

# The rational formula from the runhydrograph

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## Abstract

The rational formula is possibly the simplest flood estimation technique available using rainfall-runoff relationships. In spite of the many criticisms regarding its over-simplification of the processes of rainfall conversion into runoff, it remains possibly the most widely used method for estimating peak flood flows for urban drainage systems and small (<100 km<sup>2</sup>) rural catchments. However, as a result of the criticisms, the formula carries with it many cautions. One such caution regards the determination of the formula's runoff coefficient  $c$ , which is seen as the main difficulty in the design application of the formula. Mindful of this, it was decided to investigate the calibration of this coefficient, on past flood peak and flood volume pairs for a number of catchments in South Africa. To this end the "data set" of runhydrographs, which describe the characteristic peak and volume discharges of a catchment for a given recurrence interval, was used to calibrate the coefficients for selected catchments and to explore the assumptions underpinning this simple model. This article describes the methods employed in achieving this as well as a discussion of the results.

**Keywords:** design flood estimation, probabilistic rational formula, runhydrograph, calibration of runoff coefficients

## Introduction

The rational formula is perhaps the best known and most widely used method for the determination of peak flood flows from rainfall events. It has survived numerous criticisms regarding its over-simplification of the complex hydrological processes of flood production but nonetheless is possibly the most favoured method used by practitioners for peak flood estimation. The rational formula owes its popularity to the fact that it is easy to understand and simple to use. The peak flood flow due to a rainfall event on a catchment, determined from the rational formula, is expressed (in SI units) as:

$$Q_{RF} = ciA/3.6 \quad (1)$$

where:

$Q_{RF}$  is the flood peak in m<sup>3</sup>/s

$c$  is the runoff coefficient, which is (in the traditional deterministic approach) defined as the proportion of precipitation that contributes to runoff

$i$  is the storm rainfall intensity in mm/h

$A$  is the catchment area in km<sup>2</sup>.

The criticisms concerning the rational formula in the above form are not unfounded and the use of this method carries valid cautions that are based on the following assumptions built into the formula (which are not always explicit in its presentation):

- The maximum rate of runoff from a catchment is achieved when the duration of rainfall is equal to the time of concentration ( $T_c$ ) of the catchment, which is defined as the time taken for the outflow from a catchment to reach near equilibrium due to a storm uniformly spread in space and time,

- The spatial and temporal characteristics of rainfall are consequently ignored and the storm rainfall, as input into the formula, is assumed to be a rectangular pulse of duration  $T_c$ , deposited in lumped form on the catchment (i.e. there is no routing component implicit in the formula).

As a consequence, the rational formula was previously limited in its application to small catchments (<15 km<sup>2</sup> in South Africa (HRU, 1972)) and was only to be used as a check method (it was not to be used in isolation). It was further noted that sound engineering experience and judgment was required for its use. However, work that has since been done, locally by Alexander (2002) and Pegram (2003), and abroad in Australia (Institute of Engineers Australia, 1987), has shown that these cautions were too timid and its use may well be extended beyond small catchments.

For the estimation of design floods, a probabilistic approach to the rational formula is needed, where the variables  $c$  and  $i$  (the runoff coefficient and rainfall intensity respectively) of the formula are associated with a probability of exceedance. A probabilistic approach is different to a deterministic approach (which is the form shown in Eq. (1)), as it does not involve the representation of a historic event. As opposed to the latter case, no unique combination of rainfall and catchment conditions (such as storm patterns, ground cover conditions, antecedent moisture conditions, etc) exist to reproduce the design flood. In a probabilistic approach, the rational formula is used to estimate, for a given probability of exceedance, the magnitude of the peak discharge from a site; this peak would be equivalent to a discharge estimated from a frequency analysis of flood records if a long and representative record were available at that site.

Pilgrim and Cordery (1993) stated that the design situation is exactly suited to the probabilistic approach of the rational formula and has little similarity with the deterministic rational formula, so that the criticisms associated with the deterministic approach are not necessarily valid for the probabilistic design case. Alexander (1990) stated that as the catchment size increases the value

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