The contemporary geomorphology of the Sabie River in the Kruger National Park

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The Sabie River in the Kruger National Park has been described as the most pristine in South Africa. It has remained largely free of direct alteration along its 110 km length within the reserve and as such displays a high geomorphic diversity. This physical variability supports a great diversity of flora and fauna including a number of species endemic to the river. The diversity in fluvial form is the result of a high degree of bedrock influence coupled with a rapidly changing energy regime. Steeper bedrock-influenced areas alternate with more gently sloping alluvial segments to create a series of channel types ranging from bedrock anastomosing through to alluvial single thread and braided sections. Each channel type is part of a continuum that relates to the degree of alluviation of the river on the bedrock template. Descriptions of the characteristic channel types associated with the Sabie River, together with associated morphologic units are given together with the areal extent of the changing morphology in the Kruger National Park. Each morphologic unit is characterised by size, shape, sedimentology and flow influence. Recent research into the degree and direction of morphologic change in the Sabie River is also summarised in the light of possible catchment management.

Key words: Sabie River, geomorphology, morphological units, channel type, channel change.

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Introduction

The Sabie River in the Kruger National Park has been described as the most pristine in South Africa (Moon *et al.* 1997). It has remained largely free of direct alteration along its 110 km length within the reserve; several small capacity dams supplying local water for wildlife and minor abstractions for tourist use are the only significant channel and flow modifications. The geomorphologically varied Sabie River supports a great diversity of biota including a number of species endemic to the river.

The geomorphology and nature of changes to the physical state of any river, including the Sabie, result from complex interactions of a number of control factors that operate on scales ranging from the whole catchment, down to the scale of individual boulder outcrops in the river bed. These controls include climate, geology, water discharge and sediment influx (both in the main channel and from tributaries), the bed and bank characteristics, the development of vegetation along the rivers, and the effects of human interference (Morisawa 1985). A five-year project investigating channel form and channel change on both the Sabie and Letaba rivers has been completed recently (Heritage *et al.* 1997). In this paper, the principal findings of the research are presented in order to demonstrate the geomorphological dynamics of the Sabie River.

An understanding of the present condition of the river and its relationship with the controlling catchment variables is pertinent. There are, at present, increased demands on limited water resources and changes in land usage which are leading to a modification of the

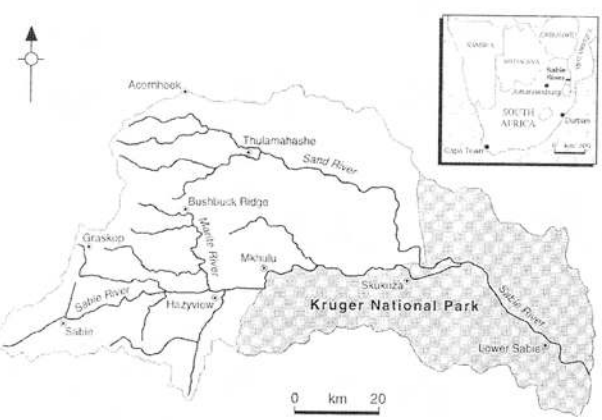


Fig. 1. The Sabie River catchment, Mpumalanga Province, South Africa.

flow regime and a shift in balance of the catchment control variables. Changes in these factors in the Sabie River catchment are reflected in the changing geomorphological nature of the river. Recent research into the type and magnitude of morphological change is summarised with respect to alterations to the catchment.

The topography, geology and regional geomorphology of the Sabie River

The Sabie River rises on the eastern slopes of the Mauch Berg in the Drakensberg, Mpumalanga Province, at an altitude of about 2200 m and flows eastward for some 210 km to its confluence with the Incomati River in Mozambique. The catchment area is approximately 7096 km^2. In the Lowveld region (downstream of Hazyview), the major tributaries are the Marite and Sand rivers (Fig. 1). A large proportion of the Sabie River catchment drains the rural areas of the former homelands of Gazankulu, Lebowa and Kangwane, now incorporated into Mpumalanga Province. The river forms the boundary between the Kruger National Park and rural areas in Mpumalanga before cutting east across the Kruger National Park to the Mozambique border (Fig. 1).

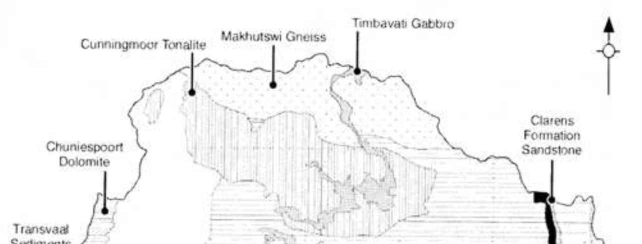


Fig. 2. Simplified geology of the Sabie River catchment.

