Investigation of geomorphology and habitat influenced by the sediment bypass tunnel operation in the downstream of Koshibu Dam

○Yixuan LIU, Sohei KOBAYASHI, Tetsuya SUMI, Yasuhiro, TAKEMON, Sameh A. KANTOUSH

Introduction

Dams obstruct the continuity of sediment movement in the river system, resulting in reservoir siltation, which can impact reservoir operations and diminish water storage (Kondolf et al., 2014). Reservoir siltation can lead directly to a reduction in reservoir storage capacity. The siltation of sediments in reservoirs not only affects the service life of the reservoirs and negatively impacts their functions (e.g. flood control, hydropower generation, irrigation, etc.) but also leads to a lack of sediments in downstream reaches to maintain a typical river ecosystem.

A sediment bypass tunnel (SBT) is a technique for dealing with reservoir sediment siltation that involves diverting sediment that normally flows into the reservoir from upstream to downstream through an artificial outflow tunnel. Sediment released downstream by the SBT causes changes in riverbed morphology as well as a reestablished proclivity to deposit previously deteriorated portions. SBT can be constructed on existing dams and effectively deal with water storage shortages caused by reservoir water level declines.

This research investigates the interrelationships between channel structure, habitat structure, and biodiversity in the downstream of the Koshibu Dam under the effect of SBT operations by analysing the yearly changes in physical and biological characteristics including years before operation, during operation, and after suspension of operation.

Method

(1) Study Area

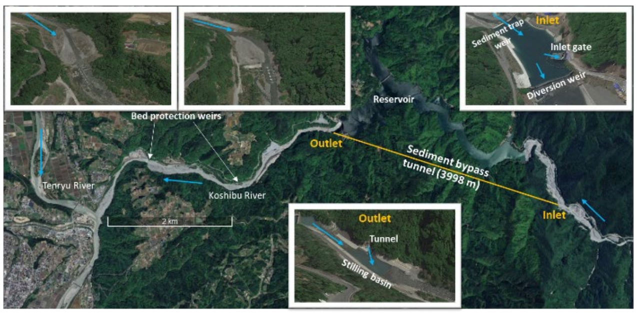

Figure 1 Map of Koshibu Dam SBT and downstream

Koshibu Dam was built in 1969 in Nagano Prefecture, Japan. The total capacity of the reservoir is 58 million m^3. The reservoir has a total storage capacity of 58 million m^3 and is utilised for hydropower generating, irrigation, and flood control (Kashiwai and Kimura, 2015). The Koshibu River is located in a region of significant erosional activity due to both excessive precipitation and seismic events (Auel et al., 2017). The SBT was built in 2009 to improve sedimentation and became operational in 2016. The application of SBT was suspended in 2020 due to the need for repairs and was commissioned again in the summer of 2023. This research is mainly focused on the downstream of the Koshibu Dam. The total channel length is about 4 km from the outlet of the SBT to the downstream confluence with the main Tenryu River.

(2) Imagery analysis for RSCC

This research analysed images from 2014 to 2022 on a year-to-year scale. All images were taken in November of the year. The periods of photographing are a relatively low-water, more stable period. Channel number (CN) and sinuosity (S) were the main parameters used to categorise the river.

(3) HEC-RAS hydrological simulation

One-dimensional river flow simulation was conducted to understand erosion/depositional potential of the channel during flood flows (50m3/s, 100m3/s, 200m3/s) and habitat conditions during normal flows (1m3/s).

The US Army Corps of Engineers created HEC-RAS, which is frequently used for analysing the hydraulic characteristics of rivers (Brunner, 2016). This model requires the use of river cross-section data and flow and can output hydrological information such as flow velocity, slope, shear stress, water depth, etc., for each cross-section. The water surface profile was calculated using the energy equation below.

$$Y_2 + Z_2 + \frac{\alpha_2 V_2^2}{2g} = Y_1 + Z_1 + \frac{\alpha_1 V_1^2}{2g} + h_e$$

Where Y = water depth; Z = channel elevation; V = average velocity; α = velocity weighting coefficient; h_e = energy head loss; g = gravitational acceleration; The subscripted numbers represent the individual cross-sections (here 1, 2 as an example).

