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Rational Monte Carlo method for flood frequency analysis in urban catchments

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SUMMARY

The January 2011 flash flood at Toowoomba, Australia was substantially larger than other high ranking observed floods. Flood frequency analysis (FFA) is often performed with limited hydrological data so the occurrence of an exceptional flood provides valuable data. Peak 1 h rainfall intensities during the storm varied from <10 to >1000 year ARI across the catchment. Average recurrence interval (ARI) estimates of the resulting streamflow peak discharge were 220 year ARI for a General Extreme Value distribution fitted to the Annual Series and 450 year ARI based on a log–Pearson 3 distribution. An independent method referred to as the Rational Monte Carlo method (RMC) was developed in order to provide an independent check of the ARI estimate. The RMC method is a simple derived distribution approach where the Rational equation links observed rainfall intensity at a reference pluviograph to the peak flood discharge. The RMC 2011 flood ARI estimate was 475–515 years, comparable with the log–Pearson 3 method. Although the proposed method has limitations, the RMC approach shows promise as an alternative and independent FFA method for urban catchments. For all methods, the ARI estimates were sensitive to whether the January 2011 peak discharge was included in the analysis. Overall, the study highlights the inherent difficulty in extrapolating ARI estimates beyond the range of the available historical record.
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1. Introduction

Flood frequency estimation in urban catchments is often needed in many hydrologic and flood assessment studies. Managing flood risk, including the design of mitigation works and emergency planning, requires information on the expected frequency of large flood events. Various techniques are available for flood frequency analysis (FFA) and several are documented by Kidson and Richards (2005).

In many cases, FFA is performed with limited hydrological data and it is only with the occasional occurrence of an exceptional flood can a FFA be better established. When such an individual event happens, an estimate of its frequency is also important in order to check the adequacy of current approaches to local flood management and to direct future enhancements.

The opportunity to utilize data recorded during a major flood for FFA arose from the January 2011 flash flood at Toowoomba, Queensland. An analysis of the available pluviograph event data was conducted to evaluate the frequency of the storm rainfall. Annual Series flood frequency analysis was then undertaken of scenarios that included and excluded the estimated January 2011 peak discharge from within the historical flood record.

Current Australian FFA practice, as recommended in Australian Rainfall and Runoff (AR&R, I.E. Aust., 1987) is to fit a log–Pearson 3 (LP3) probability distribution function (pdf) to the Annual Series. AR&R is under revision and draft FFA guidelines (Kuczera and Franks, 2006) suggest that the Generalized Extreme Value (GEV) has a strong theoretical appeal for Annual Series FFA. Both the LP3 and GEV distributions were considered in this paper.

A new method, the Rational Monte Carlo method was devised to provide an independent frequency determination of the 2011 peak discharge. The method combines the simplicity of the Rational equation as a rainfall-to-discharge transfer function and the rigor of the Monte Carlo simulation to derive probabilistic estimates of peak discharge. The theoretical basis of the RMC method is first outlined and then demonstrated by analysis of the Toowoomba flood data. The effects of using different rainfall durations, the exclusion of the January 2011 flood from analysis and assumptions relating to key variables are also explored.

2. Toowoomba January 2011 flood analysis based on rainfalls and Annual Series

2.1. The January 2011 flash flood

During the afternoon of 10 January 2011, flash flooding within the Queensland city of Toowoomba led to the loss of two lives, inundation of 50 business premises and damage to more than 300 cars and other vehicles (LGAQ, 2011). Rainfall data was captured by several pluviometers located within the 56 km^2 catchment draining to the local streamgauge (GS 422326 Gowrie

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Creek at Cranley) operated by the Queensland Department of Environment and Resource Management.

Most of the Gowrie Creek catchment contains the Toowoomba central business district and surrounding residential suburbs. The main drainage features include West Creek and East Creek which merge at the CBD to form Gowrie Creek (Fig. 1). Toowoomba Regional Council, as the local government authority responsible for urban flood management, has installed a series of flood detention basins upstream of the Toowoomba CBD.

During the 8 days prior to the flash flood, a total of 244 mm of rainfall was recorded at the Toowoomba Airport including 83.6 mm during the antecedent 24 h period. This prior rainfall led to saturation of the catchment landscape and this was a major contributing factor to the generation of high runoff rates (ICA, 2011). The storm that led to flash flooding occurred in the early afternoon of 10 January 2011, with the bulk of the rainfall falling between approximately 13:00 and 14:30 h. Measured 3 h rainfalls ranged from 66.5 mm to 120 mm.