The Sabie River is underlain by a wide variety of bedrock, comprising sedimentary, intrusive and extrusive igneous and metamorphic rocks. The major strata over which the Sabie River flows are (from most proximal to most distal to the source) laminated, well-bedded shale diamictite and occasional quartzite layers of the Pretoria Group. Chuniespoort dolomite and limestone. Nelspruit Suite biotite granite, potassic gneiss, also of the Nelspruit Suite and in the west of the Kruger National Park, Karoo sediments, Lebombo basalt and Lebombo rhyolite (Fig. 2). The river is intersected by numerous dolerite and diabase dykes and sills, with a large outcrop of Timbavati gabbro along the western boundary of the Kruger National Park. Within the Kruger National Park, the strata have a north-south strike and an easterly dip. The Cunning Moor tonalite and Makhutswi gneiss underlie a large portion of the Sand River catchment. A detailed study of the geology of the incised channel of the Sabie River was conducted as part of the Kruger National Park Rivers Research Program and is reported by Cheshire (1996).

The Sabie River, between its source and the Mozambique border, has been divided into four main geomorphological zones (Fig. 3) based on major topographic changes reflected in an altered reach river slope. These are the Mpumalanga (previously Eastern Transvaal) Highlands, an incised Granite Plain, the Lowveld Zone and the Lebombo Zone. These zones are closely related to the underlying geology with the mountainous hinterland corresponding to the Pretoria Group sediments and the Chuniespoort dolomite and limestone deposits. The Granite Plain zone corresponding to the biotite granites. The Lowveld Zone corresponding to the potassic gneiss, Karoo sediments and basalt; and the Lebombo zone to the rhyolite.

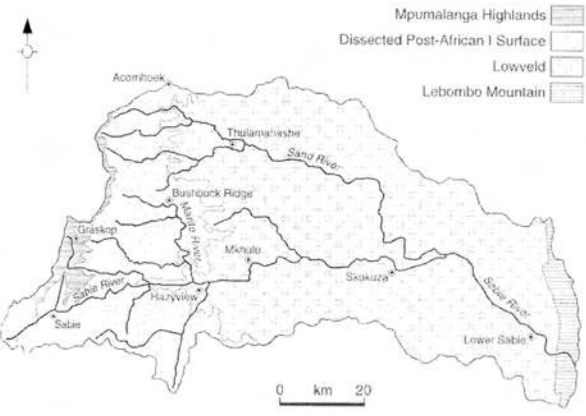


Fig. 3. Geomorphological zones of the Sabie River Catchment.

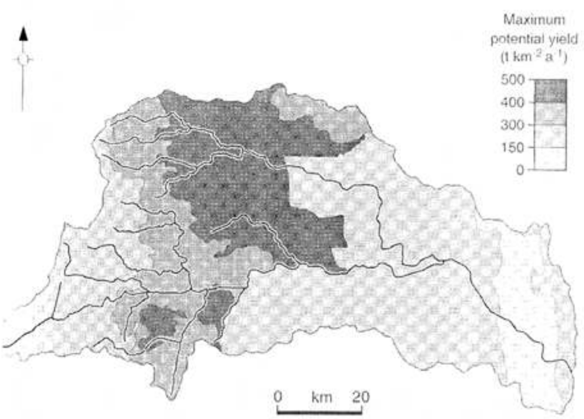


Fig. 4. Sediment production zones of the Sabie River catchment, (after Van Niekerk & Heritage 1994).

Sediment production

A number of studies have been conducted on the Sabie River catchment to quantify its sediment production potential (Rooseboom *et al.* 1992; Van Niekerk & Heritage 1994; Wadeson & Rowntree 1994; Donald *et al.* 1995). The Rooseboom *et al.* (1992) model provides an average sediment yield of 155–620 tkm^{-2}a^{-1}, depending on confidence level. Van Niekerk & Heritage (1994) predict production rates between 250 tkm^{-2}a^{-1} and 400 tkm^{-2}a^{-1} dependent on sub-catchment definition (Fig.4). These correspond to the sub-catchment estimates of Donald *et al.* (1995), which range from below 50–400 tkm^{-2}a^{-1} (Table 1). In the study of Wadeson &

Table 1.
Comparison of predicted sediment production for the Sabie River catchment from various authors

Sub-catchment	Sediment yield (tkm^{-2}a^{-1})		
	Rooseboom *et al.* (1992)	Van Niekerk & Heritage (1994)	Donald *et al.* (1995)
Upper Sabie	155–620	327	100–150
Maritsane	155–620	345	<50
Noord Sand	155–620	402	>400
Sand	155–620	378	<50 and 300–400
Middle Sabie	155–620	401	200–300
Lower Sabie	155–620	246	<50

Rowntree (1994) sediment production categories were not quantified and hence are not represented in Table 1. In all cases, the estimates vary depending on the methodology. Donald *et al.* (1995) provide the most detailed field assessment and catchment breakdown of sediment production processes.

Hydrology

Hydrology data for the Sabie River in the Lowveld region are limited. Gauging stations are located at Perry's Farm, Kruger Gate and Lower Sabie. Of these only Perry's Farm has an extensive flow record, extending back to 1959. Kruger Gate Weir has operated since 1990 and Lower Sabie since 1987. The Sabie River is perennial but it is subject to discharge extremes similar to other semi-arid systems in the eastern part of southern Africa.