Result

(1) RSCC change from 2014 to 2022

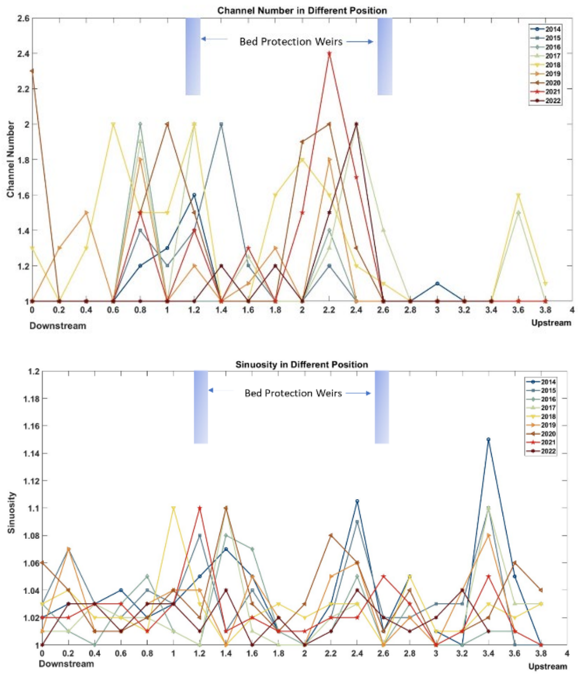

Figure 3 Historical change of channel number and sinuosity in Koshibu River

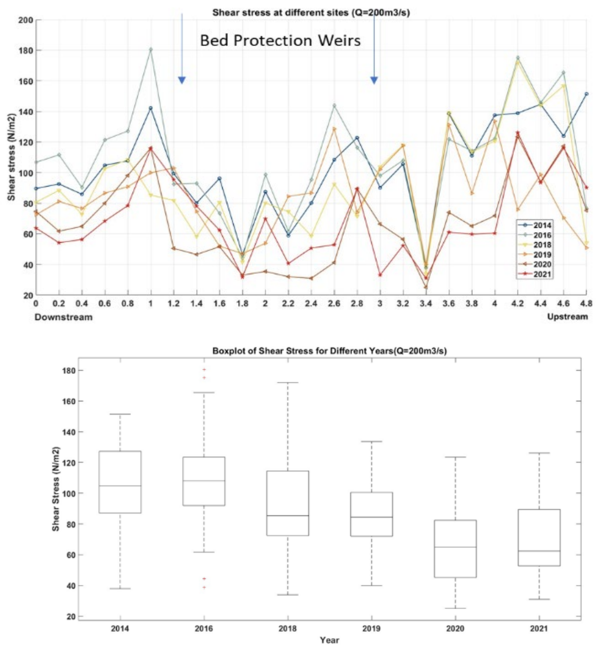

Figure 2 Shear Stress change in different sites and years

The downstream of Koshibu Dam was dominated by the Single type channel (CN=1). As shown in Figure 2, before SBT was applied, the channel type was relatively uniform, and the straight channel occurred more often than the sinuous channel within each unit. The diversity of RSCC has increased to a certain extent after the application of SBT started in 2016. Although still predominantly single channel, many sections, particularly around the bed protection weirs, significantly increased CN and sinuosity. In particular, both the number of channels and the meandering increased in 2018.

(2) Shear stress under different flow conditions

At 1.8 km and 3.4 km, the shear stresses were lower all year under high flow conditions. In contrast, high bed shear stresses were prevalent at 1.0 km. In 2016, riverbed shear stress was higher in almost all sections than in other years. In contrast, riverbed shear stress decreased in all river sectors in the years after 2016. However, this kind of change is not shown to be significant under low flow conditions. Riverbed shear stress was reduced overall under low flow conditions, but in 2018, the riverbed shear stress at 3km was much higher than the average. A similar situation occurred at 4.6 km upstream in 2016. In addition, under the low flow condition, high and low shear stresses mostly alternate in 200m increments. However, there was little change in bed shear stress in the 1.6km to 2.6km portion of the river in 2020.

Conclusion

Through annual analysis of the channel morphology downstream of Koshibu Dam, it is evident that sediment replenishment via SBT contributes to ecological restoration to a certain extent. The once continuous single-channel structure of the Koshibu River has been enriched with sediment, resulting in a diverse array of channel types. Notably, changes in channel morphology, particularly in the vicinity of the bed protection weirs, exhibited a more pronounced response to sediment inputs, with a higher degree of alteration in channel number and sinuosity compared to another river reaches. Examining specific channel change patterns concerning yearly flow and sediment supply is crucial.

Reference

Auel, C., Kobayashi, S., Takemon, Y., Sumi, T., 2017. Effects of sediment bypass tunnels on grain size distribution and benthic habitats in regulated rivers. Int. J. River Basin Manag. 15, 433–444. https://doi.org/10.1080/15715124.2017.1360320

Brunner, G.W., 2016. HEC-RAS River Analysis System: Hydraulic Reference Manual, Version 5.0. US Army Corps Eng. Eng. Cent. 547.

Kashiwai, J., Kimura, S., 2015. Hydraulic examination of Koshibu dam’s intake facilities for sediment bypass., in: First International Workshop on Sediment Bypass Tunnels. ETH Zurich, pp. 45–53.

Kondolf, G.M., Gao, Y., Annandale, G.W., Morris, G.L., Jiang, E., Zhang, J., Cao, Y., Carling, P., Fu, K., Guo, Q., 2014. Sustainable sediment management in reservoirs and regulated rivers: Experiences from five continents. Earths Future 2, 256–280.