A hydrological perspective of the February 2000 floods: A case study in the Sabie River Catchment

JC Smithers*, RE Schulze, A Pike and GPW Jewitt
School of Bioresources Engineering and Environmental Hydrology, University of Natal, Pietermaritzburg, Private Bag X01, Scottsville 3209, South Africa

Abstract

The exceptionally heavy rains which fell over the north-eastern parts of South Africa, Mozambique and Zimbabwe during February 2000 resulted in disastrous flooding, loss of hundreds of lives and severe damage to infrastructure. The objective of the study reported in this paper is to assess the severity, from a probabilistic perspective, and spatial variability of the extreme rainfall and flooding which occurred in the north-eastern part of South Africa during February 2000. This is performed for events ranging from 1 to 7 days in duration using the Sabie River catchment, upstream of the South African/Mozambique border, as an example. The analyses indicate that the floods experienced in the Sabie catchment during February 2000 were the result of rare rainfall with return periods in excess of 200 years in parts of the catchment. The extent of the extreme rainfall increased for longer durations.

The magnitudes of the February 2000 floods were such that many gauging stations did not function and numerous gauging structures were inundated. Hence, a modelling approach was adopted to investigate the spatial variability, magnitudes and probabilities of the floods which occurred during February 2000 in the Sabie catchment. The return periods of simulated runoff depths for durations of 1 to 7 days generally exceeded 50 years for the upper and middle portions of the catchment and 200 years in some parts of the Sabie catchment. Hence, some extremely large and rare flow depths were experienced and the spatial variability of the return periods associated with the simulated runoff depths varied substantially within the catchment.

Introduction

Exceptionally heavy rains fell over the north-eastern parts of South Africa, Mozambique and Zimbabwe during February 2000 which resulted in disastrous flooding, loss of hundreds of lives and severe damage to infrastructure (Dyson, 2000). The extreme rainfall was concentrated in two periods, *viz*. 5 to 10 February and 22 to 25 February 2000, and was caused by tropical weather systems that moved from West to East over the subcontinent (Dyson, 2000). The combination of the two systems and high levels of antecedent soil moisture from an already wet December resulted in the excessive flooding (Van Biljon, 2000).

Alexander (2000) using the South Africa Weather Bureau's (SAWB) monthly district rainfall database, not only showed that the February 2000 rainfall in District 48, situated in the north-eastern part of South Africa, slightly exceeded the 100-year return period event, but also indicated that the severity of the rainfall was highly variable with adjacent districts (49 and 34) associated with return periods of less than two years for the February 2000 rainfall. These analyses were performed on monthly totals of rainfall and do not reflect the variability of daily extreme rainfall that occurred.

Based on the design rainfall depths computed by Adamson (1981), Van Biljon (2000) estimated the return period for 1 and 2 day rainfall depths to be greater than 200 years at certain sites in South Africa. Damage occurred to most river gauging stations in the flood ravaged area (Van Biljon, 2000). However, at a number of sites the magnitudes of the February 2000 flood could be estimated and these indicate that the February 2000 flood was the largest recorded value at some sites, but at other sites the estimated magnitude of the February 2000 flood was exceeded in the historical record. Van Bladeren and Van der Spuy (2000) reached a similar conclusion and reported that the flooding in the Limpopo, Sabie, lower Crocodile and lower Komati Rivers exceeded the 100-year return period event.

The objective of the study reported in this paper was to assess the severity, from a probabilistic perspective, and spatial variability of the extreme rainfall and flooding which occurred in the north-eastern part of South Africa during February 2000. This was performed for events ranging from 1 to 7 days in duration using the Sabie River catchment, upstream of the South African/Mozambique border, as an example. The Sabie catchment is located in South Africa as shown in Fig. 1 and has been the focus of numerous studies (e.g. Jewitt and Görgens, 2000). The Sabie River is important from agricultural and eco-tourism perspectives and is one of the rivers which flows through the Kruger National Park before flowing into Mozambique**.**

Methodology

This assessment was performed for durations ranging from 1 to 7 days for both extreme rainfall and floods. This included the maximum values for the February 2000 floods as well as an assessment of the severity of rainfall on individual days or periods within February 2000.

The exceptional flooding resulted in the failure and, in some cases, the destruction of many river gauging stations (Van Biljon, 2000). Hence, the *ACRU* model (Schulze, 1995) was utilised to assess the extent of the flooding. Some initial hydraulically-based assessments of the flood magnitudes have been made at selected sites by Van Bladeren and Van der Spuy (2000) and these estimates and observations at selected gauging weirs are used to evaluate the peak discharges simulated by the *ACRU* model.

