The February 2000 floods on the Sabie River, South Africa: an examination of their magnitude and frequency

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The floods that affected much of southern Africa in February 2000 have been reported as the largest in living memory by many observers. However, the force of the floods damaged the majority of the gauging stations located on the affected rivers, many of which were not constructed to measure flows of such a magnitude. This paper presents an estimation of the peak flood discharge on 6 February 2000 for the bedrock influenced Sabie River in the Kruger National Park, by simulating the hydraulic and geometric characteristics of the peak flow and relating these to the roughness character of the channel. Peak water surface slope data in the form of strandline measurements at channel type breaks along the river were collected for six sites along the Sabie River within the Kruger National Park. Flood conditions within each channel type were considered to approximate to uniform flow. The cross-sections are located between major tributary inputs allowing for approximate sub-catchment flow contributions to be estimated. The results indicate that the flow peaked at around 3000 m^3/s at the Kruger Gate entrance to the Kruger National Park, increasing to approximately 5500 m^3/s at Skukuza and 7000 m^3/s at Lower Sabie close to the Mozambique border following inputs from the Sand River sub-catchment. These estimates compare well with the simulated rainfall runoff total of 4300 m^3/s at Skukuza, however, precipitation inputs over the lowveld appear to indicate that the discharge only rises to 4950 mm^3/s at Lower Sabie. A flood flow of this magnitude has never been experienced based on the simulated flow data generated by the ACRU hydrological model calibrated against measured flows therefore suggesting a return period in excess of the 60 years of record.

Key words: February 2000 flood, flood frequency, flood magnitude, Sabie River.

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Introduction

A series of tropical depressions and cyclone activity affected much of southern Africa including South Africa, Zimbabwe, Mozambique and Madagascar throughout February and March of 2000. Unprecedented rainfall fell across the region, Smithers *et al.* (2000) estimated the return period of runoff depth for seven days duration of 50 years in the middle and upper catchment, rising to 200 years across other parts. This served to swell many of the rivers to levels above anything recorded previously. Van Bladeren & Van der Spuy (2000) have established that the peak discharge at Kruger weir in the Sabie catchment was in excess of the 100 year return period.

The Sabie River, which drains part of Mpumalanga Province, South Africa and southern Mozambique (Fig. 1) rose to a peak discharge in February following exceptional precipitation in the catchment (Fig. 2). The flow was sufficient to overtop the incised macro-channel in places including Skukuza and Lower Sabie tourist camps within the Kruger National Park. The peak flow was not

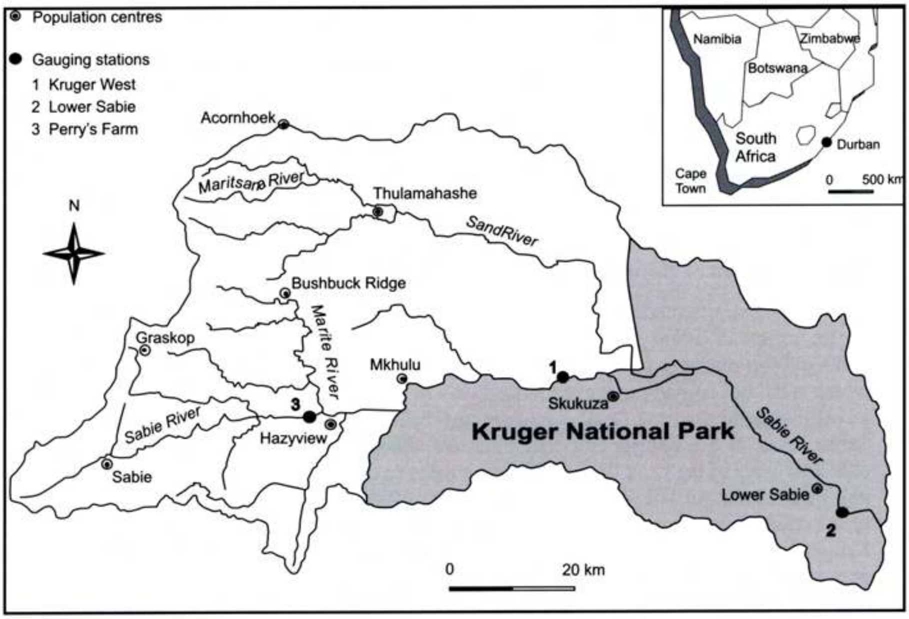

Fig. 1. The Sabie River Catchment, Mpumalanga Province, South Africa.