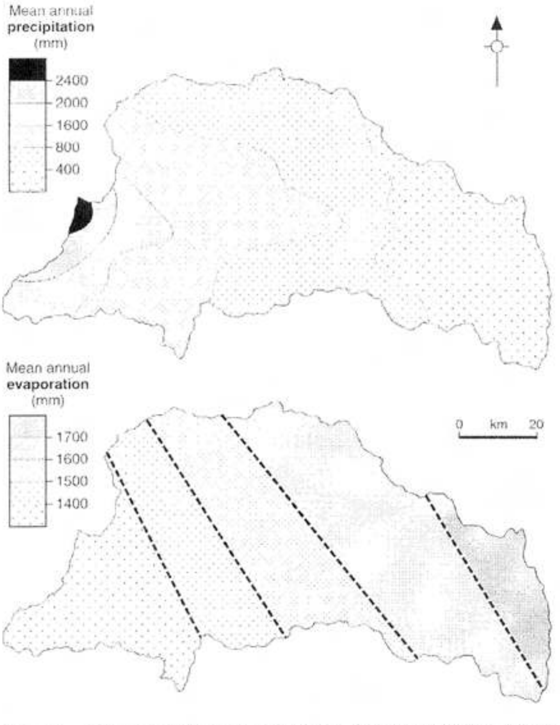


Fig. 5. Average annual precipitation and evaporation for the Sabie River.

Precipitation is concentrated in the highland areas west of the catchment (1800–2000 m/a) declining to 450–650 mm/a over the Lowveld and Lebombo geomorphological zones (Fig. 5). In contrast, potential evaporation is lower in the west (1400 mm), rising to 1700 mm in the east (Fig. 5) (Chunnet Fourie & Partners 1990). Seasonal trends are clear in both the precipitation and the flow regime (Chunnet Fourie & Partners 1990). At Perry's Farm gauge station, low flows of the order of 1–2 m^3/s occur in the dry winter months of April through to September. Elevated and more variable flows are linked to the rains between October and March. Climatic variability has also been identified for the Lowveld region (Tyson 1987; Mason 1995). A quasi 18-year rainfall cycle appears to exist and has been linked to the influence of El-Ninõ on the region, which is reflected in the flow pattern of the Sabie River. The recent 'double' El-Ninõ event led to an extended dry period in the region (Mason 1995) and much reduced flow magnitude and variability in the Sabie River.

The 1984 anthropogenic water requirements represented some 28 % of the natural mean annual runoff (MAR) in the Sabie River catchment, with exotic afforestation in the upper catchment representing the largest usage. The projected water demand by the year 2010 is some 52 % of the MAR representing an 84 % growth, the majority of which will be involved in development of the rural areas (Chunnet Fourie & Partners 1990).

Geomorphology

The Sabie River in the Kruger National Park is incised into the Post African I and II surfaces (Partridge & Maud 1987) which consist of gneiss west of the conservation areas, separated from the basalt in the east by a narrow band of Karoo Sequence sed-

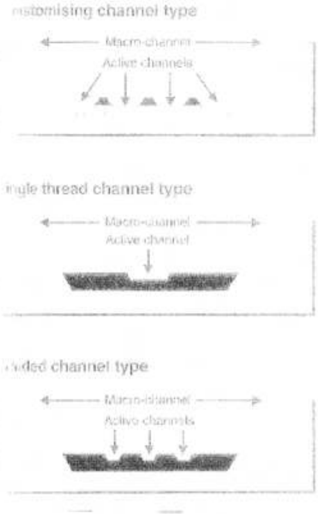


Fig. 6. The structure of the Sabie River macro-channel (after Van Niekerk *et al.* 1992).

iments. This has resulted in a large degree of bedrock control within the incised 'macro-channel'. The longitudinal profile of the Sabie River in the Lowveld is highly irregular on large and small scales. Outcrops of resistant rocks in the bed and banks cause local downstream steepening of the river and upstream decrease in gradient, resulting in a reduction in channel energy and localised sediment accumulation.

Incision by the Sabie River in the Lowveld has resulted in the development of macro-channel and one or more active channels (Fig. 6). The macro-channel extends across the width of the incised valley and contains the full extent of sedimentary deposits and riparian vegetation within the 'valley'. Flow within the macro-channel is normally confined to smaller active channels. Extensive alluvial deposits occur in places; in other areas bedrock features dominate. The active channels carry water throughout the year and some seasonal channels may become active during the higher summer flows. There are sediment deposits in the active channels and along their margins, although bedrock outcrops frequently, controlling water surface slopes. The morphology of the macro-channel is controlled by large magnitude, low frequency events, whereas the active channels are continuously evolving in response to all flows, via sedimentation (all channels) and erosion (all non-bedrock channels).