Smithers and Schulze (2000) used a regional index-storm approach based on L-moments to estimate design rainfalls for

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* To whom all correspondence should be addressed.
☎ (033) 260-5408; fax: (0 33) 260-5818; e-mail: smithers@nu.ac.za
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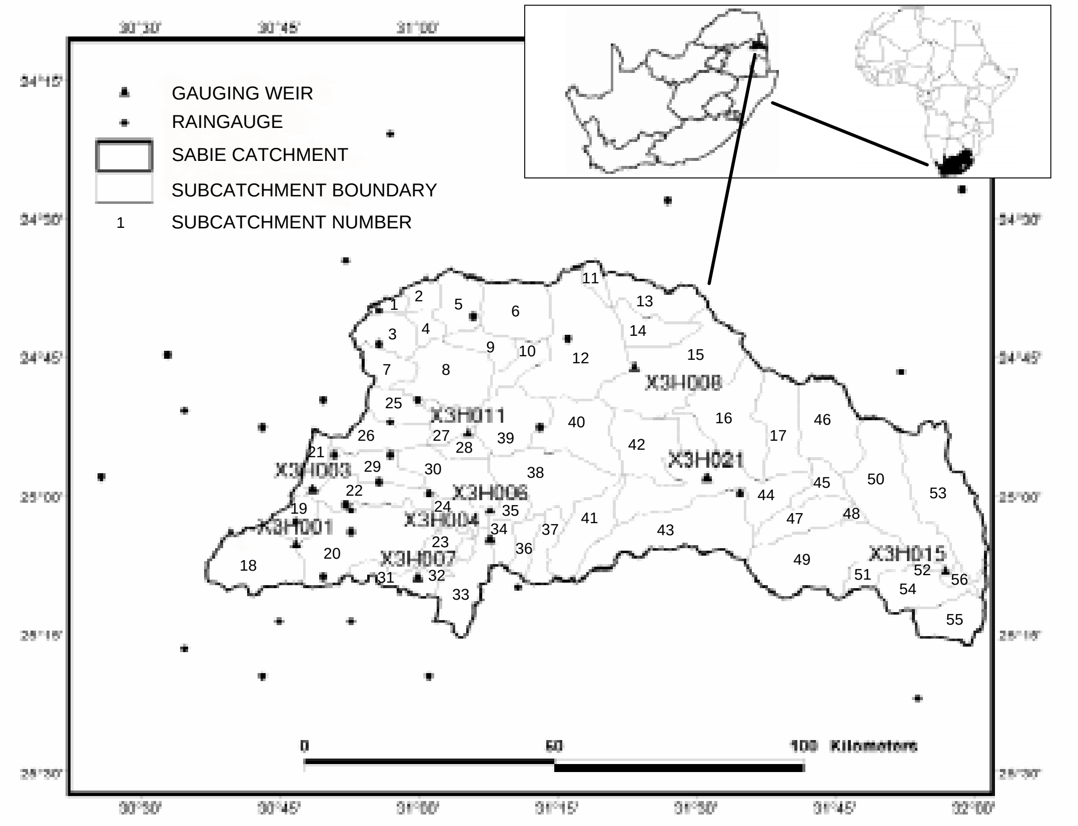

Figure 1
Location of Sabie River catchment within South Africa, subcatchment delimitation as well as raingauges and flow gauging weirs

durations ranging from 1 to 7 days in South Africa. They found the General Extreme Values (GEV) distribution to be a robust and suitable distribution for extreme rainfalls in South Africa. Hence, the severity of the February rainfall, data for which were obtained from the SAWB, was assessed using the GEV and regionalised parameters for the GEV as determined by Smithers and Schulze (2000). The routines developed by Hosking (1996) were used to fit the GEV distribution to the Annual Maximum Series and to determine the return period for an event of a given magnitude.

Owing to the lack of sufficient reliable observed flow data for the February 2000 floods, the daily time step semi-distributed physical-conceptual *ACRU* model was used to simulate the runoff for a period of record extending from January 1945 to June 2000. Daily peak discharges simulated using the *ACRU* model and input to a frequency analysis have been shown to represent observed design flows adequately (Smithers et al., 1997).