gauged at any of the gauging stations located along the river in the lowveld as these stations were inoperable due to prior flood damage. However, Department of Water Affairs and Forestry (DWAF) preliminary discharge estimates (Table 1), based on flow levels at these sites, place the flow peak as high as 8000 m^3/s at Lower Sabie. This compares with the significantly lower figure of 5300 m^3/s based on rainfall simulation (Smithers *et al.* 2000)

The peak flood discharge for the Sabie River is widely believed to have been exceptional. This belief is placed in context with the historical flow record for the river derived from the ACRU hydrological simulation model (Schulze 1989) previously calibrated against actual flow data from the gauging weirs on the river (Birkhead *et al.* 2000).

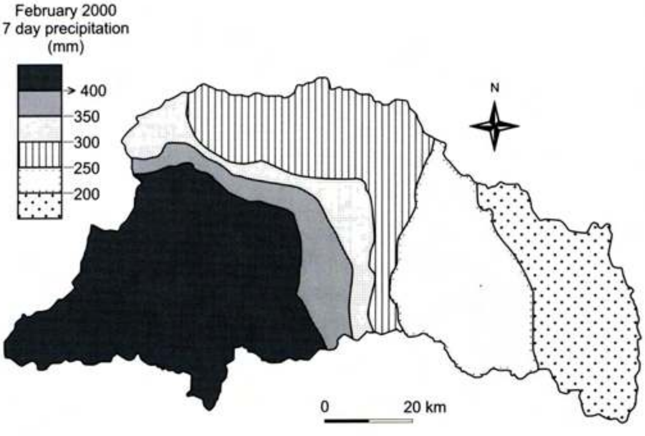

Fig. 2. Precipitation over the Sabie catchment in early February 2000.

Catchment characteristics

The Sabie River drains a 6300 km^2 catchment in the Mpumalanga Province, South Africa before flowing into Mozambique (Fig. 1). It rises in the Drakensberg Mountains to the west (1600 masl), descending rapidly onto the flat lowveld (400 masl) and Lebombo zones (200 masl) in the east. Frontal rainfall is highest in

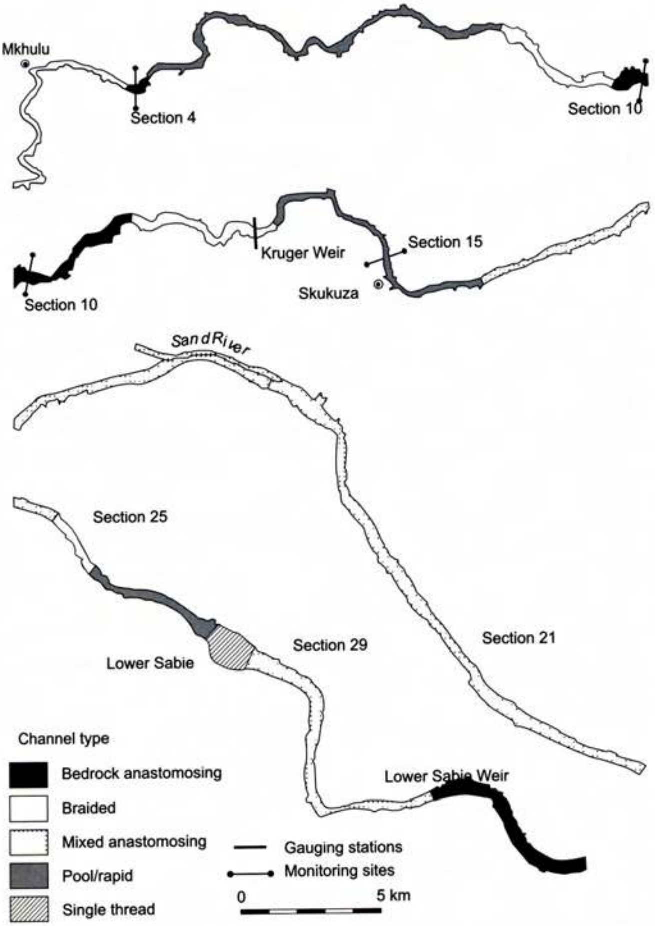

Fig. 3. Location of the cross-sections used in the peak flow discharge estimation along the Sabie River in the Kruger National Park.

