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The energy budget and design framework for step-pool system

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Step-pool system is the most common bedform in steep mountain streams and stabilizes the riverbed against channel incision and provides locally diverse aquatic habitats. Step-pool system has been applied in river restoration projects around the world. The design of artificial step-pool system was mostly based on the maximum flow resistance criterion, as $1< H/L/S <2$ (H is the step height; L is the step wavelength; and S is the reach slope), proposed by Abrahams et al. (1995). However, this criterion cannot differentiate the stable step-pools from the unstable ones, and could only be applied in designing identical step-pools in the sequence. The objective of this study is to establish a detailed and comprehensive design framework for step-pool system, for better performance in channel stabilization and ecological functioning, based on the longitudinal energy distribution, i.e., the energy budget. We built the database for energy dissipation rate of individual step-pools in various morphological and hydraulic conditions from flume and field results. We found that the energy dissipation rate can be described by a power function with H_c/H, where H_c is the critical water depth. Coupling the power function with the energy and mass conservation equations, a 1-D model to simulate the longitudinal distribution of total hydraulic head, velocity head and water depth for step-pool reach was established. The geometric features of the reach and dimensions of the designed step-pool sequence are the input parameters for the energy budget model. The maximum step height and step wavelength was calculated based on the local scouring theory, with the discharge threshold for the failure of step-pools set as the exceptional flood events (return time $>$ 50 yrs). The maximum step width was obtained from the jamming ratio for stable step-pools. The criteria for step-pool design are: (i) flow velocity is well controlled along the reach; (ii) the stability of the step-pools are guaranteed during exceptional events. At last, we built the design framework for step-pool system, balancing the energy dissipation efficiency and stability. The energy budget and framework allow the designers to set different geometrics for the step-pool units in the sequence and examine the possible influence of morphological variation of the step-pool units on the whole system.