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

G.L. Heritage, B.P. Moon and A.R.G. Large

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Accurate estimates of the magnitude of the floods that affected southern Africa in February 2000 are difficult to obtain since floodwaters damaged the majority of gauging stations on affected rivers. It is possible to estimate the peak discharge experienced in the Letaba River in the Kruger National Park by simulating the hydraulic and geometric characteristics of the peak flow and relating these to the roughness of the channel. Peak water surface slope data were determined from debris and mudline measurements at breaks in channel type. These data are combined with published high-flow channel resistance coefficients for different channel types to generate peak flow estimates for eleven different cross-sections, located between tributaries to allow for sub-catchment contributions to be estimated. In February 2000 flow peaked at approximately 4000 m^3/s near to Black Heron Dam (in the west of the park), and increased to approximately 7000m^3/s just upstream of the confluence with the Olifants River. Comparison with gauge records indicates that the February 2000 peak was higher than any flow during the preceeding four decades.

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

G.L. Heritage, Geography Department, University of Salford, Manchester M5 4WT, England; B.P. Moon, Centre for Water in the Environment, University of the Witwatersrand, Private Bag 3, WITS 2050, Republic of South Africa; A.R.G. Large, Department of Geography, Daysh Building, University of Newcastle, Newcastle upon Tyne, England.

Introduction

Tropical depression and cyclone activity over southern Africa during February and March 2000 produced unprecedented rainfall across the eastern subcontinent. Many rivers, including the Letaba River, rose to peak discharges in early February, but these exceptional discharges were not gauged since many monitoring stations were damaged by floodwaters.

Along the Letaba River in the Kruger National Park flow depths of the order of 10 m were recorded in the incised macrochannel. The magnitude of such ungauged flows may be estimated using information from previous work on the geomorphology and hydraulics of Kruger National Park rivers (Heritage *et al.* 1997; Broadhurst *et al.* 1997; Birkhead *et al.* 2000). Data on flow depths at previously surveyed channel cross-sections, determined from flood debris and mudline evidence, are linked to the resistance characteristics of the channel to generate a discharge estimate. Peak discharge for the Sabie River for the same period has been estimated in a similar manner (Heritage *et al.* 2001). In this paper the same methodology is used to estimate the flood peak for the Letaba River within the Kruger National Park, and the flows in tributaries are shown to contribute to the peak flood. The flood estimates are also compared with the historical daily average flow record derived from gauged data.

Catchment characteristics

Situated in the Northern Province, the 13400 km² Letaba catchment (Fig. 1) comprises a mountainous area to the west and an

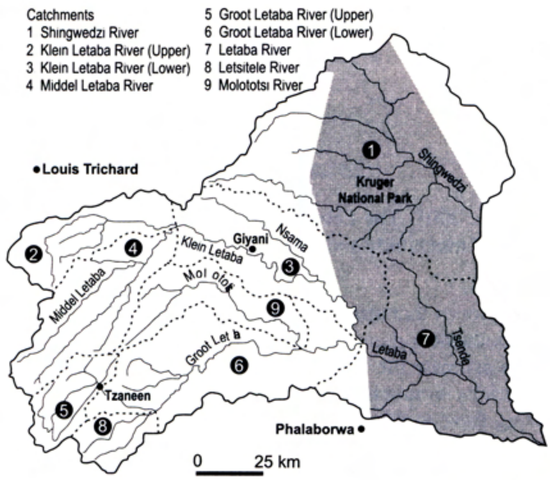

Fig.1. The Letaba River catchment, Northern Province, South Africa.

area of low relief (the Lowveld), in which the Kruger National Park is situated, in the east. The major tributaries are the Molotsi and Klein Letaba Rivers, and within the park the principal tributaries are the Tsende and the Shipikana. The Letaba joins the Olifants River a few kilometres west of the Mozambique border. The catchment has been classified as semi-arid (Steffen Robertson & Kirsten 1990); rainfall, which is concentrated in the summer months, varies between 500–1800 mm in the mountainous west, to 450–700 mm in the east. Evaporation potential ranges from 1400 mm in the west to 1900 mm in the east. Flow in the Letaba during the drought of the 1990s was seasonal, and there was surface flow in the lower reaches only in response to significant storm events in the catchment.

