Drought conditions and sediment transport in the Sabie River

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Drought conditions in the Sabie catchment in the eastern Transvaal (now called Mpumalanga), South Africa, has had an observable effect on the sediment dynamics of the river. Sediment production within the catchment is largely unaffected by a reduction in the frequency and magnitude of rainfall events, although the rate of translocation of the weathered material from the catchment into the river channel is noticeably altered. The infrequent storm events during drought conditions generate a greater sediment input to the river from the catchment than a similar-magnitude event under average conditions. This sediment is also less likely to be transported through the system due to the reduced frequency of intermediate flows which act to rework in-channel sediment accumulations. Thus, significant accumulations of alluvial material are likely to form at specific locations, particularly where the local sediment transport capacity of the channel is low. Studies of the transport dynamics of the Sabie River, under both normal and drought conditions, reveal that there are major depositional zones between Kruger Weir and Skukuza, and in the area around Lower Sabie. The 1992 drought resulted in a significant build-up of sediment in these areas, with a consequent reduction in geomorphic diversity. This sediment is becoming stabilised due to the lower and less variable flows of the recent drought and associated vegetative colonisation. An increase in the magnitude and frequency of high and intermediate flows is needed to mobilise this accumulated sediment and to prevent its stabilisation by riparian vegetation.

Key words: Sabie River, sediment transport, drought.

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Introduction

The Sabie River drains an area of 7 096 km^2, its headwaters rise on the eastern slopes of the Mauch Berg. It flows through three main geomorphic zones, the eastern Transvaal highlands to the west, the Lowveld zone through the centre of the catchment and the Lebombo zone towards the east (Fig. 1). The natural mean annual runoff for the catchment has been estimated at 762 million m^3/annum. Most of the runoff is generated in the eastern Transvaal highlands (up to 2000 mm/annum) with only 450-650 mm/annum falling on the lowveld region of the Kruger National Park. Three main tributaries enter the Sabie River, namely the Sand, the Mac Mac and the Marite (Fig. 1). In recent geological time (< 100 ka) the Sabie River experienced an erosional phase (Partridge & Maud 1987), creating an incised channel heavily influenced by bedrock outcrops.

The flow regime of the Sabie River is characteristic of semiarid watercourses; extremes of discharge occur with low winter baseflows of 1 or 2 cumecs and occasional high summer flood flows exceeding 100 cumecs. During average years several