The *ACRU* model was configured for the Sabie catchment by Pike et al. (1997) and used by Jewitt and Görgens (2000) and, with the exception of the updating of the daily rainfall files, this configuration of the Sabie catchment for the *ACRU* model was used in this study. The *ACRU* model's peak discharge (Schulze and Schmidt, 1995) and multiple reach flood routing (Smithers and Caldecott, 1995) options were invoked, in addition to the standard simulation of the runoff volume which considers soils and land use as well as abstractions for irrigation and domestic use. The model uses the Muskingum technique to route flows in river reaches and the storage-indication method of routing flows through reservoirs. The parameters for the Muskingum procedure were determined using the physical characteristics of the reach such as length, slope, shape of channel cross-section and channel roughness according to the procedure developed by Muskingum-Cunge (Viessman et al., 1989).

The Sabie catchment was delimited by Pike et al. (1997) into 56 subcatchments (Fig. 1), with subcatchment areas ranging from 8.5 to 311.7 km^2. Month-by-month subcatchment area-weighted values of monthly means of daily maximum and minimum temperatures and mean A-pan equivalent potential evaporation were determined by Pike et al. (1997) from 1' x1' of a degree latitude and longitude gridded values developed by Schulze (1997). The hydrological characteristics of the soils within each subcatchment were determined by Pike et al. (1997) using Land Type information obtained from the Institute for Soil, Climate and Water. The land cover and land use within each subcatchment were derived from a 1993 LANDSAT TM image and these were translated into month-by-month values required by the *ACRU* model (Pike et al., 1997). The extent of irrigation practices and modes of scheduling were determined by Pike et al. (1997) from Chunnett, Fourie and Partners (1990). The reservoir information required by the model was determined using various sources which included the LANDSAT TM image, Chunnett, Fourie and Partners (1990) and 1:50 000 topographic maps (Pike et al., 1997). The verifications of streamflow volumes simulated with the *ACRU* model by Pike et al. (1997) were accepted and are not repeated in this study.

An assessment of the historical primary runoff data from many of the gauging weirs in the catchment indicated that the observed flows frequently exceed the rating capabilities of the weirs during large events and are thus not suitable for estimating design floods (e.g. X3H004 and X3H007). Comparisons between design floods

