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Journal of Hydrology 326 (2006) 257–276
Journal of Hydrology
www.elsevier.com/locate/jhydrol

Effective discharge for sediment transport in a mountain river: Computational approaches and geomorphic effectiveness

M.A. Lenzi *, L. Mao [1], F. Comiti [1]

Department of Land and Agro-Forest Environments, University of Padova, Agripolis, Viale dell' Università 16, 35020 Legnaro, Padova, Italy

Received 18 May 2005; revised 30 September 2005; accepted 27 October 2005

Abstract

Dominant, effective, bankfull and channel-forming discharges are different concept-based flows, often applied as design parameters in river management and restoration. In order to achieve a better understanding of channel-forming conditions in high-gradient, boulder-bed streams, the long-term sediment loads data obtained from the Rio Cordon (Italian Alps) measuring station have been analysed. The effective discharge (Q_e, calculated using both Wolman and Miller's method and the so-called 'mean' approach) for bedload transport proves to be more appropriate than that determined for the suspended sediment load in describing the channel formation and maintenance for this type of channels. The analysis demonstrates that Q_e is strongly influenced by the number of flow classes, the fraction of transported sediments and the methodology used in its computation. The result questions the appropriateness in considering Q_e as an unique value, and also suggests the possible definition of two dominant discharge ranges for steep mountain rivers: (a) a relatively frequent flow range responsible for maintaining channel form; and (b) a more infrequent high flow range responsible for macro-scale channel shaping.

Keywords: Effective discharge; Bankfull discharge; Bedload transport; Magnitude–frequency analysis; Duration curve; High-gradient streams

1. Introduction

Alluvial rivers adjust their channel and floodplain dimensions depending on the range of flows which are capable of mobilizing sediment from the bed and banks, and of transporting sediments delivered from upstream reaches. Since the early work by Schaffernak (1922), many authors have proposed that a single, representative discharge may be used to define the channel geometry that, in the long-term, could be considered stable. The design of a channel for environmental enhancement or ecological restoration of rivers requires the application of a proper water discharge considered responsible of long-term channel stability (Shields et al., 2003). A stable stream

* Corresponding author. Tel.: +39 49 8272675; fax: +39 49 8272686.
E-mail addresses: marioaristide.lenzi@unipd.it (M.A. Lenzi), luca.mao@unipd.it (L. Mao), francesco.comiti@unipd.it (F. Comiti).
[1] Tel.: +39 49 8272695; fax: +39 49 8272686.

0022-1694/$ - see front matter
doi:10.1016/j.jhydrol.2005.10.031

Nomenclature

D	grain size for which i% of the grains are finer, m
E_b	effective discharge curve for bedload transport
E_s	effective discharge curve for suspended sediment transport
f	flow frequency, %
Q	water discharge, $m^3 s^{-1}$
Q_{bf}	field-identified bankfull discharge, $m^3 s^{-1}$
Q_{ci}	critical water discharge associated to the entrainment of D_i particles, $m^3 s^{-1}$
Q_{dom}	dominant discharge, $m^3 s^{-1}$
Q_e	effective discharge, $m^3 s^{-1}$
Q_{eB}	effective discharge for bedload transport, $m^3 s^{-1}$
Q_{eBMM}	effective discharge calculated using measured bedload rates and measured flow frequencies ('mean' approach), $m^3 s^{-1}$
Q_{eBRL}	effective discharge calculated using a bedload rating curve and a lognormal flow frequency distribution ('traditional' approach), $m^3 s^{-1}$
Q_{eS}	effective discharge for suspended sediment transport, $m^3 s^{-1}$
Q_{eSMM}	effective discharge calculated using measured suspended sediment rates and measured flow frequencies ('mean' approach), $m^3 s^{-1}$
Q_{eSRL}	effective discharge calculated using a suspended sediment load rating curve and a lognormal flow frequency distribution ('traditional' approach), $m^3 s^{-1}$
Q_{ri}	water discharge for a specified recurrence interval, $m^3 s^{-1}$
Q_{sb}	bedload rate, Kg s^{-1}
Q_{ss}	suspended sediment rate, Kg s^{-1}
RI	recurrence interval, year
SSC	suspended sediment concentration, g l^{-1}

configuration is essentially dependent on the channel ability to convey the whole amount of sediments supplied from above, with neither net erosion nor aggradation of streambed and banks.

This channel-forming, also named dominant discharge (Q_{dom}) is the discharge, which a channel should be designed to convey. Given the complexity of its quantification, such a discharge has been associated with different concepts by different researchers, including the field-identified bankfull discharge Q_{bf} (Wolman and Leopold, 1957; Leopold et al., 1964), a specified recurrence interval discharge Q_{ri} (Dury et al., 1963; Williams, 1978) and the effective discharge for sediment transport Q_e (Wolman and Miller, 1960; Andrews, 1980). Such a variety of approaches have led to some confusion about both terminology and understanding of the fundamental processes involved.

Bankfull discharge (Q_{bf}) is the maximum discharge that a channel can convey without overflowing onto its floodplain, and is considered to have morphological significance because it represents the boundary between channel and floodplain formation processes. It is commonly determined by identifying the bankfull stage and then determining the associated discharge. Among the most common indicators of bankfull stage are: the elevation of the active floodplain (Wolman and Leopold, 1957); the maximum elevation of channel bars (Wolman and Leopold, 1957); the height of the lower limit of perennial vegetation (Schumm, 1960), and changes in the vegetation composition and distribution (Leopold, 1994). A more analytical and geomorphological-based approach, assumes the bankfull stage to correspond to the elevation at which the width/depth ratio of a typical cross-section is at a minimum (Pickup and Warner, 1976). However, none of these field methods can be used alone to obtain reliable results (Williams, 1978).

Owing to the difficulties associated with identifying Q_{bf} from field evidence, many researchers have related the bankfull discharge to a specific recurrence interval discharge (Q_{ri}) by analysing at-equilibrium natural channels where the bankfull stage could be easily identified and stream gauges were located in the vicinity. Under these conditions, Q_{bf} is assumed to be