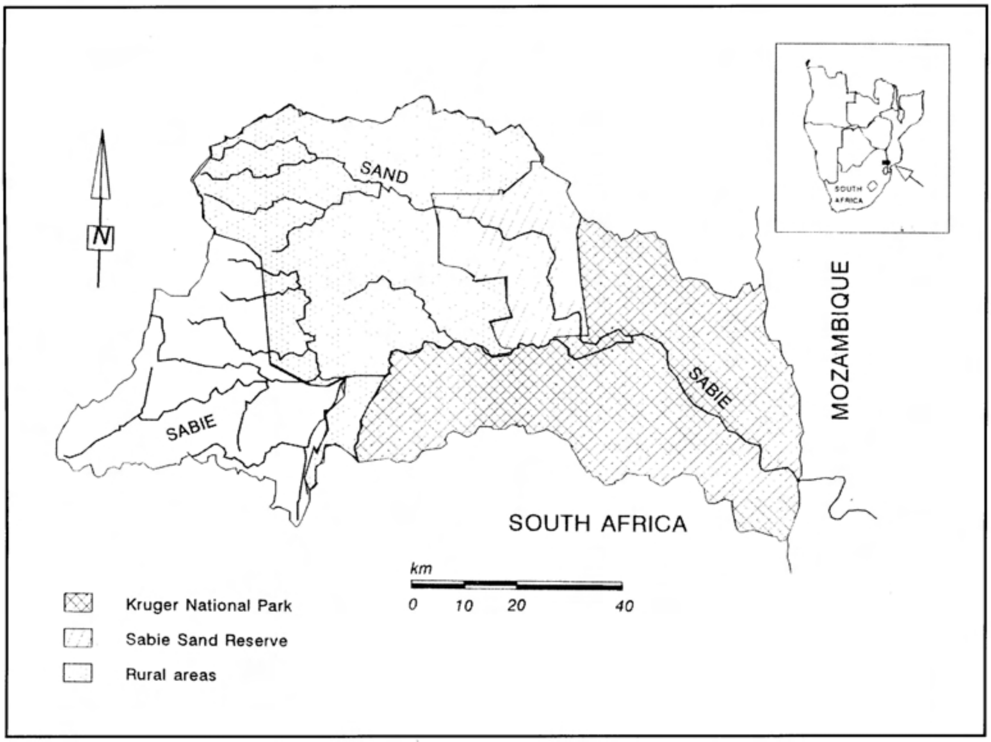

Fig. 1. Geography of the Sabie River catchment.

mid-range flows of the order of 20-40 cumecs occur. During periods of drought, however, these flows are absent from the discharge record. The alternation between wetter and drier conditions has been linked to climatic cyclicity by Tyson & Dyer (1978) who identified a quasi 20-year oscillation in the rainfall records for northern and eastern South Africa.

Sediment transport rates for the Sabie River are highly dependant on the antecedent conditions within the catchment, as such periods of drought have a marked effect. The degree of transportation and sedimentation of material is controlled by a variety of inter-linked factors. Sediment production in the catchment and its translocation into the main channel defines the level of new inputs. Local channel sediment transport capacity and in-stream storage of sediment then define the pattern of deposition within the Sabie River and controls the total throughput of material.

Drought conditions affect many of the controlling factors listed above as patterns of sediment generation and translocation are modified by the reduction in precipitation volume and frequency. This in turn alters the flow regime of the river directly affecting the sediment transport dynamics and sediment stabilisation by vegetative colonisation.

Factors determining sediment production and transport

Sediment transport in rivers has been shown to be episodic in nature, with a combination of factors interacting to control the pattern of sediment distribution and overall transport rate for a given river (Table 1).

No direct relationship exists between the transport rate and the controlling factors. A storm of one magnitude may transport large volumes of sediment as suspended and bedload material, however a subsequent storm of the same magnitude would transport less material as the status of the other controlling factors has been modified by the first storm (Hayward 1980; Van Sickle & Beschta 1983). Sediment transport is also often supply controlled, local inputs from bank collapse or disruption of an in-channel storage area may lead to release and movement of previously stationary material downstream (Meigh 1987).

Table 1
Factors affecting sediment transport

Discharge regime	Flow volumes Flow frequency Flow duration
Sediment supply	Land degradation rates Sediment translocation In-channel storage
Channel competence	Channel roughness Channel shape Channel slope