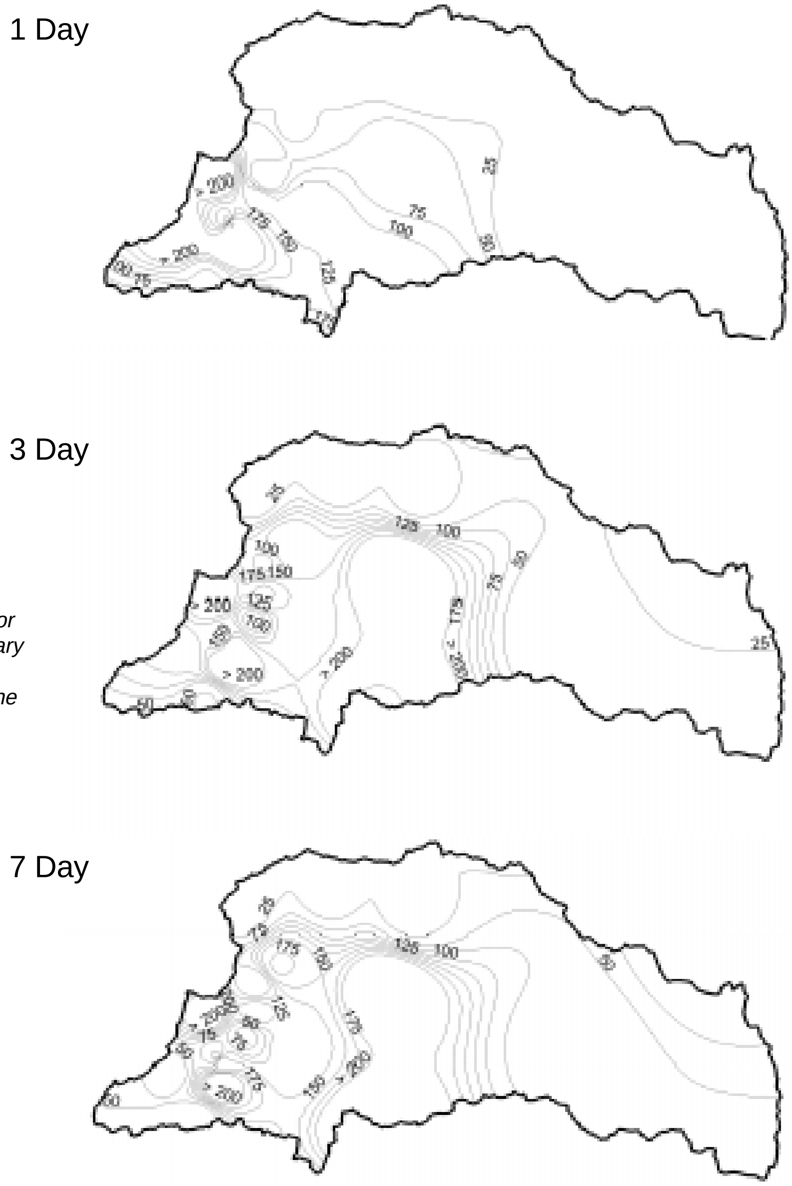

Figure 2
Estimated return periods for observed rainfalls in February 2000 for durations of 1, 3 and 7 day periods in the Sabie River catchment

estimated at gauging weirs which have relatively good and long records were performed and the magnitude of peak discharges simulated for the February 2000 floods by the model were also verified against estimates published by Van Bladeren and Van der Spuy (2000). For consistency and to enable a comparison with the extreme rainfall, the GEV distribution was used to assess the severity and spatial distribution of the floods as simulated by the *ACRU* model.

Results

Rainfall

The estimated return period associated with each observed maximum rainfall depth which occurred during February 2000 is illustrated in Fig. 2 for 1, 3 and 7 day periods. The 1 day extreme rainfall was the most extreme in the upper eastern portion of the catchment, with return periods in excess of 200 years associated with daily rainfall amounts at some stations. The 3 and 7 day extreme rainfalls were more widely spread and rainfalls with return periods in excess of 200 years were recorded in the upper and middle portions of the catchment for these longer durations.

The estimated return period associated with each observed daily rainfall depth which occurred during the two largest events in February 2000 is illustrated in Figs. 3 and 4 for 1, 2 and 3 day periods. Clearly, the rainfall event which occurred between 22 and 24 February 2000 (Fig. 4) was not large, relative to historical values. However, for the event from 5 to 7 February (Fig. 3), rainfall depths with return periods in excess of 200 years fell over the middle and upper portions of the catchments for 1, 2 and 3 day durations.

Runoff

The estimated peak discharges during the February 2000 flood in the Sabie River as reported by Van Bladeren and Van der Spuy (2000) and simulated by the *ACRU* model are listed in Table 1. The peak discharges on the Sabie River at Gauging Weirs X3H006 (766 km^2) and X3H021 (2 461 km^2) during February 2000 were estimated by Van Bladeren and Van der Spuy (2000) to be 1 690 m^3·s^{-1} and 3 710 m^3·s^{-1} respectively. The simulated peak discharge of 1 554 m^3·s^{-1} at X3H006 compares favorably with the discharge of 1 690 m^3·s^{-1} estimated by Van Bladeren and Van der Spuy (2000).

