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Streams frozen in time? Particle- to catchment- scale dynamics of high-latitude post-glacial streams

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The post-glacial adjustment of streams can be described as a battle between two geomorphic giants: the magnitude and resistance of the glacial imprint and the competence of subsequent fluvial flows. In northern Fennoscandia, which deglaciated ~9500 y BP, the outcome of this battle provides both insight into poorly studied high-latitude regions and a glimpse into the trajectory of currently deglaciating regions. The glacial signature of eroded bedrock and deposited till in this region have organized tributary stream networks into three distinct process domains: lakes, slow-flowing reaches (S0<0.1% in peat/ fine sediment), and rapids (S0: 0.1-7% with gravel to boulder beds). Thus, these post-glacial streams have two characteristics that complicate a process-based understanding of channel form and sediment transport: (1) they are typically semi-alluvial, in that they contain coarse glacial legacy sediment, and (2) mainstem lakes buffer sediment and water fluxes. Here, I present research to constrain controls on channel geometry and sediment transport in semi-alluvial rapids at three scales: (1) the particle-scale, quantifying sediment transport with a field tracer study, (2) the reach-scale, determining the potential for bedforms or sediment clusters through a flume experiment, and (3) the catchment scale, examining downstream variations in width using GIS-based analyses.

Sediment particle dynamics within five semi-alluvial rapids (S0: 2.1-7%) were quantified using RFID-tagged tracer clasts. After a large snowmelt flood (>Q50), median transport distances for D10- to D50-sized clasts were <0.1 m, with no clear relationship between slope or shear stress and transport distance. Rather, as previous studies in boulder-bed mountain streams show, boulder protrusion and grain resistance likely play a greater role, increasing critical shear stress and reducing sediment transport. Based on a flume study mimicking reach-scale conditions of semi-alluvial rapids, it is clear that large clasts (>D84) are basically immobile and do not adjust to form step-pool features. But patterns of deposition and scour around boulders exist, with more deposition upstream of boulders at higher flows. Most geomorphic work is done at low and intermediate flows (Q2-Q10), with little additional transport at Q50 flows, which has a relatively low magnitude due to lake buffers. To determine whether channel width has adjusted to contemporary flow regimes at the catchment scale, downstream variation in bankfull width was analyzed in two medium-sized catchments. Regressions of width vs. drainage area (derived from 2m DEMs) have low explanatory power (R2: 0.05-0.5); coefficients (α) are low (<1) and regression exponents (β) show wide variation (0.26-0.75). Instead, spatial variability in till deposits and peat formation likely control channel width.

While these semi-alluvial streams in stream-lake catchments are technically in equilibrium, as they are not aggrading or degrading, their stable channel geometry does not reflect the contemporary landscape sediment yield or hydroclimatic regime. Past studies have shown that bedrock river gorges in northern Sweden formed during deglaciation with little Holocene erosion. Similarly, tributary channels with coarse glacial sediment and mainstem lakes are frozen in time, reflecting catchment- and reach-scale morphologies shaped during high flows at deglaciation, with contemporary adjustment occurring only at the particle to sediment-cluster scales.