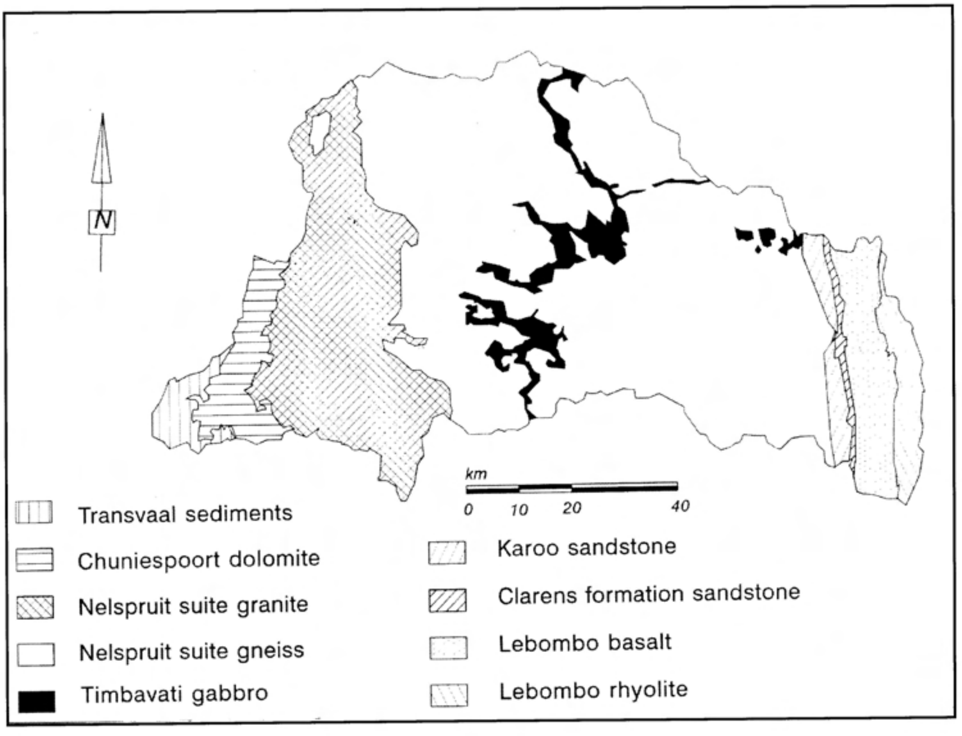

Fig. 2. The geology of the Sabie River catchment.

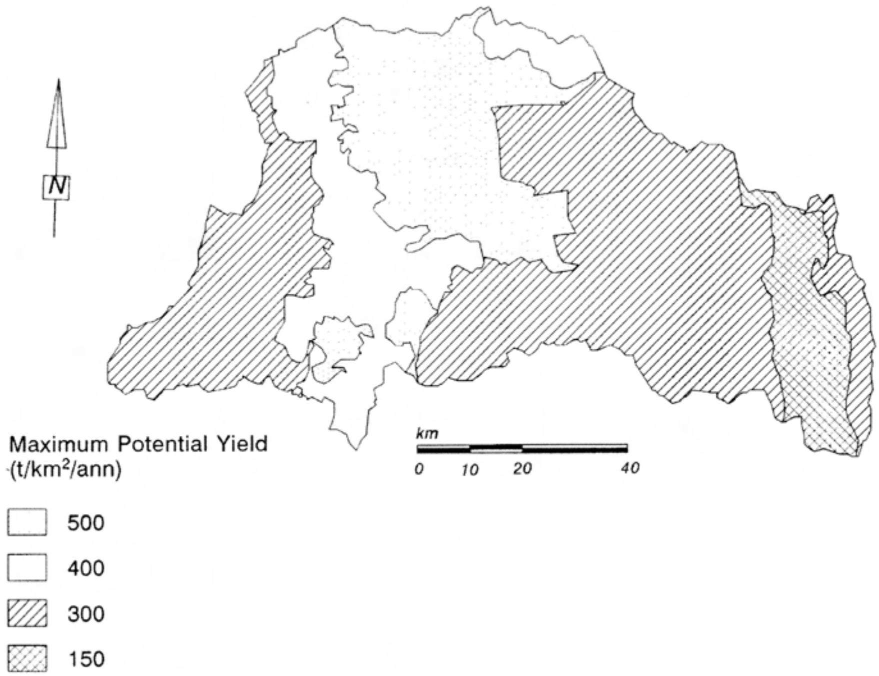

Fig. 3. Sediment production in the Sabie River catchment.

The supply of sediment from the catchment varies spatially and temporally. External inputs will depend on the degree of weathering and the frequency of overland and gully flow to translocate the material to the river. Once it has entered the channel it is generally transported, in a sporadic manner, slowly downstream by a number of separate flow events of varying magnitude. This is achieved in the Sabie River via a series of storage zones. Meade *et al* (1981) demonstrated similar patterns of sediment movement between bars and lenses on the East Fork River, Wyoming.