The dynamics of alluvial channels are relatively well understood, but there have been very few studies conducted on bedrock channels and it is not known how variable most bedrock channel forms can be and on what scale variations occur (Baker 1984; Selby 1985). In order to begin to understand this very diverse physical system with a

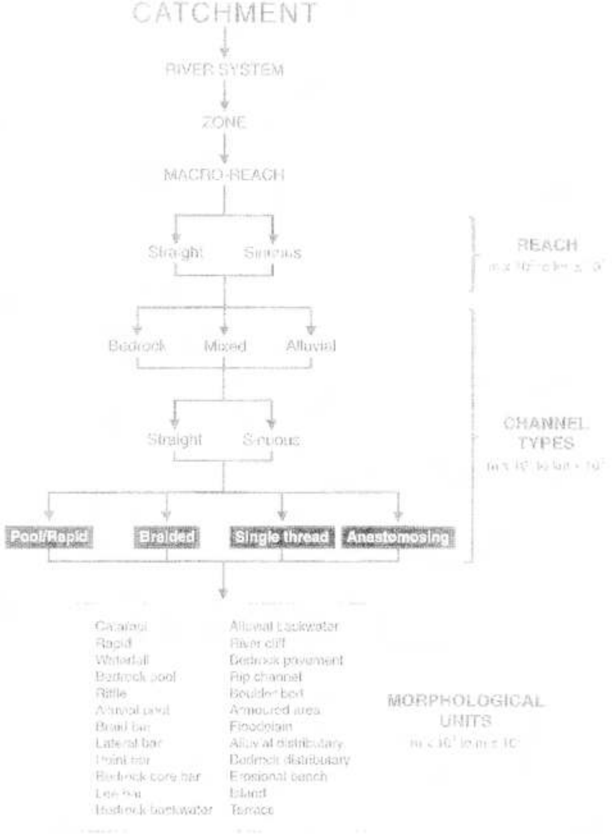


Fig. 7. A hierarchical classification of the Sabie River in the Kruger National Park (after Van Niekerk *et al.* 1995).

large variety of morphological units, it is important to rationalise the system structure.

The geomorphology of the Sabie River was investigated through the classification of channel lengths on the basis of their component morphological units. In this agglomerative hierarchical approach to river classification, a spatial hierarchy is constructed from associations between the smallest units, allowing simultaneous consideration of all characteristics of the object that are considered to be important (Mather 1976). By determining spatial geomorphological associations from the scale of morphological unit upwards, using an agglomerative approach, the physical structure of the system becomes apparent and the finer scale components of the physical system become better defined. These can subsequently be related to wider catchment influences, such as tributary junctions and geological boundaries, to describe the broader scale levels of the hierarchy, thus generating a complete picture of the geomorphological structure of the river system (Fig. 7).

The morphological units of the Sabie River

A large number of morphological units have been identified for the Sabie River in the Kruger National Park and these are described below in terms of their shape, size and sedimentology (where appropriate). Due to the incised nature of the river and the extreme nature of the flow regime, many of the units can form on more than one scale. For example, a lateral bar may develop along the edge of an active channel distributary, forming a small sedimentary feature; alternatively, a larger lateral bar may develop within the macro-channel as a result of flood flows. Table 2 summarises the structure and sedimentology of the units and also indicates the scales on which each might develop.

Rapid

Steep bedrock, or occasionally boulder, obstructions outcropping within the active channel to form single or successive abrupt breaks in the local channel and water surface slope. The rapids form on areas of more resistant lithology which have eroded at a slower rate than the rocks up and downstream. Pathways through the more resistant material have been found where the river has exploited structural weaknesses to create a series of smaller steep channels within the rock (Figs. 8a & 8b).

Waterfall

Abrupt vertical discontinuity in channel slope of the order of several metres, again the result of bedrock influence where a resistant outcrop is slowly being eroded by headward retreat.

Riffle

Accumulation of coarser sediment as a topographic high point forming part of a pool-riffle sequence that may occur between meander inflections in a sinuous channel or approaching the confluence of two distributary channels in a braided system. The feature acts as a temporary sediment storage zone and may remain fixed in its location whilst bed material is moved through the pool-riffle sequence during high flows (Fig. 9a).

Pool

Generic term for topographic low point in the bed profile of the channel often characterised by finer sediments. Pools may be subdivided further into:

a. Pool-riffle-pool. Those occurring as part of a pool-riffle sequence that may occur at meander inflections in a sinuous channel or downstream of the confluence of two distributary channels in a braided system. Fine material, winnowed from the upstream riffle or coming in from the catchment may accumulate, preferentially on the bed of the channel in these low energy units during low flow periods.
b. Apical-pool. Deep section of channel located on the outer bend of a meander.

Table 2
Summary character of the nature and scale of morphological units in the Sabie River in the Kruger National Park

Unit	Bedrock/Alluvial influence	Unit Dimensions		Sedimentology	Associated channel scale
		Vertical	Horizontal		
Rapid	Bedrock	<1.5m	5–50m	Bedrock/boulder	Active, seasonal
Waterfall	Bedrock	>2m	–	Bedrock	Active
Island	Alluvial	<10m	50–500m	Silt/sand	Ephemeral
Terrace	Alluvial	<10m	<5km	Silt/sand	Ephemeral
Bedrock Pavement	Bedrock	1–10m	10–500m	Bedrock	Active, seasonal
Pool:					
Pool-riffle	Alluvial	<1m	10–30m	Gravel/sand/silt	Active
Pool-rapid	Bedrock/mixed	<2m	10–30m	Gravel/sand/silt	Active, seasonal
Apical	Alluvial	<2m	10–30m	Gravel/sand/silt	Active
Bar:					
Braid	Alluvial/mixed	<2m	5–100m	Sand/gravel	Active
Lateral	Alluvial/mixed	1–5m	10–500m	Sand/gravel	Active, seasonal
Point	Alluvial/mixed	1–5m	10–500m	Sand/gravel	Active, seasonal
Bedrock core	Alluvial/mixed	1–5m	5–500m	Silt/sand	Active, seasonal
Lee	Alluvial/mixed	<2m	1–10m	Sand/gravel	Active
Riffle	Alluvial/mixed	<1m	<50m	Gravel	Active, seasonal
Backwater	Alluvial/mixed/bedrock	<2m	<50m	Any	Seasonal
River cliff	Alluvial	<5m	<200m	Silt/sand	Active
Rip-channel	Alluvial/mixed	<2m	<500m	Silt/sand	Seasonal
Boulder bed	Alluvial/mixed	<1m	<50m	Boulder	Active, seasonal
Armoured area	Alluvial/mixed	<1m	<50m	Cobble/gravel	Active, seasonal
Distributary	Alluvial/mixed/bedrock	<2m	<500m	Any	Seasonal, ephemeral