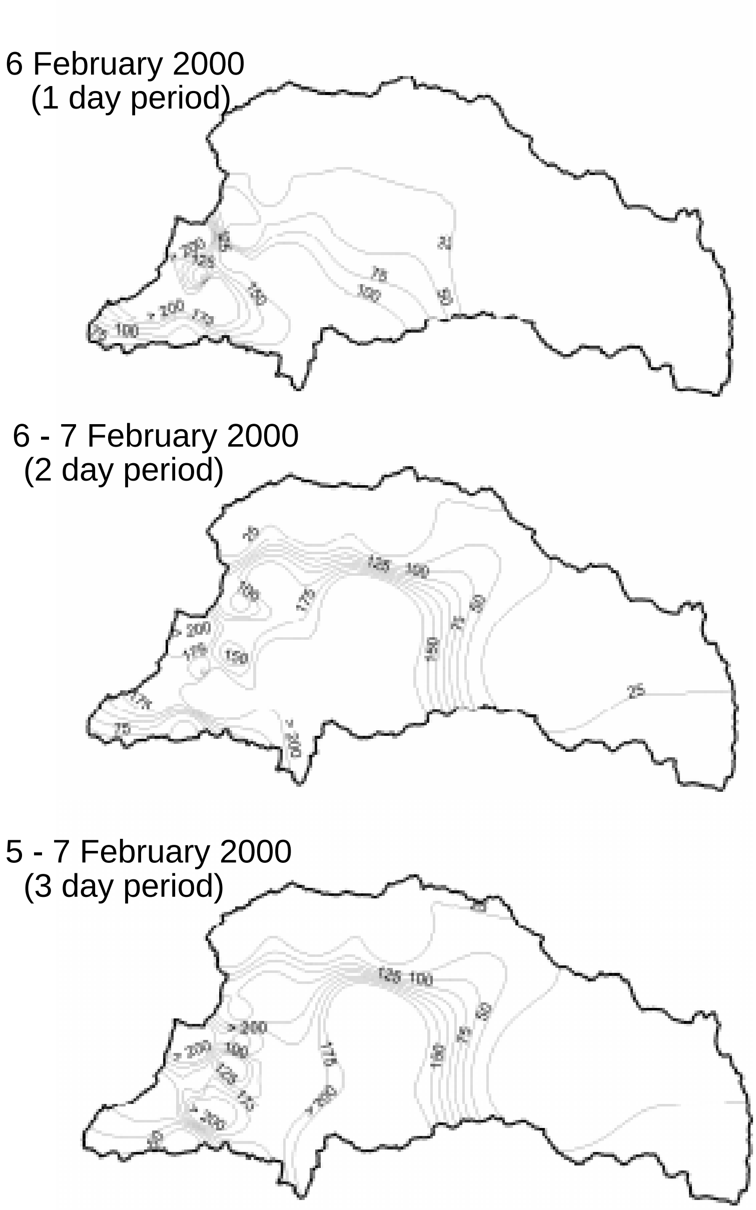

Figure 3
Estimated return periods for observed rainfalls for 5 - 7 February 2000 for durations of 1, 2 and 3 day periods in the Sabie River catchment

TABLE 1
Estimated peak discharges and return periods of the February 2000 floods in the Sabie River

Station	Place	Catchment area (km²)	Van Bladeren and Van der Spuy (2000)		Simulated	
			Peak discharge ($m^3 \cdot s^{-1}$)	Return period (years)	Peak discharge ($m^3 \cdot s^{-1}$)	Return period (years)
X3H006	Perry's Farm	766	1 690		1 554	> 200
X3H021	Skukuza	2 461	3 710	100	3 448*	130**
	Subcatchment 44	2 961			4 148	130
X3H015	Subcatchment 52	5 713			4 817	88
	Subcatchment 56	6 260			4 830	86

* Scaled using catchment area from the simulated peak discharge for Subcatchment 44
** Estimate from Subcatchment 44

The peak discharge at weir X3H021 was estimated by Van Bladeren and Van der Spuy (2000) to be equivalent to a 100 year return period event. Unfortunately, the subcatchment configuration used did not include a delineation at the site of gauging weir X3H021. The estimated peak discharge of 3 448 $m^3 \cdot s^{-1}$ at Gauging Weir X3H021, computed from the simulated discharge at the next downstream catchment (Subcatchment 44) and scaled by the respective catchment areas for Subcatchment 44 and Gauging Weir X3H021, also compares well with the value of 3 710 $m^3 \cdot s^{-1}$ estimated by Van Bladeren and Van der Spuy (2000).