Sediment supply to the Sabie River

The Sabie River catchment is underlain by a number of bedrock types ranging from the dolomites of the eastern Transvaal highlands through granites and gneisses in the Lowveld zone to basalts in the Lebombo zone (Fig. 2).

Sediment yields have been estimated for the Sabie catchment by Rooseboom *et al.* (1992) and this has been refined using GIS techniques to incorporate the sediment supply factors listed in Table 1 by Van Niekerk & Heritage (1994). Figure 3 illustrates the spatial distribution of sediment generated within the catchment. It is clear that very little sediment production occurs in the eastern Transvaal highlands, most is concentrated in the Lowveld zone in the centre of the catchment, particularly in the areas of the former bantustans created under the old Apartheid regime. Much of the sediment generated is coarse sand and fine

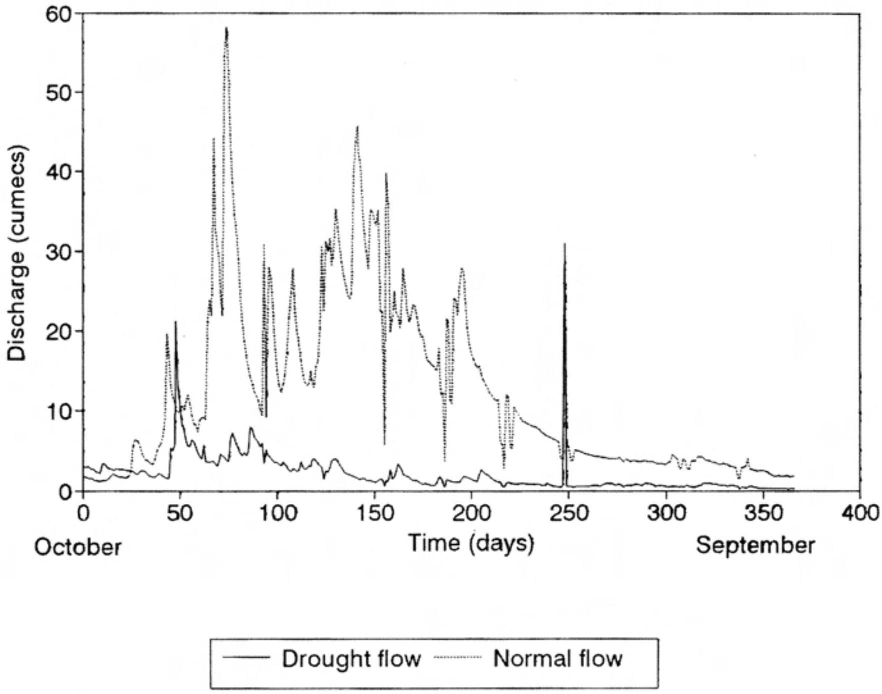

Fig. 4. Drought and average flow frequencies for the Sabie River for the water years October 1991 - September 1992 and October 1989 - September 1990 respectively.

gravel as a result of the weathering of the tonalitic gneiss.

The 1992 drought and its effect on the Sabie River flow regime

The Sabie River flow regime is characterised by extreme discharge events; even during drought periods occasional floods occur. Figure 4 illustrates the mean daily flows experienced during the 1992 drought and 1990, a year with more average runoff. Flow magnitudes and the frequency of mid and high range discharges are significantly reduced for the drought year with only two peaks above 20 cumecs as compared to nearly 20 for the more normal year. Fifty percent of the drought flows are below 1.5 cumecs, in the average year this figure increased to 8 cumecs (Fig. 5). The magnitude of the 1992 drought appears to be the result of a prolonged El Niño/Southern Oscillation event and has resulted in a 38% reduction in expected rainfall for the Lowveld in the eastern part of South Africa over the last 20 years (Mason 1995).

To summarise, much of the sediment supplied to the Sabie River is produced in the Lowveld zone particularly in the areas of the former bantustans, where it can accumulate until a local rainstorm event translocates it into the river. The frequency of occurrence of such an event decreases markedly during drought periods.

