Towards an empirical method to determine an engineering design peak discharge for debris flows

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INTRODUCTION

The estimation of design debris flow hydrographs, including corresponding peak discharges and event volumes is a difficult task in engineering hazard assessment and typically comprises larges uncertainties. Especially the expected debris flow peak discharge of a certain return period is a planning prerequisite for the design of protection measures. Different empirical and semi-empirical approaches have been proposed, including simple equations that relate debris flow peak discharge (QDF) to an equivalent flood peak discharge (QW), where IC is an empirical intensity coefficient, sometimes also termed bulking factor: QDF = QW * IC

Since the definition of QW is rather vague, this quantity may be viewed as the peak discharge of a hypothetical flood if the same rainfall had not triggered a debris flow. On the one hand IC considers the reduction of the duration of a debris flow hydrograph in comparison to a flood hydrograph caused by a rainfall event; on the other hand the parameter includes the increased sediment concentration (Hübl, s.a.). Rickenmann, 2014 and Hübl, s.a. describe the spread of back-calculated IC's from 1 to 100. Chen & Chuang, 2014 find an upper limit of 40 and a lower limit of 5. This large scatter may be partially due to the fact, that there is no standardized method to calculate QW. The Austrian Standards (ONR 24800, 2009) propose an intensity coefficient > 1.4 and define this value as a potential lower limit.

To optimize the planning criteria of debris flow mitigation measures the present work builds on earlier studies and analyses different questions: What is the typical range of all IC's found in literature and can we find a trendline or define envelopes (i.e. upper bounds that include 50/90% of the data)? Can we distinguish certain patterns in the data pool based on morphometric or climate constraints?

METHODS

We aim to answer these questions by conducting an extensive literature review to gather all available data that has been published so far about this topic. Additionally we carry out a hydrologic modelling of rainfall events that triggered debris flows in the monitored Gadria catchment in South Tirol (Italy) in the years 2011, 2013 and 2014. We reconstruct the theoretical hydrographs with the software tool ZEMOKOST (Kohl & Stepanek, 2005), which is a conceptual hydrologic model based on the travel time method after Zeller, 1981. Since no data for calibration were available, we conducted a sensitivity analysis with a range of realistic input parameters and pre-moisture conditions. Subsequently the results were tested for plausibility by independent methods.

RESULTS

The comparison of the debris flow peak discharges with the hydrologic modeling of the three debris flow events in 2011, 2013 and 2014 in the Gadria basin yielded mean IC's of 21, 45 and 21, with a variation from 18 to 100, reflecting uncertainties of model input.

The analysis of the debris flow peak discharge of 85 events with flood discharges that were back-calculated or estimated from 14 authors shows that debris flow discharges and corresponding IC can vary over two orders of magnitude (1-114). Most of the intensity coefficients fluctuate from 1 to 50. To precise the intensity coefficient we fit envelopes (cp. table 1) and a trendline (QDF=~11∗QW) with a stability index of 0.7.

Table 1: Summary of determined envelopes and boundary functions

flood peak discharge	lower limit	upper limit	50 % of the data lower IC of	90 % of the data lower IC of
< 10 m³/s	$Q_M = 0,5\ Q_W^2$	$Q_M = 25\ Q_W^2$	14	50
> 10 m³/s	$Q_M = 2\ Q_W$	$Q_M = 30\ Q_W$	10	23

By definition of an upper and lower limit, a scaling break at a maximal flood discharge of 10 m³/s has been observed. While the limits functions below a flood discharge of 10 m³/s were described with a quadratic function, the relationship above of 10 m³/s follows a linear function.
Besides the uncertainties associated with hydrologic modeling, the great variability of the intensity factor may be caused by different triggering and propagation mechanism of the debris flow event or other parameters, like amount and type of debris, gully steepness or other morphometric parameters. Because of the missing metadata on the majority of debris flow events found in literature, a further comparison of the data based on morphometric or climate constraints is difficult. A simple correlation-analysis with site- and event-specific parameters shows that the intensity coefficient tends to increase with increasing sediment concentration and density of the debris flow event as well as with increasing (estimated) sediment mobilization intensity.
This implies that for the determination of an adapted intensity coefficient the characteristics and parameters of the analyzed basin have a strong influence and have to be considered.
Despite some uncertainties and simplifications, the investigated empirical method allows an order- of-magnitude determination of debris flow peak discharges and enriches so the pool of methods for engineering practice.

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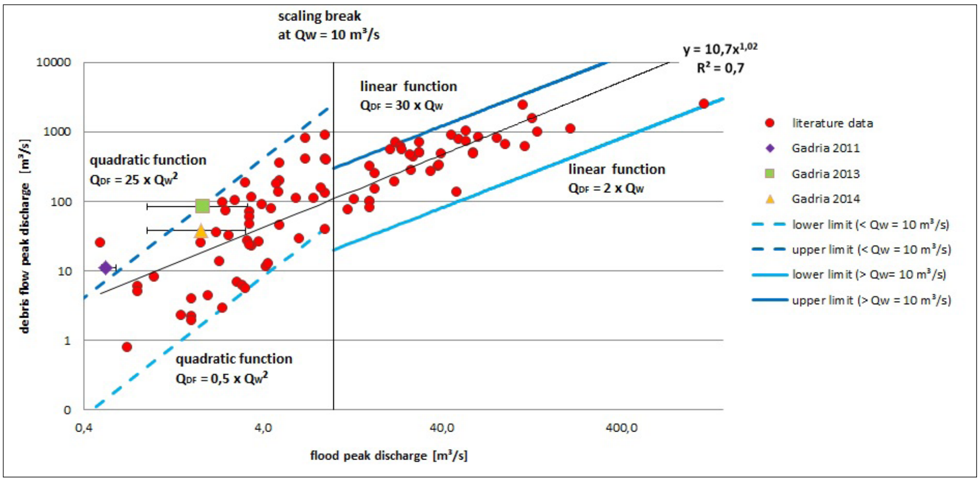

Figure 1. Relation between observed debris flow peak discharge and back-calculated / estimated equivalent flood peak discharge, including data of 85 debris flow events. Besides the variations of the determined QW of the three debris flow events in the Gadria basin, the trendline and the upper and lower bounds are shown.

KEYWORDS

debris flow; peak discharge; intensity coefficient

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