associated with point bars.

c. Pool-rapid-pool. Those occurring as part of a bedrock or boulder pool-rapid sequence where the rapid creates an obstruction within the active channel generating a topographic low upstream. The pool may have a bedrock bed or be covered in finer alluvial bed-material or bar deposits (Fig. 9b).

Braid bar

Accumulation of unconsolidated sediment attached to the side of the channel, possibly associated with a rip-channel causing the flow to diverge over a scale that approximates to the channel width. Characteristically, these features are destroyed and reformed with each major flood (Figs. 8e & 10b).

Lateral bar

Accumulation of unconsolidated sediment attached to the side of the channel, possibly associated with a rip-channel at the base of the macro-channel, forming in areas subject to reduced flow energy. They may occur sequentially downstream as alternate bars. Sediment may be routed through these units, however, the bar position remains fixed through time (Figs. 8e & 10b).

Point bar

Accumulations of unconsolidated sediment, in the form of sands and gravels, on the inside of a meander bend, possibly associated with rip-channel at the base of the macro-channel bank. Characterised by a convex sloping surface in all directions towards the water surface, formed as a result of the local

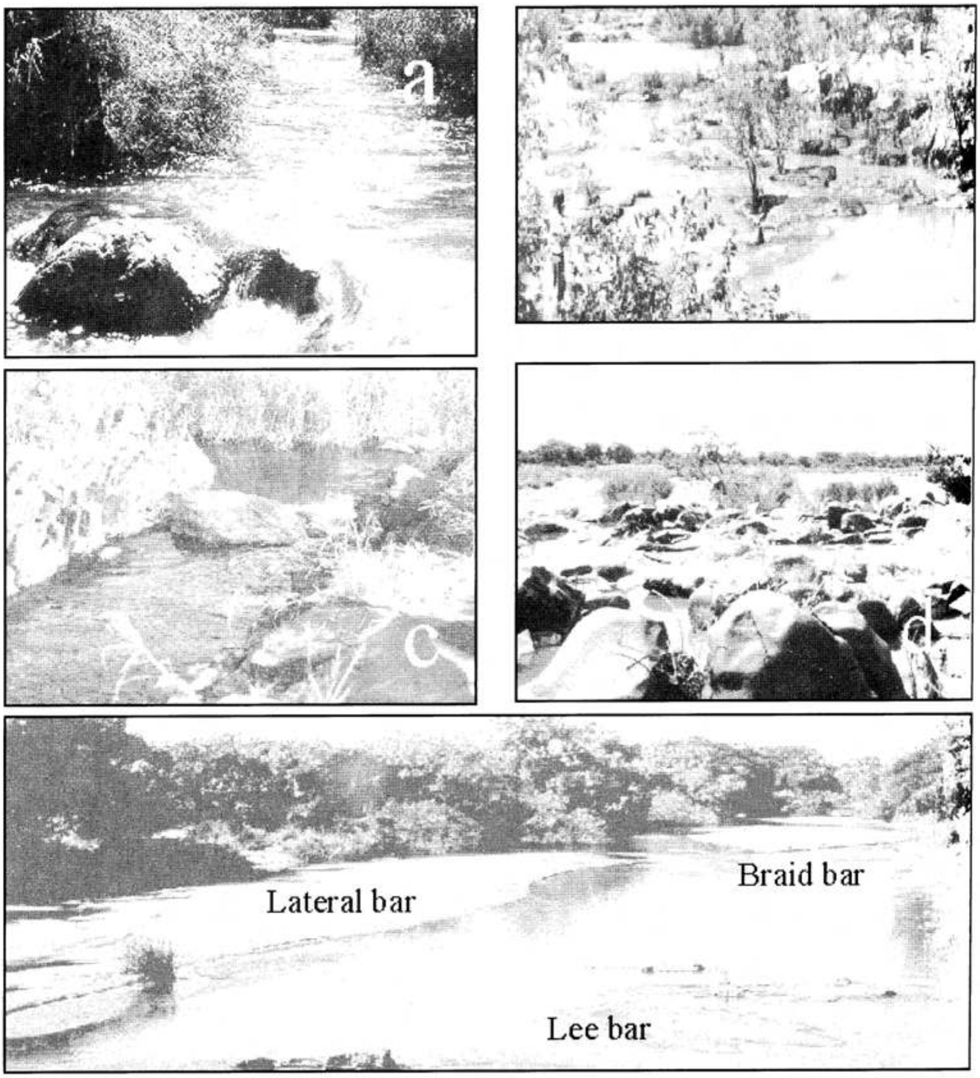


Fig. 8. Sabie River geomorphic units: a) Mixed distributary channel with bedrock rapids in the foreground. channel width is approximately 8 m; b) Bedrock rapid, channel width approximately 30 m; c) Bedrock distributary, channel width is approximately 3 m; d) Boulder bed, foreground boulders are approximately 1 m; e) Lateral bar located downstream on left of photograph, braid bar upstream to the right, lee bar downstream on in-channel rocks in centre foreground.

flow and sediment transport pattern in a sinuous channel. Sediment may be routed through these bars, but the unit position remains fixed through time (Fig. 10b).

Bedrock core bar

Accumulation of finer consolidated sediment and sands on top of bedrock in bedrock anastomosing areas. Their size and shape may vary considerably and is influenced by the bedrock topography. Accumulation occurs as a result of vertical accretion during the falling stage of major floods as suspended sediment is deposited, this process is often aided by the growth of vegetation (Fig. 10a).

Fig. 9. Sabie River geomorphic units: a) Armour area and riffle, scale left to right is approximately 30 m.; b) Bedrock anastomosed channel with bedrock pavement exposed to the right of the photograph, bedrock pools and bedrock distributaries to centre and left of the photograph, macro-channel width is approximately 600 m.

Lee bar

Accumulation of unconsolidated sands and gravels in the lee of flow obstructions such as rocks or tree stumps. The size of the accumulation is controlled by the dimensions of the original upstream obstruction, gradually tapering away vertically and laterally in the downstream direction. Sediment may be routed through these units, but the unit position remains fixed through time (Fig 8e).

Backwater