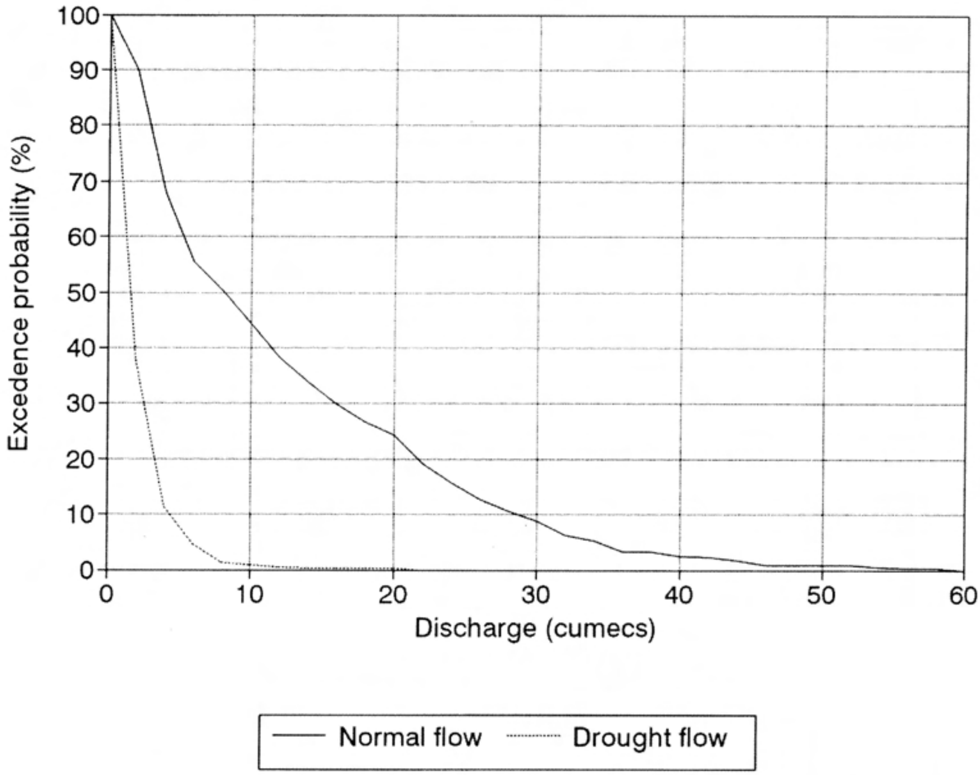

Fig. 5. Drought and average flow exceedence probability plots for the Sabie River, based on the water years October 1991 - September 1992 and October 1989 - September 1990 respectively.

Consequently, heavy storms under normal conditions will translocate less eroded sediment from the catchment to the river than would an equivalent storm under drought conditions.

Consequences for sediment transport in the Sabie River as a result of drought conditions

Prolonged drought in the catchment has had many consequences for the sediment transport dynamics and geomorphology of the Sabie River. The combination of transport control variables is altered significantly from those of the average runoff regime. These can be summarised as follows:

Average climate

Weathering processes are likely to be active in the catchment, in particular sediment production will be high in the centre of the catchment. Frequent rains maintain a high baseflow in the Sabie River. Storm events can occur throughout the whole catchment