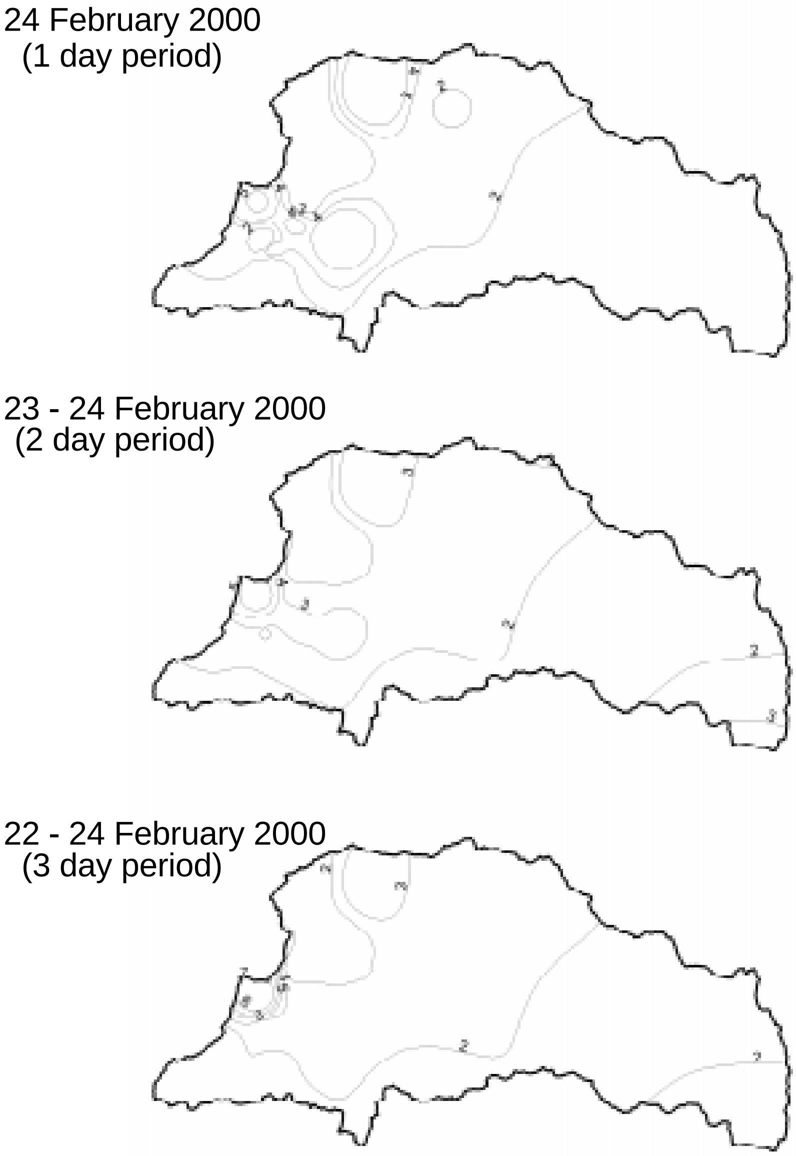

Figure 4
Estimated return periods for observed rainfalls during 22 - 24 February 2000 for durations of 1, 2 and 3 day periods in the Sabie River catchment

A frequency analysis of the simulated and daily peak discharges at Gauging Weirs X3H001 (173 km^2) and X3H006 (766 km^2), as shown in Fig. 5, indicates that the simulated values generally exceed the observed values for smaller events. However, the distributions and magnitudes of the simulated and observed daily peak discharges are similar for larger flood events, which are the focus of this study. An example of the simulated and observed daily peak discharges for the February 2000 floods is shown in Fig. 6. The overtopping of the weir at X3H001 during the large flood event is evident in Fig. 6. Observed data for February 2000 were not available for Gauging Weir X3H006 during this study.

From the selected results presented, it is evident that the model appears, for the larger flood events, to be simulating peak discharges of the correct order of magnitude and it is postulated that the simulated values can be used with some confidence to assess the design flows at the outlet of each subcatchment.

The estimated return periods associated with the maximum simulated runoff depths during February 2000 are illustrated in Fig. 7 for 1, 3 and 7 day periods. The return periods of runoff depths in the middle portion of the catchment exceed 200 years and were up to 75 years in the upper portions of the catchment. Comparison of Figs. 2 and 7 indicates that the return period of rainfall events are generally larger over a greater portion of the catchment than the return periods associated with the depth of runoff.

The estimated return period associated with the simulated maximum daily peak discharge during February 2000 is illustrated in Fig. 8. These return periods exceed 100 years over the middle portion of the catchment and exceed 200 years in certain parts of the catchment and, as expected, have a distribution similar to the simulated runoff depth.

Discussion and conclusions

Observed daily rainfall was used in conjunction with regionalised parameters of the GEV distribution to estimate the return periods associated with rain events during February 2000. This analysis was performed for durations ranging from 1 to 7 days. Return periods of rainfall in excess of 200 years were obtained for all durations considered in the upper and middle portions of the Sabie catchment. Hence, not only was the magnitude of the rainfall that fell in portions of the catchment extremely rare, but the return period of the events were noted to vary significantly within the catchment. The network of rain gauges in the lower portion of the catchment is very sparse, which may have affected the analysis of

