Understanding Long-Term Geomorphic Responses and Sediment Budget Changes under the Combined Impacts of Sediment Replenishment and Dam Operation in the Naka River

〇Cheng WEI・Sameh A. KANTOUSH・Sohei KOBAYASHI・Binh Quang NGUYEN

Abstract. This study investigates how Sediment Replenishment (SR) interacts with dam operation and flood dynamics to control channel morphology and sediment budgets in the Naka River, Japan. By integrating threshold-based flood frequency analysis, multitemporal geomorphic change detection (GCD), and sediment grain-size characterization, we evaluate the spatial and temporal extent of SR-driven geomorphic adjustments over a decadal timescale.

Geomorphically effective floods were identified using a Peaks-Over-Threshold (POT) approach applied to long-term discharge records. An optimal threshold of 357.55 m³/s was determined to delineate flows capable of producing significant morphological changes (Fig. 1). This framework captured major typhoon-driven floods, including the extreme 2014 event (5,411 m³/s; approximately 134-year return period), which exerted dominant control on sediment redistribution. Bathymetric digital elevation models from 2010 to 2015 were analyzed using the Difference of DEM (DoD) techniques to quantify erosion and deposition patterns. Results reveal pronounced incision at the SR site, with bed lowering of up to −0.89 m, accompanied by downstream aggradation reaching +0.65 m in the meandering mid-reach between 7 and 14 km. These spatially coherent patterns provide strong evidence for downstream dispersal of replenished sediment.

Keywords. Geomorphic Responses, Sediment Budget Changes, Sediment Replenishment, Dam Operation, Naka River.

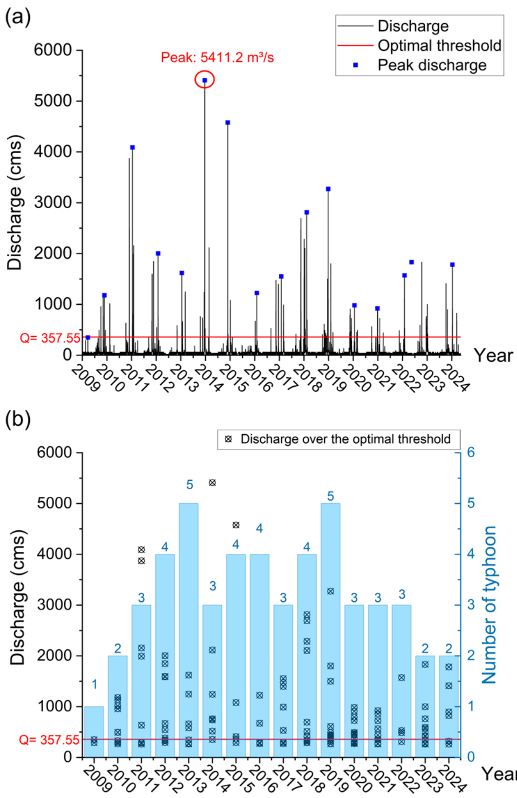

Fig. 1 (a) Discharges released from the Nagayasuguchi Dam (2009–2024); (b) Exceedance events based on the optimal POT threshold and numbers of typhoons.

Sediment budget analysis indicates that the most substantial geomorphic adjustment occurred during 2013–2014, when gross erosion peaked at 27.98 Mm³, coinciding with high-magnitude typhoon floods. Following this period, sediment volumes stabilized, suggesting partial system recovery and redistribution of SR material. Generally, it shows dominant deposition effects than erosion from 2010 to 2015 (Fig. 2). Cross-sectional analyses further confirm active lateral channel migration, characterized by erosion on outer bends and deposition on inner bends, reflecting natural meander dynamics enhanced by flood-driven sediment supply. In contrast, reaches beyond 14 km exhibited minimal morphological change due to the backwater influence of the Kawaguchi Dam. These findings demonstrate that channel curvature and longitudinal hydraulic controls strongly regulate sediment connectivity and geomorphic response.

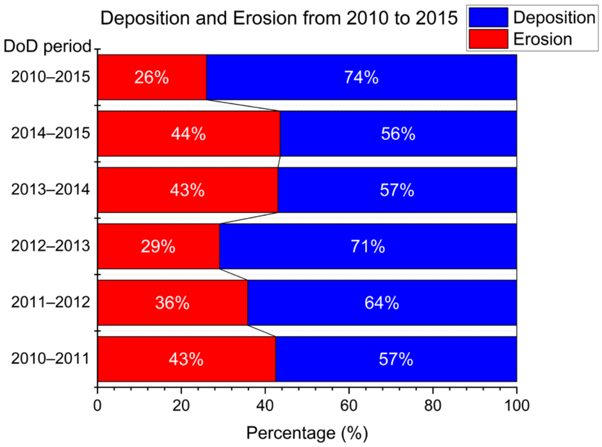

Fig. 2 The variation of deposition and erosion in the Naka River (2010–2015).

To evaluate sediment source tracking and transport interpretation, grain-size distributions were analyzed using data collected between 2014 and 2025 through both sieving and image-based methods. Riverbed sediments are predominantly gravel, with surface layers consistently coarser than subsurface materials.

The SR site is characterized by poorly sorted, multimodal grain-size distributions, whereas downstream reaches display progressive fining, improved sorting, and increasingly symmetrical distributions.

Field observations and cross-sectional surveys conducted in 2025 further reveal localized channel aggradation and the emergence of new sand bars whose grain-size characteristics closely resemble those of the SR deposits. Evidence is shown around 2 km downstream from the SR site, where the grain-size distribution curve (October 2025) displays similar trends as the sediment composition of the SR material (December 2024). It indicates that the sediment grain was transported within one year (Fig. 3).

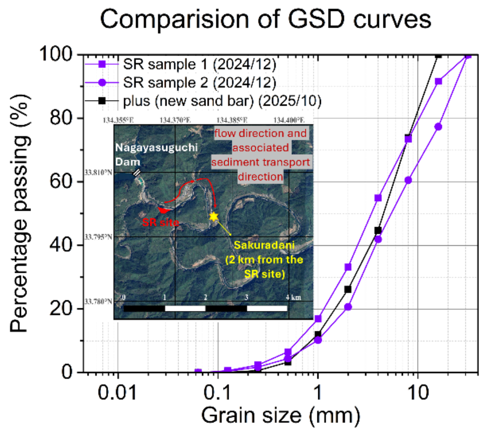

Fig. 3 Comparison of grain-size distributions between the SR-site sample (December 2024) and newly deposited sediment at downstream Sakuradani (October 2025).

These patterns suggest selective transport processes, and the sediment material is capable of altering the downstream sediment composition during high flows.

The combined analyses demonstrate that SR effectiveness is highly dependent on flood magnitude, channel planform, and downstream hydraulic constraints. Sediment mobility was greatest within the first 0–13 km downstream of the SR site, where meander geometry enhanced transport efficiency, while connectivity declined sharply farther downstream due to dam-induced backwater effects. Overall, SR has contributed to improving sediment continuity, promoting bar formation, and enhancing geomorphic diversity in the upper and middle reaches of the Naka River. This study highlights the importance of integrating flood threshold analysis with geomorphic change detection to objectively identify effective discharge conditions and quantify their spatial influence. By coupling morphological evidence with grain-size characteristics, we provide a process-based assessment of SR performance under dam-regulated conditions. The results emphasize that successful sediment management requires explicit consideration of hydrological variability, channel morphology, and downstream hydraulic controls to achieve sustainable river restoration outcomes.