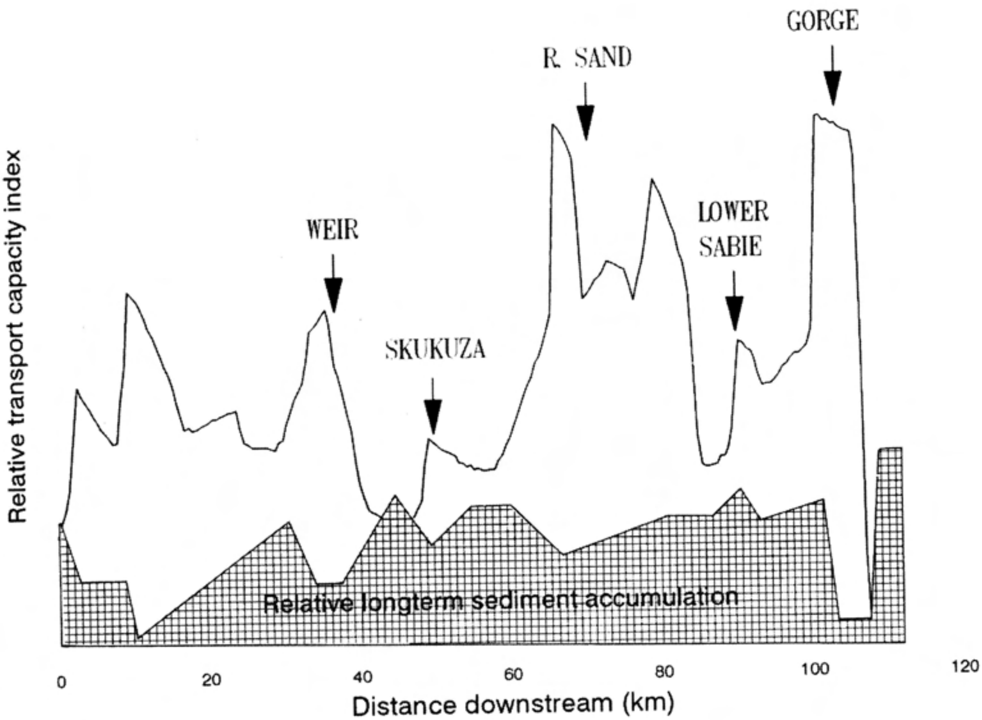

Fig. 6. Comparison of sediment accumulation zones and sediment transport capacity on the Sabie River. (After Heritage & Van Niekerk 1994).

hence much of the sediment generated is translocated into the main-channel as a series of small pulses. There is little chance of significant accumulations of sediment building up in the catchment. In-channel sediment transport will redistribute the translocated sediment creating zones of alluvial sedimentation and bedrock transport zones. Intermediate flows will continue to transport material downstream reworking the deposits of larger floods. Vegetative stabilisation of these deposits is uncommon.

Drought climate

Weathering processes are active in the catchment, in particular sediment production will be high in the centre of the catchment. The baseflow in the Sabie River will, however, be reduced, storm events can occur throughout the whole catchment but are much rarer, thus most of the sediment generated in the catchment remains untranslocated until a single isolated storm event moves large quantities of material into the Sabie River. In-channel sediment transport will move the sediment downstream depositing much of it in the major zones of alluvial sedimentation. Intermediate flows are largely absent during the drought thus there is only minimal reworking of the deposits from the rarer large flood events. Vegetative stabilisation of deposited sediment is common.

Physical changes to the Sabie River as a result of the 1992 drought

Field investigation of sedimentation in the Sabie River has revealed that there was an increase in the size and number of in-channel bar deposits between 1940 and the mid 1960s, and 1975 to 1985, with an erosional phase in between, (Van Niekerk & Heritage 1993). This is in agreement with the findings of Vogt (1992). In both cases in-channel bar growth corresponds to drier periods, and erosion to the wetter periods in the climatic cycle defined by Tyson & Dyer (1978). In particular the severe recent drought has resulted in a significant build-up of in-channel sediments along many parts of the river. Such a process has been aided by vegetative stabilisation as reeds colonise sand bars which have remained static under the lower, more stable, drought flow regime. Open sand bars are now much rarer in the Sabie River than before the drought began.

Zones of sediment accumulation along the Sabie River have been identified from increased in-channel bar deposition. These features are now much more common in the reach between Kruger Weir and Skukuza and downstream of the Sand River confluence. This has been shown to correlate with areas of low sediment transport capacity in the river (Heritage and van Niekerk 1994). Figure 6 details the calculated sediment transport capacity index based on channel geometry, frictional characteristics and sediment types for 22 sites along the Sabie River in the Kruger National Park. No figures are attached to the index as the transport equations used in the study have not been calibrated against measured rates of sediment movement. It is argued, however, that the equations incorporate all of the factors defining the dynamics of sediment transport and hence will reflect the relative changes expected along the river.

