Development and assessment of a daily time-step continuous simulation modelling approach for design flood estimation at ungauged locations: ACRU model and Thukela Catchment case study

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ABSTRACT

The estimation of design floods is necessary for the design of hydraulic structures. Commonly used event-based approaches to design flood estimation have several limitations, which include the estimation of antecedent soil moisture conditions and the assumption that the exceedance probability of the design flood is the same as the exceedance probability of the design rainfall. Many of the limitations of event-based approaches may be overcome by the use of continuous simulation modelling for design flood estimation. This paper contains a brief summary on the development and assessment of a continuous simulation modelling system for design flood estimation in ungauged catchments. These developments include an investigation into the appropriate spatial scale of model configuration for optimum performance of the system, the temporal disaggregation of daily rainfall for hydrograph generation, flood routing in ungauged catchments and the use of radar information and rain-gauge data to improve the estimation of catchment rainfall. Results from the application of the system for design flood estimation in the Thukela Catchment in South Africa are presented and discussed. The results from the study highlight the challenges of hydrological modelling in an operational catchment and the need for reliable rainfall and runoff data. From the results obtained, it is concluded that reasonable and consistent estimates of design floods in the Thukela Catchment, particularly in smaller sub-catchments, can be obtained using the ACRU model.

Keywords: Design flood estimation; continuous simulation modelling, Thukela Catchment

INTRODUCTION

Estimates of design floods, where the magnitude of a flood is associated with a level of risk (e.g. exceedance probability or return period), are necessary in the planning, design and operation of hydraulic structures (e.g. bridges, culverts, dam spillways, drainage canals) for the preservation of human life and property (Rahman et al., 1998; Smithers and Schulze, 2003; Pegram and Parak, 2004; Reis and Stedinger, 2005). Under or over-design of even small hydraulic structures can result in a considerable waste of resources. The choice of an acceptable and cost-effective engineering solution is dependent upon having reliable estimates of the frequency–magnitude relationship of floods, both in terms of peak flows and volumes of water. However, while flood frequency estimation in ungauged catchments is of great practical interest, it is a continuing challenge (Blazkova and Beven, 2002).

The situation which faces design engineers and hydrologists most frequently is when no, or inadequate, observed streamflow data are available at the site of interest, and then either regional approaches or rainfall-runoff models have to be used for design flood estimation. Standard techniques for flood estimation have been developed for most countries and procedures for design flood estimation may be broadly categorised as methods based on the analysis of observed floods and rainfall-based methods, as shown schematically in Fig. 1. Regionalisation, by developing regressions between the flow statistics from gauged catchments with catchment characteristics (e.g., catchment area, slope, shape, hydraulic length), has been the dominant methodology used in the past to estimate design floods at ungauged locations. Continuous hydrograph simulation, driven by either historical or stochastic rainfall as input, is an approach which utilises the more widely available rainfall records (Blazkova and Beven, 2002) and is a viable method for flood frequency estimation (Blazkova and Beven, 2004).

Most of the methods used for design flood estimation in South Africa were developed in the late 1960s and early 1970s, as summarised in HRU (1972), and are in need of updating, with more than 40 years of additional data currently available and with new approaches used internationally (Alexander, 2002b; Smithers and Schulze, 2003; Görgens, 2007; Van der Spuy and Rademeyer, 2010; Smithers, 2012). Software to implement design flood procedures currently used in South Africa has been developed (e.g. Schulze et al., 1992; Van Dijk, 2005; Gericke, 2010), but there is no universally applicable method for design flood estimation in South Africa (Van der Spuy and Rademeyer, 2010).

According to HRU (1972), design floods may be estimated using either a statistical approach, which is an ordering and transposition of past experience, or a deterministic approach, in which rainfall is translated into a flood. Methods used for design flood estimation in South Africa are based on empirical, deterministic and probabilistic approaches (Pegram and Parak, 2004; Van der Spuy and Rademeyer, 2010) and Pegram (1994) presents a decision tree for the selection of design flood

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