbars is maintained, which restricts the forestation on sandbars as in Figure 1(d).

Thus, information viewed from long-term river channel change provides important technical knowledge for the rational river management in the future.

In general, the check of sediment transport rate caused by cross-structures such as weirs is serious common problems for flood control and the river environment. Reconstructing aging weirs into movable weirs or groundsills, and improving the river channel so that existing bed protection works and groundsills are placed at appropriate foundation height and longitudinal intervals, is an effective river management technique to improve the flow capacity and sediment transport rate in the upstream and downstream reaches and to stabilize the longitudinal bed profile of the main channel as well as conservation of the river environment.

4 Conclusion

We investigated the long-term change of the river channel in response to large floods and river improvement works in the middle reach of Tama River and evaluated the Tama River management up to now.

1. Long-term data analysis showed that effects of river improvement works and foundation height of the cross-structures were evident in the bed stabilization of the main channel to floods.
2. The river bed height has been controlled by the cross-structures such as bed protection works, reconstructed weirs and groundsills installed at proper foundation heights and longitudinal intervals, which has caused waterside erosion of the immobilized sandbars. This brought the increase in the main channel width, and resulted in sediment supply from banks to river bed, stabilization of the main channel and recovery of channel with characteristic sandbars.
3. Considering the main channel bed stability based on long-term river channel change leads to effective river management in harmony with flood control and river environment.

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