the highland areas (2000 mm/a) and declines rapidly towards the border of South Africa with Mozambique (450 mm/a) and is concentrated in the summer months, from November to March. Cyclonic activity is also occasionally recorded within the catchment. Evaporation varies from 1700 mm in the east, to 1400 mm in the west, with summer values 60 % higher than winter ones in the lowveld. Winter base flows are supplied by the dolomitic aquifers in the mountainous areas to the west. Precipitation associated with the tropical depression affecting the catchment between the 5th and 10th February 2000 was exceptional with 245 mm recorded at Skukuza and 544 mm at Graskop in the upper catchment.

River characteristics

The Sabie River is underlain by a wide variety of bedrock lithologies, comprising sedimentary, intrusive and extrusive igneous and metamorphic rocks. Lithological differences in the geology control the longitudinal slope profile of the Sabie River and consequently the geomorphological form (Van Niekerk *et al.* 1995; Cheshire 1994). The Mpumalanga region has been subject to uplift in the recent geological past (10 Ka to 100 Ka), resulting in the incision of the Sabie River into bedrock. This has created a channel that has a 'floodplain' restricted by the width of incision into bedrock. This incised feature has been termed the macro-channel (Van Niekerk *et al.* 1995), as opposed to the smaller, active, perennially flowing channels and seasonally flooded features within its confines. The Sabie is a physically diverse river system that displays marked changes in channel type as the distribution of sediment over bedrock varies. Van Niekerk *et al.* (1995) have identified morphological units on the Sabie River which form associations with each other to create channel types and these have been mapped for the entire length of the river within the Kruger National Park (Fig. 3).

Each channel type has a characteristic morphology and vegetative assemblage, both of which contribute to the overall channel roughness or resistance to flow. Bedrock

Table 1

Channel roughness values quantified for the channel types of the Sabie River in the Kruger National Park

Channel type	Discharge (mΔ/s)	Mannings Resistance coefficient ('*n*')	Darcy Weisbach Resistance coefficient (*f*)	Source
Braided	660 0.0597	1705 0.11	0.043 0.155	Broadhurst *et al.* (1997) Birkhead *et al.* (2000)
Single-thread	1705	0.0617	0.165	Birkhead *et al.* (2000)
Pool-rapid	1705	0.0535	0.138	Birkhead *et al.* (2000)
Mixed anastomosing	1000 0.0395	2259 0.37	0.082 0.125	Broadhurst *et al.* (1997) Birkhead *et al.* (2000)
Bedrock anastomosing	660 0.0901	1705 0.0.15	0.043 0.456	Broadhurst *et al.* (1997) Birkhead *et al.* (2000)

outcrops in the form of rapids isolated rocks and bedrock pavement generate large scale roughness, particularly in the pool-rapid and bedrock anastomosed channel types. The larger macro-channel cohesive sedimentary deposits alter the path of the river within the confines of the macro-channel, producing additional planform roughness. Vegetative roughness elements exist on most morphological features ranging from semi-terrestrial species such as *Diospiros* spp. and *Acacia* spp. found on the macro-channel banks to large fig trees (*Ficus* spp.) associated with the macro-channel lateral deposits and islands.

Estimation of peak discharge

Broadhurst *et al.* (1997) and Birkhead *et al.* (2000) computed channel roughness values for each of the channel types found on the Sabie River (Table 1) based on the reach approach of Barnes (1967). The values are higher than previously reported in the literature for the bedrock anastomosing channel type and are comparable to estimates for single-thread, braided and pool-rapid channel types given elsewhere (Broadhurst *et al.* 1997).