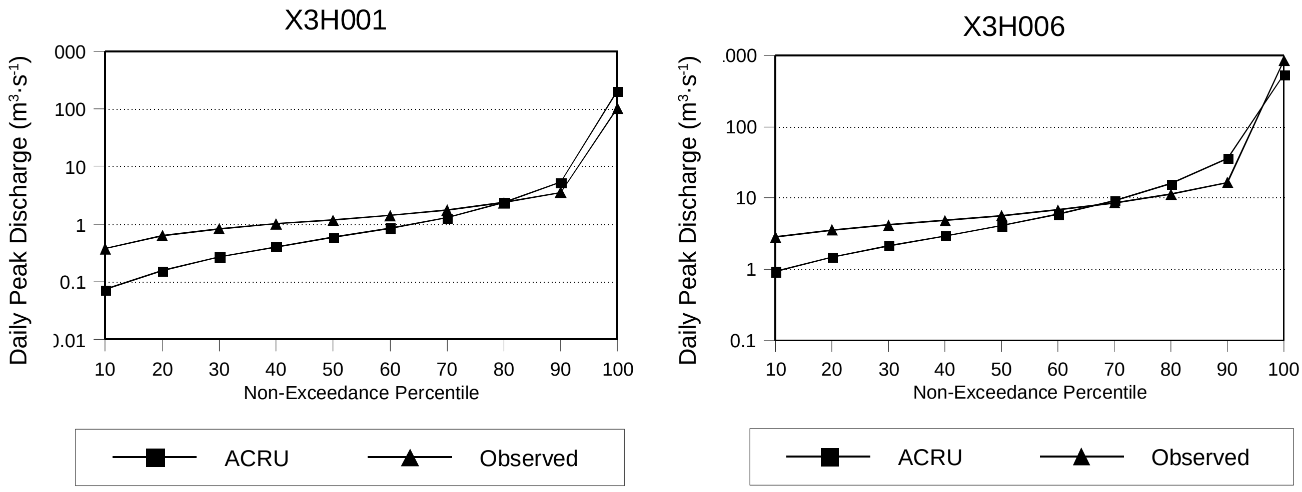

Figure 5
Frequency analysis of simulated and observed daily peak discharges at Gauging Weirs X3H001 and X3H006

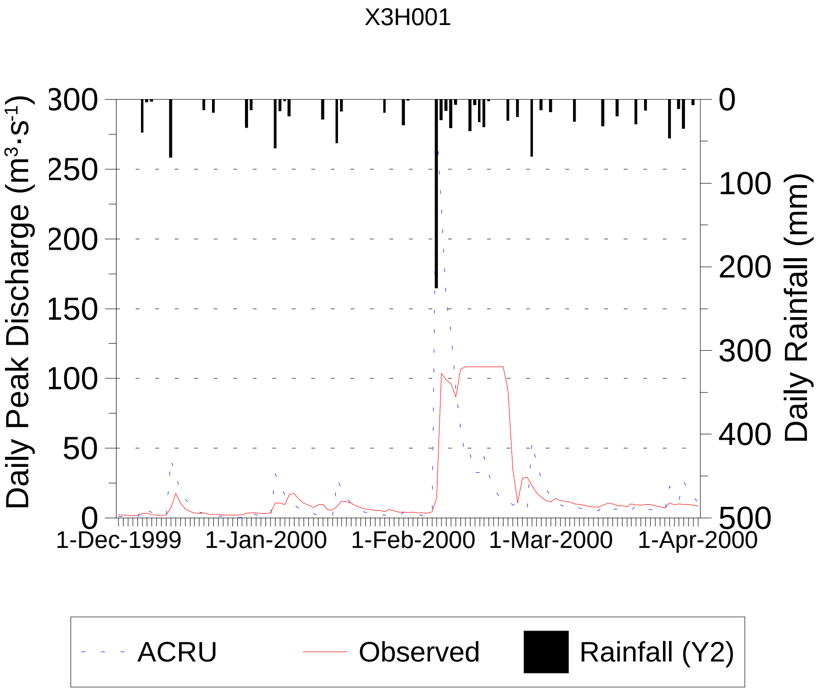

Figure 6
Simulated and observed daily peak discharges during the February 2000 floods

rainfall there. The use of rainfall data captured using radar, which would give complete spatial coverage of the catchment, would have been useful to verify the spatial variability exhibited in the observed daily rainfall data.

The magnitudes of the February 2000 floods were such that many gauging stations did not function and numerous gauging structures were inundated. Hence, a modelling approach was adopted to investigate the spatial variability, magnitudes and probabilities of the floods which occurred during February 2000 in the Sabie catchment. A comparison of simulated and observed daily peak discharges indicated that the simulated values were acceptable and, in many instances where the gauging thresholds were exceeded, the simulated values are more realistic than the observed values. The simulated peak discharges for the February 2000 floods also compared very well with peak flows reported in the literature, which were estimated by hydraulic calculations and surveyed flood lines. Thus, the daily peak discharges simulated by the *ACRU* model were considered to be reasonable.

The probabilities of the simulated flow depth and peak discharge were determined relative to simulated values for the entire period of historic rainfall record. Hence, it is postulated that even if the simulations were biased, they would be consistently biased and the derived probabilities for the February 2000 floods would be still be reasonable.

