Geophysical Research Abstracts
Vol. 20, EGU2018-16941, 2018
EGU General Assembly 2018

The concept of “bar-forming” discharge for alternate bar in gravel-bed rivers

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In the last centuries, most Alpine rivers were rectified to improve hydraulic safety and land availability. This often led to the formation of free alternate bars, large scale bedforms that migrate downstream during flood events. Theoretical works (i.e. Colombini et al. (1987); Nelson (1990)) demonstrated that free alternate bars are growing because of a process of riverbed instability. Equilibrium bar characteristics (i.e. amplitude and wavelength) are governed by the width to depth ratio, which is not a constant parameter but is naturally varying with water discharge.

The aim of this work is to propose a novel integration of a statistical approach using the analytical perturbation model of Tubino (1991) to describe the evolution of bar properties under unsteady flow conditions. This allows the definition of a “bar-forming" discharge as the flow value which would reproduce the most likely bar properties in a river reach. In literature, most of river geomorphic characteristics are described by a discharge value associated to a return period of 1.5-2 years, which corresponds to the classic concept of effective discharge proposed by Wolman and Miller (1960). However, free alternate bars exhibit a markedly different behaviour, insofar as their height decreases with increasing discharge. As a consequence, typical values of effective discharge would give a vanishing bar height, which makes, the classic concept clearly unsuitable in this case.

The outcomes of our integrated modelling approach are probability distributions of the bar properties, which depend essentially on two ingredients: (i) the statistical properties of the flow regime (duration, frequency and magnitude of the flood events, and (ii) the reach-averaged hydro-geomorphic characteristics of the channel (bed material, channel gradient and width). Therefore, the evolution of bar height during flood events depends on the relation between the time scale of bar growth and the timescale of flood. The behaviour of natural rivers ranges between two different limiting cases: (i) bar evolution is instantaneous, so that quasi-equilibrium conditions are achieved for all discharge values during the flood; (ii) bar slowly respond to discharge variations, so that their characteristics depend on the long term flow history.

Theoretical results are compared with observations in three channelized gravel bed rivers: the Alpine Rhine River in Switzerland, and the Arc and Isère Rivers in France. The properties of the free alternate bars observed in the three rivers are consistent with the model predictions, thus supporting the idea that a new definition of “bar-forming discharge” is needed.