The peak flow magnitude of the Febuary 2000 flood (Q_{peak}) was estimated from the frictional characteristics of the channel defined by the highest previous flood recorded in Table 1 by rearranging the Darcy Weisbach and Colebrook White flow resistance equations:

Channel flow resistance (*f*) may be calculated from the sedimentary and cross-sectional characteristics of the channel using the Colebrook White equation:

$$V = \sqrt{\frac{8gRS}{f}} \tag{1}$$

where R = the hydraulic radius, D_{84} = the bed-material size for which 84 % of the material is finer (2 mm for the Sabie deposits) and

$$a = 11.1\left(\frac{R}{d_{max}}\right)^{-0.314} \tag{2}$$

where d_{max} = the maximum flow depth.

Given this value, the Channel flow velocity (V) may be determined from the Darcy Weisbach equation:

$$\frac{1}{\sqrt{f}} = 2.03 \log\left[\frac{aR}{3.5D_{84}}\right] \tag{3}$$

where g = Gravitational acceleration (9.81 m/s^2) and S = Water surface slope as defined by the flood peak strandline.

Using the continuity equation the peak discharge may be estimated:

Table 2

Channel geometric and hydraulic properties for the February flood peak on the Sabie River at selected cross-sections, (see Fig. 3 for section locations)

Flood Parameter	Section 4	Section 10	Section 15	Section 21	Section 25	Section 29
Channel type	Bedrock anastomosed	Bedrock anastomosed	Pool-rapid	Mixed anastomosed	Braided	Mixed anastomosed
Darcy Weisbach Resistance value	0.456	0.456	0.138	0.125	0.0115	0.0125
Section flood slope	0.00629	0.00318	0.00258	0.00275	0.00270	0.00275
Channel area (m≈)	1414	1037	1777	2161	1999	2290
Wetted perimeter (m)	316	342	270	378	305	338
Hydraulic radius (m)	4.5	3.0	6.6	5.7	6.6	6.8
Average velocity (m/s)	2.2	2.5	3.1	3.1	3.5	3.3
Discharge (mΔ/s)	3113	3900	5522	6789	6950	7453
Contributing sub-catchment (area km≈)	Upper Sabie (770), Maritsane (472)		North Sand (254), Sand (1910)	Middle Sabie (1466)		Lower Sabie (1389)

$$Q_{peak} = VA \qquad (4)$$

where A = the peak flow channel area.

Peak discharges were calculated for 6 cross-sections previously surveyed on the river (Van Niekerk & Heritage 1993). These were chosen as they are located within a specific channel type (Table 2) allowing accurate estimation of the peak flood water surface height and slope (Fig. 3). The peak water levels at these sections was close to or only just over the top of the macro-channel, hence the use of the previous highest Darcy Weisbach flow friction value (f) in the resistance equations represents the best estimate of channel roughness for the peak flow. This assumes that no further reduction in channel roughness has occurred between the previous highest flow and the February peak. Such an assumption is not unreasonable given the asymptotic nature of resistance reduction demonstrated by the different channel types at very high flows (Broadhurst *et al.* 1997). However, the removal of vegetation cover from the macro-channel floor at sometime during the flood coupled with the development of large-scale surface waves will have had some unmeasured effect on these values.

The peak flood water surface slope change along the river was reconstructed through strand line measurements taken in May 2000 within the Kruger National Park downstream as far as the Lower Sabie gauge station. Peak flow levels were indicated by vegetation strandlines in trees and on the ground and the farthest lateral extent of mud drapes. Several measurements were taken at the selected cross-sections and at each change in channel type along the river as these reflect changes in channel gradient. The survey generated linked *xyz* data was combined with the macro-channel thalweg distance measured along the river to the cross-sections and channel type breaks to produce a long-profile of the flood (Table 2). The hydraulic and geometric data used to calculate the peak discharge along the river is summarised in Table 2.

