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A DESIGN PEAK FLOW ESTIMATION METHOD FOR MEDIUM-LARGE AND DATA-SCARCE WATERSHEDS WITH FRONTAL RAINFALL[1]

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ABSTRACT: We developed a reliable peak flow estimation method for the design of hydraulic structures. The method is valid in medium-large watersheds (100-5,000 km^2) located in Chile between 32°45′ and 43°50′S, with scarcity of hydro-meteorological information, and where frontal rainfall prevails. The proposed method requires only rainfall data and geomorphologic descriptors as inputs, and relates the instant peak flow with the time of concentration rainfall flux (the contributing watershed area multiplied by the rainfall). The parameters of the model were defined with peak flows obtained from statistical analyses of historical fluviometric records from 25 watersheds. The quality of the proposed method is evaluated by applying it to three external watersheds different from those used to define model parameters, and comparing it with three other indirect methods and with peak flows obtained from statistical analyses, which were also used as the benchmark. The proposed method estimates peak flows with mean differences of less than 10%, which is two times less than other similar indirect methodologies, making it a recommendable option for estimating design peak flows.

(KEY TERMS: peak flows; flooding; ungauged basins; runoff; surface water hydrology.)

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INTRODUCTION

Historically, humanity has been affected by water resources problems caused by extreme events such as floods and draughts. Flood disasters have been more devastating in terms of deaths, suffering, and economic damages than other natural hazards as earthquakes, volcanoes, wildfires, etc. (Kundzewicz *et al.*, 1993). Despite progress in science and technology, humans are still vulnerable to extreme hydrological events (Cheng *et al.*, 2009), which constantly destroy infrastructure and erode productive fields located next to rivers. As an example of these types of events we have the floods of July 2006 that caused severe damage in the central zone of Chile, destroying bridges and irrigation canals. To prevent such damage, engineers design protective structures like dikes, spillways, and stormwater evacuation canals, whose designs require the estimation of peak flow values.

Reliable estimations of peak flow values are an indispensable requisite for planning measures, which reduce or even prevent flood damages (Pilon, 2004). There is a great need for such estimations on the

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mesoscale, as was observed in the aftermath of the 2005 flood events in the European Alps and 2006 flood events in south-central Chile.

In watersheds with long gauge records, floods with various recurrence intervals are estimated with relatively little effort using extreme value statistics (Michalek *et al.*, 2008), but due to information scarcity and the rise in human land occupation, it is far more frequent that flood estimates are sought for ungauged watersheds (Viviroli *et al.*, 2009).

The understanding of floods, their mechanisms, characteristics, and impacts is of crucial importance for water assessments, design, and management of water resources systems. Moreover, often the cost of minor hydraulic works together with the scarcity of hydro-meteorological information and data does not justify detailed hydrological studies capable of defining extreme flows in the design phase. Therefore, in the design phase, indirect methods are commonly used to estimate those flows.

Indirect methods for the estimation of peak flows in ungauged watersheds could be undertaken mainly in three different ways which are based on (a) The Unit Hydrograph (Gray, 1961; Linsley *et al*., 1986; Sorman, 1995; Hromadka, 1997; Mishra and Singh, 2004; and Sahoo *et al.*, 2006; among others), (b) The Curve Number Method (Titmarsh *et al.*, 1995; Van Mullem and Woodward 1995; Şen, 2008), and (c) Empirical Formulas (e.g., Chow, 1964; Kölla, 1987; Verni and King, 1977; DGA, 1995; Amini and Smith, 1995; Cuevas and Stowhas, 1999; Grover *et al.*, 2002; Fill and Steiner, 2003; Chen *et al.*, 2007). In watersheds without hydro-meteorological information or with scarce data, the application of method (a) is not suitable because it is necessary to know the shape of the design storm and the unit hydrograph of each watershed; in the case of (b) moreover, it is necessary to have representative information of soil characteristics. Hence, case (c) Empirical Formulas are normally used to solve those problems.

In Chile, the design of minor hydraulic works is controlled by design guidelines published by the Dirección General de Aguas (DGA, 1995) ("*Chilean Water Resources Framework*") and the Ministerio de Obras Públicas (MOP, 2000) ("*Ministry of Public Works*"). These official guidelines recommend the calculation of extreme flows in uncontrolled watersheds with the empirical formulas: DGA-AC (DGA, 1995), Verni-King (Verni and King, 1977) modified by DGA (1995) and Rational Method (Chow, 1964), using runoff and frequency coefficients defined by DGA (1995). Alternatively, Ogden and Dawdy (2003) proposed a method to estimate annual peak flows in small Hortonian basins (<10 km^2) through a function that relates the peak flow with the basin area and the annual maximum of 1 h of rainfall. Using these variables, a high correlation (R^2 > 0.98) with observed peak outflows was observed.

This study presents a method to estimate design peak flows in medium-large watersheds (100-5,000 km^2) without flow records, where frontal rainfall prevails. The model structure is adapted based on the predominant processes of the study area and their influence on the peak flows. The model parameters are defined based on the quantile regression method using flow records of 25 watersheds located between 32°45′ and 43°50′S in Chile. The quality of the proposed method is evaluated by comparing its results with the results from other indirect methods and with peak flows obtained from statistical analyses.

MATERIALS AND METHODS

Theoretical Background

The peak discharge response of a watershed reflects aspects of rainfall rate, space-time variability, and physical watershed characteristics, like soil moisture, infiltration capability, groundwater table existence and elevation, land use, land cover, and geomorphology. The relative importance of each variable depends on the runoff mechanism, scale of watersheds, runoff distribution, and its generation mechanism.

Commonly, flood events are related to three phenomena, which occur at the same time: (1) most of the watershed has rainfall, (2) the rainfall duration is longer or near the watershed time of concentration (t_c), and (3) the mechanism, which produces extreme events runoff occurs when rainfall exceeds the infiltration capacity of well-drained soils, so-called Hortonian runoff or behavior (Horton, 1933).

A special case of (t_c) is time to equilibrium, which occurs when a rainfall rate persists for enough time in a region to reach equilibrium. Conceptually the time to equilibrium is more difficult to achieve when the watershed scale increases due to higher space-time and infiltration conditions variability, therefore when equilibrium discharge exists, the peak discharge (Q_p) of a watershed follows this relationship:

$$Q_p = (\bar{i} - \overline{K_s}) \cdot A \qquad (1)$$

where $\bar{i}$ is average rainfall intensity, $\overline{K_s}$ is average soil saturated hydraulic conductivity, and A is