Approximately three quarters of the Letaba catchment is underlain by granite and gneiss, but in the east volcanics and rocks of the Karoo Sequence form the geological template. The region has been subject to tectonic uplift (10 Ka–100 Ka) and the Letaba River has incised forming a bedrock-bounded macro-channel (Van Niekerk *et al.* 1995). The distribution of sediment varies in the macro-channel giving rise to different

Table 1

Geomorphic character of the Letaba River in the Kruger National Park, South Africa

Channel type	Geomorphic character
Alluvial anastomosing	Wide sand sheet covering the macro-channel floor dissected by two or three deeper channels. Channels divide and rejoin over distances in excess of the width of the macro-channel.
Mixed anastomosing	Wider macro-channel than the average for the river. Sedimentary and bedrock features present within a highly tortuous multiple distributary network.
Alluvial braided	Multi-channel network of alluvial distributaries that dissect the sand sheet macro-channel infill. The low-flow channels split and rejoin over distances that approximate the distributary width. Planform change is rapid.
Mixed pool-rapid	Bedrock exposures generate a series of bedrock rapids and associated upstream sub parallel pools. Sedimentation across much of the macro-channel in these areas has formed extensive sand sheets dissected by higher flow alluvial distributaries.
Alluvial single thread	Low flows are conveyed along a single thread channel, often close to one side of the macro-channel but alternating from side to side bearing no relation to the macro-channel planform.

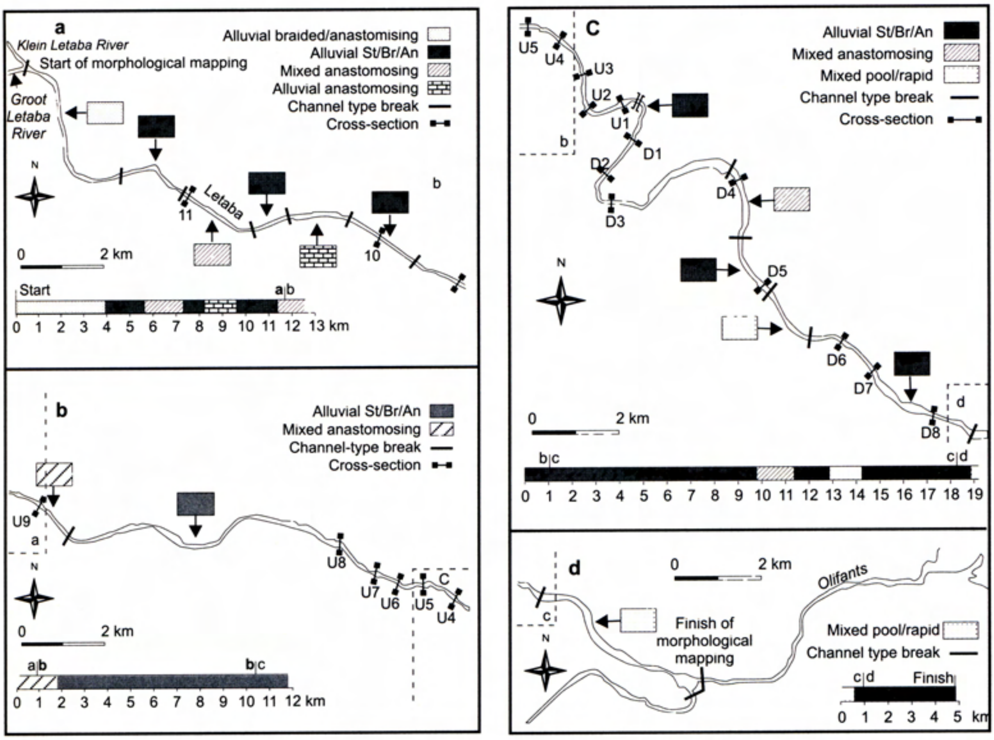

Fig. 2. Geomorphic variation along the Letaba River in the Kruger National Park (after Moon & Heritage 2001). (Surveyed cross-sections referred to in Table 3 are numbered U1-11 and D1- 8 upstream and downstream respectively of the bridge to the north of Letaba rest camp).

morphological units along the river. Such morphological units, in different associations, generate a variety of channel types (Table 1) and these have been mapped for the section of the Letaba within the Kruger National Park (Fig. 2) (Heritage *et al.* 1997; Moon & Heritage 2001). Each channel type (Table 1) is characterised according to its morphology and vegetative nature.

Alluvial channel types dominate the river in the Kruger National Park, particularly near Letaba rest camp (Fig. 2). Bedrock influence is pronounced downstream of Shimuweni dam and close to the confluence with the Olifants River. Large terrace features composed of fine alluvial material are common at the sides of the macro-channel along much of the river.