The return periods of runoff depths for durations of 1 to 7 days generally exceeded 50 years for the upper and middle portions of

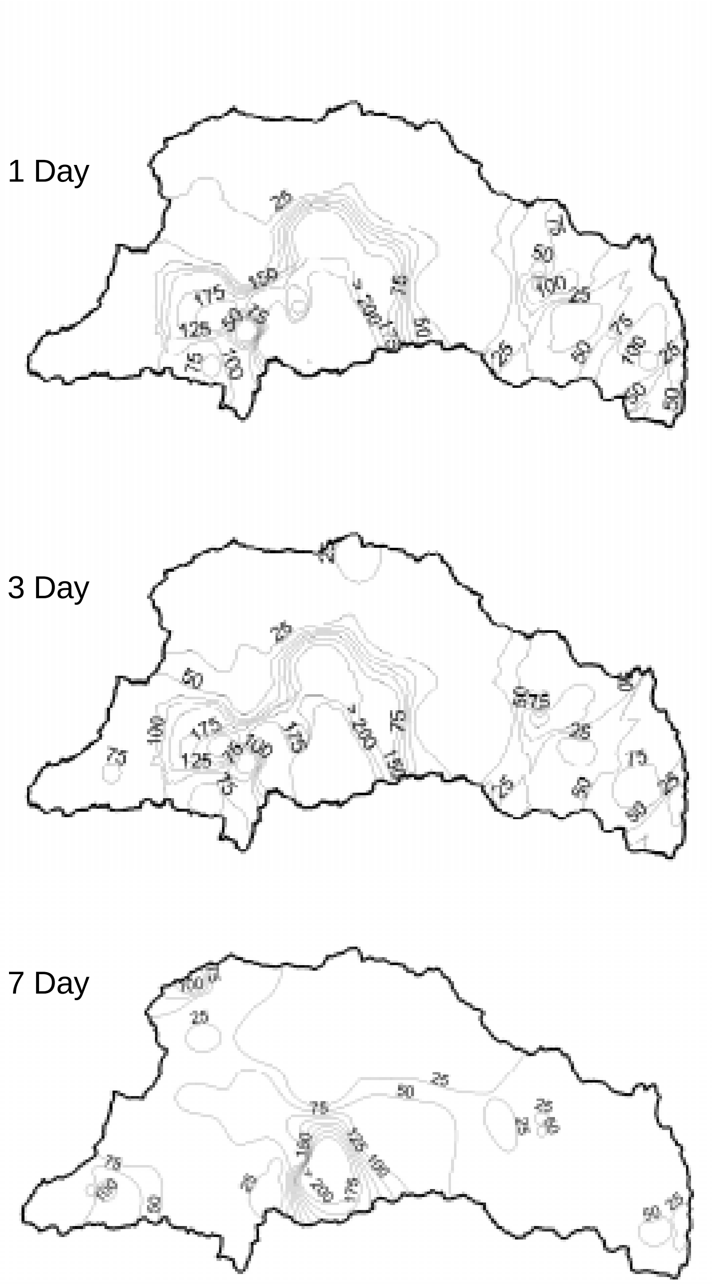

Figure 7
Estimated return periods for simulated runoff depth during February 2000 for durations of 1, 2 and 3 day periods in the Sabie River catchment

Figure 8
Estimated return periods for maximum daily peak discharge during February 2000 in the Sabie River catchment

the catchment and 200 years in some parts of the Sabie catchment. Hence, some extremely large and rare flow depths were experienced and the spatial variability of the return periods associated with the simulated runoff depths varied substantially within the catchment. It was generally found that the distribution of return periods for the simulated peak discharges were similar to the distribution of runoff volume and the return periods of runoff volume and peak discharge were generally less than those associated with the rainfall.

The analyses indicate that the floods experienced in the Sabie catchment during February 2000 were the result of rare rainfall with return periods in excess of 200 years in parts of the catchment. The extent of the extreme rainfall increased for longer durations. It was expected that antecedent soil moisture would have resulted in floods with return periods larger than the rainfall. However, exceptions were noted, particularly in the upper portion of the catchment, where the return periods of the runoff are substantially lower than that of the rainfall. It is postulated that the reduction in the return period of the runoff relative to rainfall is the result of the extensive forestry in the upper reaches of the catchment. Hence, it is probable that anthropogenic influences in the catchment may have influenced the severity of localised flooding within the catchment.

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