It is clear that the peak discharge increases in the downstream direction with significant inputs at the peak of the flow of around 3600 m^3/s from the Maritsane and Sand

Table 3

Flood peak discharge estimates from frictional and rainfall-runoff discharge estimates

Location	DWAF extended gauging station estimates (Venter *pers. comm.*) (mΔ/s)	Smithers *et al.* (2000)	Van Bladeren & Van der Spuy (2000)	Frictional discharge (mΔ/s)
Section 4				3113
Section 10				3900
Section 15	4000		3700	5522
Section 21				6789
Section 25				6950
Section 29 (Lower Sabie weir)	8000	5314		7453

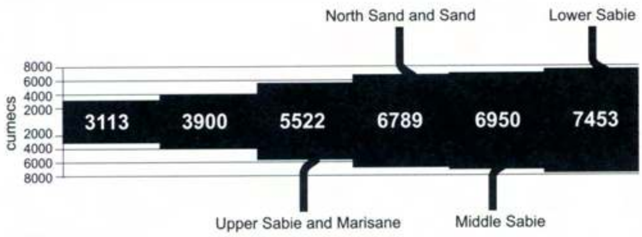

Fig. 4. Peak discharge change along the Sabie River in the Kruger National Park including inferred sub-catchment tributary inputs.

rivers (Figs. 1 & 4), this compares well with the DWAF flow estimate for the Sand River of 3700 m^3/s. Peak flow at Kruger weir upstream of section 15 was estimated by DWAF at 4000 m^3/s, compared with 5500 m^3/s from the resistance method. The smaller Nwatimwambu, the Nwatimhiri and the Lubleluble tributaries draining part of the Lower Sabie sub-catchment generate a much smaller increment to the flow resulting in a resistance estimate flow of 7450 m^3/s at section 29 close to Lower Sabie gauging weir. This compares well with the DWAF peak flow estimate of 8000 m^3/s (Table 3). A plot of peak discharge against catchment area (Fig. 5) reveals a strong relationship between the two variables. Comparison with ACRU rainfall-derived flood estimates reveal a considerable discrepancy, with the frictional results overestimating by 40–50 % compared to the rainfall-derived figures. This may not be too surprising as the ACRU model outputs are only claimed as correct to the right order of magnitude (Smithers *et al.* 2000).

The ACRU hydrologic model, used to generate daily flow data for the Sabie River by Birkhead *et al.* (2000), was utilised to generate a flood frequency time-series based on 60 years of record with which to compare the peak flow estimates. The ACRU data generated for segment 12 (equivalent to section 4) of the river was used in the comparison. It is clear from the annual maximum flow data (Fig. 6) that the flood peak of 3113 m^3/s exceeds all previous maximum flows simulated since 1932. It is to be expected that the instantaneous flood peak would be higher than the daily average flow given that the flow peak probably only lasted a matter of hours. However the significant difference between the peak value and the highest daily average flow would certainly indicate that the February flood has a return period well in excess of 60-year record. This accords with

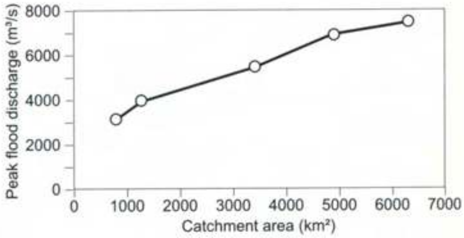

Fig. 5. Peak discharge-catchment area relationship for the February flood on the Sabie River.

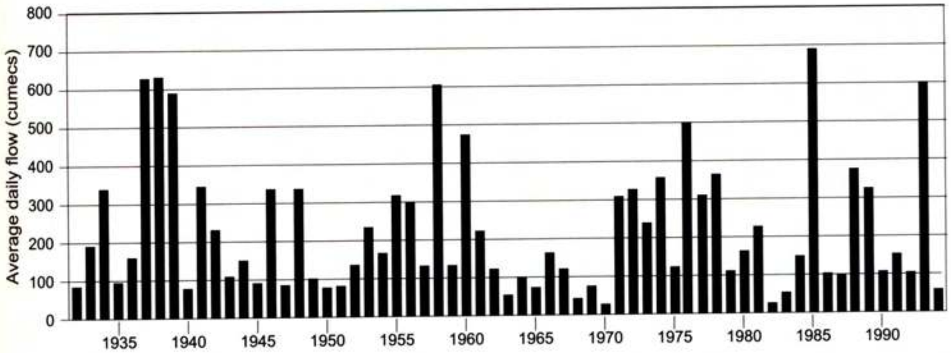

Fig. 6. Simulated peak annual flows for the Sabie River at section 4 based on the ACRU hydrologic model.

the results of Smithers *et al*. (2000) who calculated the flood return period as being greater than 200 years.