Discharge estimation based on channel characteristics

Peak discharge in February 2000 along the Letaba River may be estimated using a method similar to that applied to the equivalent flood on the Sabie River (Heritage *et al.* 2001). The requirements for such determinations are frictional characteristics of the different channel types, data pertaining to water surface slope and flood stage at cross-sections of known form.

The frictional resistances of the five different channel types have been determined from work on the Sabie River, a river in the same geomorphological setting and with channel characteristics equivalent to those found on the Letaba River. The work of Heritage *et al.*

Table 2

Channel roughness values quantified for the channel types of the Sabie River in the Kruger National Park based on measured flow level and slope data up to a maximum discharge of 2259 m³/s (after Heritage et al. *1997, Broadhurst* et al. *1997, Birkhead* et al. *2000)*

Channel Type	Discharge (m^3/s)	Manning's Resistance Coefficient	Darcy-Weisbach Resistance Coefficient	Source
Braided	660	0.043	0.11	Broadhurst *et al.* (1997)
	1705	0.0597	0.155	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/Alluvial	1000	0.082	0.37	Broadhurst *et al.* (1997)
Anastomosing	2259	0.0395	0.125	Birkhead *et al.* (2000)
Bedrock	660	0.043	0.015	Broadhurst *et al.* (1997)
anastomosing	1705	0.0901	0.456	Birkhead *et al.* (2000)

(1997), Broadhurst *et al.* (1977) and Birkhead *et al.* (2000) provides resistance characteristics (Table 2) calculated from flows in the highest previously recorded flood using the Colebrook-White equation in the form

Channel flow resistance,

$$f = 8gRS/V^2 \quad \ldots\ldots\ldots(1)$$

where g is gravitational acceleration, R is the hydraulic radius, S is the energy slope assumed equivalent to the water surface slope as defined by the flood strandline, and V is flow velocity.

On the Letaba River water surface slope was determined from strandline heights recorded at breaks of channel type using a differential GPS survey system. Flood stage was recorded at 11 cross-sections previously surveyed within specific channel types (Fig. 2). Using the resistance coefficient for the specific channel type at each of the 11 cross-sections the peak average velocity (V) at these sections was estimated using the Colebrook-White equation in the form

$$V = \sqrt{8gRS/f} \quad \ldots\ldots\ldots\ldots\ldots(2)$$

The peak velocity can be used to determine peak discharge (Q) using the equation

$$Q = VA \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

where A is the cross sectional area of flow.

In all channel types peak flow levels were close to the top of the macro-channel and hence the use of the previous highest flow resistance value in the equation represents the best estimate of channel resistance for the peak flow. The assumption is that there has been no reduction in channel roughness between the previous highest flow and the February peak. Such an assumption is acceptable given the asymptotic nature of frictional resistance reduction demonstrated by the different channel types at very high flows (Broadhurst *et al.* 1997). In addition, no major new frictional element was introduced at any of the cross-sections at the peak discharge as the flow remained in the channel. The hydraulic and geometric data used to

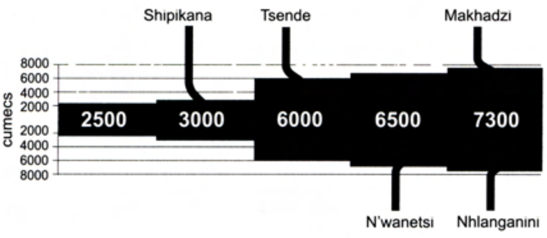

Fig. 3: Peak discharge change along the Letaba River including inferred sub-catchment inputs.

Table 3
Channel geometric and hydraulic properties for the February flood peak on the Letaba River at selected cross-sections

Section Number	Channel Area (m^2)	Hydraulic Radius (m)	Flood Velocity (m/s)	Flood Slope	Discharge (m^3/s)	Contributing tributary junctions
U11	753	4.211	4.674	0.0076	3520	
U9	816	4.254	4.697	0.0076	3832	
U8	1491	6.096	3.886	0.00363	5795	Shipikana
U6	2736	7.776	2.099	0.00083	5742	
U3	1948	7.804	2.128	0.00085	4145	Tsende
U2	2534	8.553	2.227	0.00085	5645	
U1	2904	7.260	2.052	0.00085	5961	Nwanetsi
D2	2924	9.316	2.325	0.00085	6797	
D4	2207	6.535	3.419	0.00285	7548	Makhadzi & Nhlanganini
D5	2121	6.375	3.490	0.0028	7402	
D7	2064	5.416	3.268	0.00289	6762	

calculate the peak discharge along the river is summarised in Table 3, together with the peak flow estimates.