The high runoff generation and relatively short time of concentration of the catchment (of the order of 1 h) led to rapidly increasing flows within the Gowrie Creek drainage system. The streamgauge suffered damage and failed to record the discharge peak.

Given the loss and damage associated with this individual flood event, it was considered important to derive an estimate of the average recurrence interval (ARI) of the January 2011 flood peak. Flood flows overwhelmed the capacity of local flood mitigation assets which were designed to a 100 year ARI design standard, sized consistent with Queensland requirements (SoQ, 2007).

2.2. Event rainfall analysis

A frequency analysis of the event rainfall is a useful starting point in investigating the resulting flood response. Observed point 1 h rainfall intensities, corresponding to the estimated catchment time of concentration of 1 h, were extracted from a local network

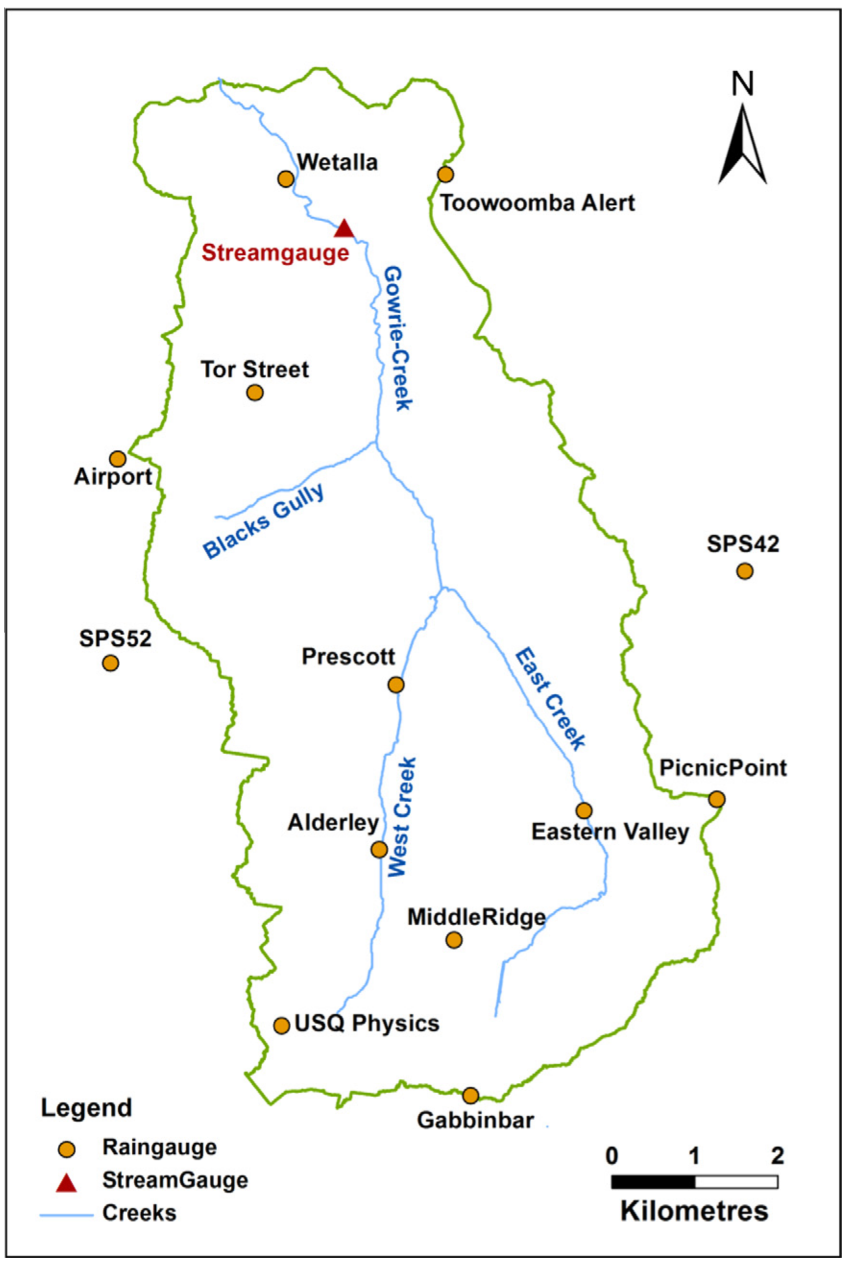

Fig. 1. Gowrie Creek drainage features.

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