Generic term for stationary or near stationary bodies of water adjacent to, but isolated from, the active channel. May exist as:

a. Bedrock backwater, contains no consolidated or unconsolidated sediment.
b. Alluvial backwater, a stationary or near stationary body of water in alluvium, adjacent to, but isolated from the active channel (Fig. 10b).
c. Mixed backwater, a stationary or near stationary body of water with a bedrock channel bed displaying some alluvium, adjacent to, but isolated from the active channel.

River cliff

Vertical or near vertical alluvial erosion face. Most characteristically found on the outer bank of the apex of a sinuous bend in an alluvial channel but may occur anywhere there is active erosion of consolidated sedimentary deposits.

Rip-channel

High discharge distributary channel in alluvium on the inside of point and lateral bars, formed as a result of the river cutting a channel along the shortest downstream route at higher flows (Fig. 11b).

Boulder bed

Accumulation of locally derived material on the bed of the river with clast sizes generally exceeding 0.5 m (Fig. 8d). These deposits are fixed in position, as the current flow regime is not competent to transport such large calibre material downstream.

Armoured area

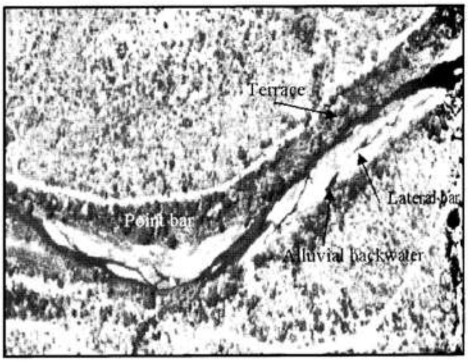
Accumulation of coarser gravels and cobbles on the bed of the channel often forming a 'riffle' like area. Much of the material is too large to be moved by all but the highest flood flows and remains *in situ* whilst other sediment is moved downstream and local fines are winnowed at intermediate flows (Fig. 9a).

Distributary channel

Generic term used to describe an individual active channel in an alluvial braided or anastomosing system. These may be sub-divided as follows:

a. Bedrock distributary, an individual active channel in a bedrock anastomosing system containing no consolidated and/or unconsolidated sediment (Fig. 8c). The underlying bedrock controls the irregular dimensions and planform of the channel.
b. Alluvial distributary, an individual active channel in an alluvial anastomosing or alluvial braided channel type containing consolidated and/or unconsolidated sediment (Fig. 8e & 11a). The dimensions and planform of the channel may be relatively uniform long sub-linear networks of distributary channels in alluvial anatomised areas and shorter more sinuous channel networks in alluvial braided systems.
c. Mixed distributary, an individual active channel in a mixed anastomosing system containing limited consolidated and/or unconsolidated sediment deposited within the bedrock channel (Fig. 8a). The underlying bedrock largely controls the irregular dimensions and planform of the channel.

Fig. 10. Sabie River geomorphic units: a) bedrock anastomosed channel with bedrock core bars across most of the macro-channel, macro-channel width is approximately 400 m; b) Single-thread and braided channel displaying prominent lateral bar to the right with alluvial backwaters and a large point bar to the left of the photograph and extensive terrace deposits on the right bank (flow is from left to right). Both bars are approximately 500 m long.