It is clear from the figures (Table 3, Fig. 3) that peak flood discharge increases in a downstream direction with significant input from the Tsende subcatchment and lesser contributions from the Shipikana, Nwanetsi, Makhadzi and Nhlanganini tributaries.

The results have been validated against flood peak estimates at Letaba Ranch (to the west of the park) (3000 m^3/s) and close to cross-section U11 (3100 m^3/s) and the extrapolation of rating curves for Engelhard Dam (4500 m^3/s) close to cross-section D4 (6100 m^3/s) provided by the Department of Water Affairs and Forestry. The indication is that the method could be inaccurate by up to 30 percent when compared with these estimates. It should be borne in mind, however, that the dam estimates also rely on extrapolated rating curves based on local channel characteristics. Further, Engelhard Dam was damaged by floodwaters, reducing the peak flow level and thereby generating an inaccurate (low) peak flow estimate. Given the errors generally associated with the estimation of extreme floods it would appear that there is sound support for the method. In addition, the indication is that the representative reach (channel type) resistance values reported by Broadhurst *et al.* (1997) and Birkhead *et al.* (2000) may be transferred to similar channel types on other ungauged rivers in the region.

Historic gauge data from Letaba Ranch have been used to generate a flood frequency time-series based on 35 years of record (Fig. 4). Despite the difficulty in comparing daily average flows with the peak flow estimate, it is probable that the February flood is the highest recorded on the river, an inference similar to that drawn for the coincident flood that affected the Sabie River to the south (Heritage *et al.* 2001) where a 62-year simulated daily flow record revealed that the flood was the largest on record.

Conclusions

A method based on channel type frictional character, strandline measurements and stage determinations at surveyed profiles has been shown to be useful in determining peak flows in situations where gauge data are unavailable. The results show that the peak flood along the Letaba River in February 2000 ranged from approximately 3000 m^3/s

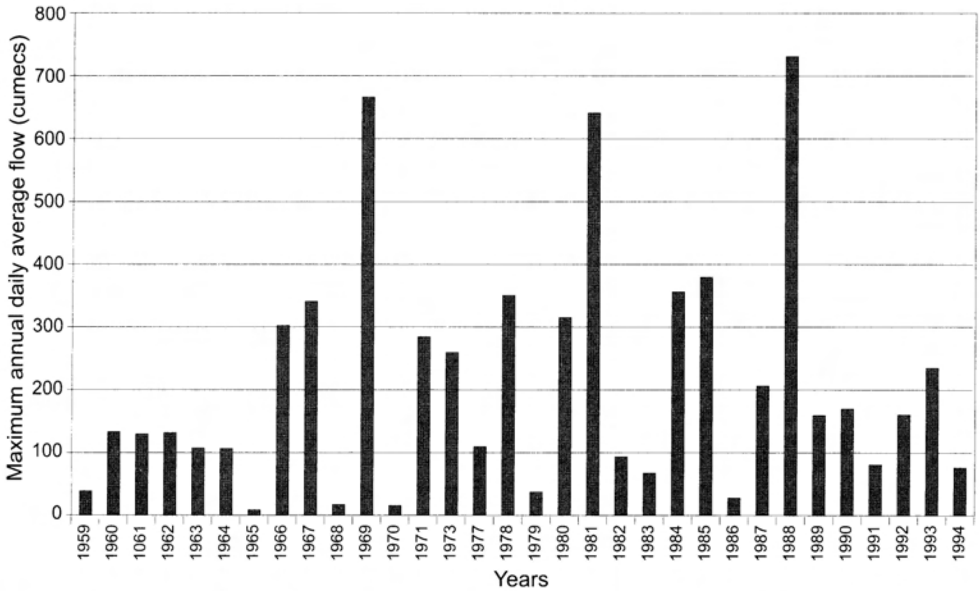

Fig. 4. Daily average peak annual flows for the Letaba River based on gauge data recorded at Letaba Ranch.

at the western boundary of the Kruger National Park (Letaba Ranch) to about 7000 m³/s near to the confluence with the Olifants River. It has also been possible to determine the contribution to the flood of the discharge from the different tributaries. The February 2000 flood appears to be the greatest experienced in the last 35 years.

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