Indirect evidence to support this comes from estimates of stored volumes of sediment within the river. Mechanical probing techniques were used at the 22 study sites within the Kruger National Park to generate approximate average sediment depths across the width of the incised channel (Fig. 6). Such accumulations represent long-term storage areas and correspond well with the predicted zones of low sediment transport capacity.

Field evidence also suggests that within these zones certain channel types are more susceptible to sedimentation than others. Steep bedrock anastomosing areas as defined by Van Niekerk & Heritage (1993) have shown no discernable change in sedimentation patterns due to the drought and remain largely sediment free. In contrast, pool-rapid areas have shown a build-up of finer sediments as bars upstream of bedrock rapids and these are becoming vegetated.

The extended recent drought has led to changes in the physical nature of the Sabie River. Vulnerable channel types in zones prone to deposition have become more alluvial, whereas others, particularly in areas where the channel sediment transport capacity is high, have not altered significantly. It is clear, however, that sedimentation is more evident in times of prolonged drought and that these areas are becoming stabilised by colonising vegetation. Reversal of this trend by erosion in wetter periods is thus made more difficult.

Acknowledgments

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References

HAYWARD, J. A. 1980. *Hydrology and stream sediments in a mountain catchment.* Tussock Grasslands and Mountain Lands Institute, Lincoln College, Canterbury, New Zealand. (Special Publication 17).

HERITAGE, G. L. AND A. W. VAN NIEKERK. 1994. Morphological response of the Sabie River to changing flow and sediment regimes. Pp. 389-403. *In: Proc. 50 years of Water Engineering in South Africa.* Johannesburg: SAICE.

MASON, S. J. 1995 (*in press*). Climatic change over the Lowveld of South Africa. *Climatic Change*.

MEADE, R. H., W. W. EMMETT AND R. M. MYRICK. 1981. Movement and storage of bed material during 1979 in East Fork River, Wyoming, USA. *In:* Erosion and sediment transport in Pacific Rim Steeplands. *Proceedings International Association Hydrological Scientists. Christchurch Symposium, IAHS Publication* No: 132: 225-235.

MEIGH, J. C. 1987. *Transport of bed material in a gravel-bed river.* PhD thesis. University of East Anglia, Norwich, UK.

PARTRIDGE, T. C. AND R. R. MAUD. 1987. Geomorphic evolution of Southern Africa since the Mesozoic. *South African Journal of Geology* 90 (2): 179-208.

ROOSEBOOM, A., E. VERSTER, H. L.ZIETSMAN AND H.H. LOTRIET. 1992. The development of a new sediment yield map of southern Africa. *Water Research Commission Report* No. 297/2/92, Pretoria, South Africa.

TYSON, P. D. AND T. G. J. DYER. 1978. The predicted above-normal rainfall of the seventies and the likelihood of droughts in the eighties in South Africa. *South African Journal of Science* 74: 372-377

VAN NIEKERK, A. W. AND G. L. HERITAGE. 1994. The use of GIS techniques to evaluate sedimentation patterns in a bedrock controlled channel in a semiarid region. Pp. 257-271. *In:* KIRBY, C. AND W.R. WHITE (eds.). *Proceedings of the International Conference on Integrated River Basin Development.* Chichester, England: John Wiley

VAN SICKLE, J. AND R. L. BESCHTA. 1983. Supply based models of suspended sediment transport in streams. *Water Resources Research* 19(3): 768-778.

VOGT, I. 1992. *Short-Term Geomorphological Changes in the Sabie and Letaba Rivers in the Kruger National Park.* MSc thesis, University of the Witwatersrand, Johannesburg.