Island

Large mid-channel accumulation of consolidated sediment at a level coincident with any floodplain deposits. These features are inundated less frequently than in-channel bar deposits.

Terrace

Relic floodplain or valley floor deposits above the present river level representing a former 'floodplain' level prior to downcutting by the river (Fig. 10b).

Channel types of the Sabie River

The agglomerative classification of the river based on the observed association of morphological units provides a structured order to a complex geomorphological system. Ten channel types may be defined on the basis of degree of bedrock-alluvial influence, of which five are commonly found on the Sabie River in the Kruger National Park, (bedrock anastomosing, mixed anastomosing, mixed pool-rapid, alluvial single thread and alluvial braided). Gradations between the five

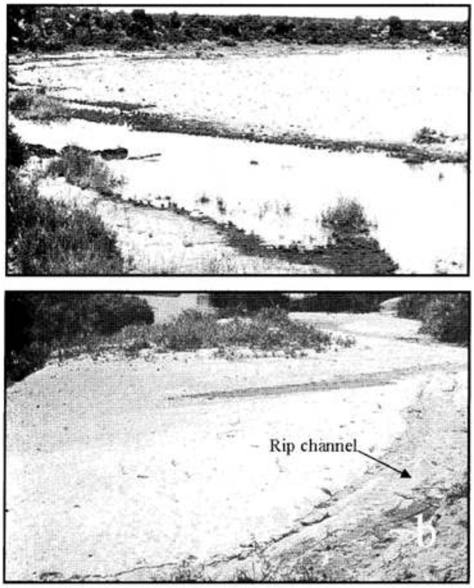


Fig. 11. Sabie River geomorphic units. Plate a: Alluvial distributary channel with right bank levee deposits, flow is left to right and the distributary is approximately 15m wide. Plate b: Rip channel along the inside of lateral bar, bar width is approximately 25m.

primary channel types were observed, creating transition states that could be related to the build-up of sediments (alluvial anastomosing, bedrock single thread, bedrock pool-rapid, mixed single thread and mixed anastomosing) (Table 3).

Differentiation between types was based on morphological unit composition and is directly related to the degree of sedimentation within the macro-channel. Their distribution is mapped as Figure 12.

Bedrock anastomosing channels were first identified on the Sabie River by Van Niekerk & Heritage (1993) and are dominated by bedrock features including bedrock pools, rapids, bedrock core bars, cataracts, waterfalls, bedrock distributaries, boulder beds, armoured areas, lee bars and bedrock backwaters (Fig. 13). Chemical differences in the host rock have generated resistant areas where the river is less able to erode vertically (Cheshire 1996). Typically, the incised macro-channel is widened to extend across an area three to four times the average width of the river and this effect may extend over several kilometres, but is variable, since the size of the feature is a function of the local geology. Numerous active channel bedrock distributaries exist flowing over a steep gradient within the incised channel, describing a tortuous route over the resistant rock. Such channels have a fixed planform as defined by the weaker pathways through the resistant outcrop (Cheshire 1996). These distributaries display very few alluvial features within their bedrock channels. Bedrock features include pools, rapids, cataracts and small waterfalls, with sediment accumulation being restricted to lee bar deposits downstream of bedrock obstructions, armoured areas and fine deposits in low energy areas of flow.

Distributaries at different elevations may be active at the same flow as there is almost no lateral water table and flow is a function of upstream conditions. Elevated bedrock areas are common and may exist as exposed bedrock pavements and as areas of limited sediment build up termed bedrock core bars (Van Niekerk *et al.* 1995). These bedrock core bars are characterised by an accumulation of basal sands overlain by finer sediments on top of bedrock areas above the active distributaries. These probably result from early deposition of sands transported out of these channels during moderate flood events and fine sediments during waning flows. The process of sedimentation is aided by growth of *Breonadia salicina*, a riparian tree that germinates in bedrock cracks, and reed growth. Fines may be deposited from suspension as the river rapidly loses energy when it floods across the over-wide incised macro-channel and the bars grow through a process of vertical aggradation.

The mixed pool-rapid channel type is also dominated by bedrock features (Fig. 14), created by differential resistance to fluvial erosion. Detailed field investigation of the geological controls has revealed a number of reasons for this, including localised chemical differences similar to the bedrock anastomosing situation and differing lithologies

Fig. 12. Channel types along the Sabie River.

(Cheshire 1996). These factors create pool-rapid sequences within the active channel, the scale of which is dependent on local geological variability and channel gradient. Typically, the rapids are free of sediment apart from occasional boulders and small-scale bedrock core bars. The pool areas are more variable, ranging from sediment free bedrock areas to sediment lined pools, incorporating a variety of bar types. Aerial photographic evidence dating back to the 1940s indicates that the pools are highly susceptible to sedimentation as flow energy is rapidly reduced in the backwaters of the bedrock rapids. The active pool-rapid channels typically occupy only a portion of the macro-channel. Large-scale sedimentary features associated with infrequent high magnitude flows have covered much of the bedrock across the rest of the incised channel.