Conclusions

It has been possible to estimate the peak flood discharge along the Sabie River in February 200. The data used were measured water suface slope as derived from strandline evidence, archival cross-section data (Van Niekerk & Heritage 1993) and assumed channel resistance characteristics based on previous work on bedrock influenced channels by Heritage *et al*. (1997), Broadhurst *et al*. (1997), Birkhead *et al*. (2000).

The results of the resistance study indicate that the peak discharge increases in the downstream direction from around 3000 m^3/s at Kruger Gate to 7000 m^3/s at Lower Sabie due to significant inputs from the Maritsane and Sand sub-catchments. The smaller Nwatimwambu, the Nwatimhiri and the Lubleluble tributaries draining part the Lower Sabie sub-catchment generate a much smaller increment to the flow. The Sabie River flood of February 2000 appears to be the largest experienced in the last 60 years based on the simulated ACRU daily flow data. This is corroborated by rangers records for the river in the Kruger National Park which mention a large flood in the 1920s that also overtopped the macro-channel bank in places, a situation that has not been reported subsequently.

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References

BARNES, H.H. 1967. Roughness characteristics of natural channels. *U.S. Geological Survey Water Supply* Paper 1849: 1–9.

BIRKHEAD, A.L., G.L. HERITAGE, C.S. JAMES, K.H. ROGERS, N.W. QUINN & A.W. VAN NIEKERK. 2000. *Geomorphological change models for the Sabie River in the Kruger National Park*. Pretoria: Water Research Commission. (Water Research Commission Report 782/1/00).

BROADHURST, L.J., G.L. HERITAGE, A.W. VAN NIEKERK, C.S. JAMES & K.H. ROGERS. 1997. *Translating discharge into local hydraulic conditions on the Sabie River: an assessment of channel flow resistance.* Pretoria: Water Research Commission. (Water Research Commission Report 474/2/97).

CHESHIRE, P. 1994. Geology and geomorphology of the Sabie River, Kruger National Park, and its catchment area. Centre for Water in the Environment. Internal report; no. 1/94. University of the Witwatersrand, Johannesburg.

HERITAGE, G.L., A.W. VAN NIEKERK, B.P. MOON, L.J. BROADHURST, K.H. ROGERS & C.S. JAMES. 1997. *The geomorphological response to changing flow regime of the Sabie and Letaba River systems*. Pretoria: Water Research Commission. (Water Research Commission Report 376/1/97.)

SCHULZE, R. 1989. *ACRU: Background, concepts and theory*. Pretoria: Water Research Commission. (Water Research Commission Report 154/1/89.)

SMITHERS, J.C., R.E. SCHULZE, A. PIKE & G.P.W. JEWITT (*in press*). A hydrological perspective of the February 2000 floods: a case study of the Sabie River catchment. *Water SA*.

VAN BLADEREN, D. & D. VAN DER SPUY (*in press*). The February 2000 flood—the worst in living memory? *In*: *Southern African floods of February 2000*. Pretoria: Department of Civil Engineering, University of Pretoria.

VAN NIEKERK, A.W. & G.L. HERITAGE. 1993. Geomorphology of the Sabie River: overview and classification, Centre for Water in the Environment. Internal report; no. 2/93. University of the Witwatersrand, Johannesburg.

VAN NIEKERK, A.W. G.L. HERITAGE & B.P. MOON. 1995. River classification for management: the geomorphology of the Sabie River in the eastern Transvaal. *South African Geographical Journal* 7(2): 68–76.