The alluvial single thread channel system is analogous to both the straight and meandering channel types of Leopold & Wolman (1957). Single thread channels have developed in alluvial sections of the Sabie River, where the freedom to make planform adjustments is restricted to the width of the incised macro-channel (Fig. 15). Typically, these channel types contain a considerable range of the features noted in temperature alluvial single

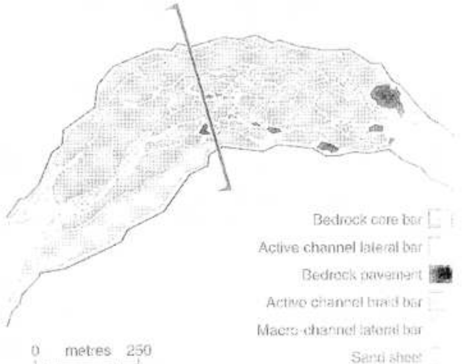


Fig. 13. Characteristic geomorphology, plan form and cross-sectional form of bedrock anastomosing channel type in the Sabie River.

Table 3

Channel types observed on the Sabie River in the Kruger National Park

Degree of sedimentation	Channel type			
	Anastomosing	Pool-rapid	Single thread	Braided
Bedrock	primary	secondary	secondary	–
Mixed	primary	primary	secondary	secondary
Alluvial	secondary	–	primary	primary

- Channel type does not occur in nature

thread channels including lateral bars, alluvial pools, river cliffs, apical pools, point bars, rip channels, riffles and terraces.

Alluvial braided channels are defined as alluvial systems that exhibit channel splitting and rejoining over a distance of a few distributary widths at low flow. The geomorphological features present largely consist of ephemeral deposits of sediment. The degree of braiding in the Sabie River, as defined by the number of braid channels , is low and appears restricted to the deposition of mid-channel and lateral bars within the active channel. Beyond this the banks are composed largely of cohesive macro-channel deposits well protected by vegetative cover (Fig. 16).

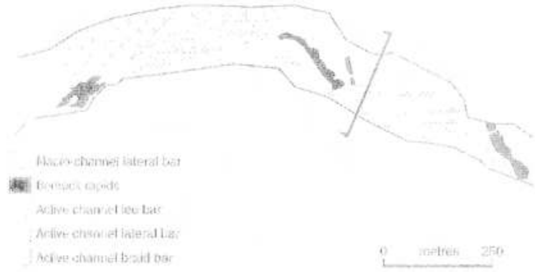


Fig. 14. Characteristic geomorphology of a bedrock pool-rapid channel type in the Sabie River.

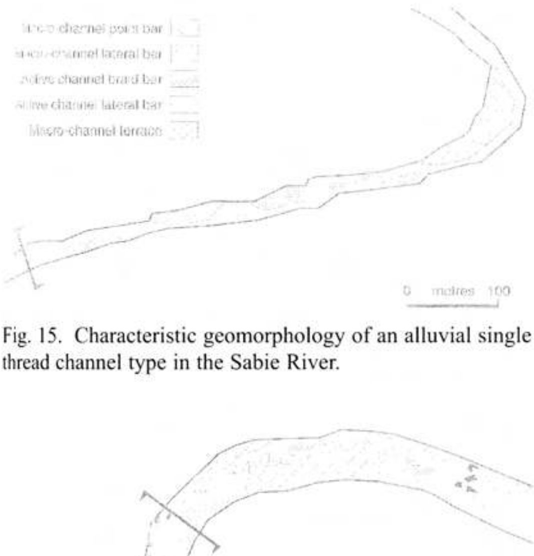


Fig. 15. Characteristic geomorphology of an alluvial single thread channel type in the Sabie River.

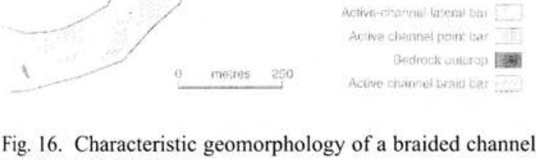


Fig. 16. Characteristic geomorphology of a braided channel type in the Sabie River.

Mixed anastomosing channel types are sections of the macro-channel displaying multiple bedrock and occasional alluvial distributary channels that divide and rejoin over a distance much greater than the distributary width. The planform of the active channels appears to be relatively stable, with the river largely reverting to its old course following floods greater than the capacity of the active channels. This stabilisation is aided by the reduction in winter base flow variation during dry cycles and the consequent growth of vegetation adjacent to the active channels (Fig. 17). Extensive reed growth (*Phragmites mauritanus*) between the active distributaries increases channel resistance during flows higher than the capacity of the distributary channels and promotes bar growth by the vertical accretion of sediment.

Dynamics of channel change

Differing degrees of sedimentation within the macro-channel of the Sabie River have created reaches than range from almost fully bedrock through to fully alluvial. Heritage *et al.* (1997) have used aerial photographs of different examples of the same channel type that display differing amounts of accumulated sediment to develop a sequence of channel types that defines the progression from a bedrock to an alluvial system as a result of alluviation of the river.

They propose two pathways depending upon whether the initial bedrock channel is single or multi-thread. Each pathway illustrates similar areas of river with respect to channel type, each successive stage displays an increasing area covered by sediment, representing a change towards the more alluvial examples in each sequence as sediment inputs into the channel increase and flow magnitude and frequency decline.

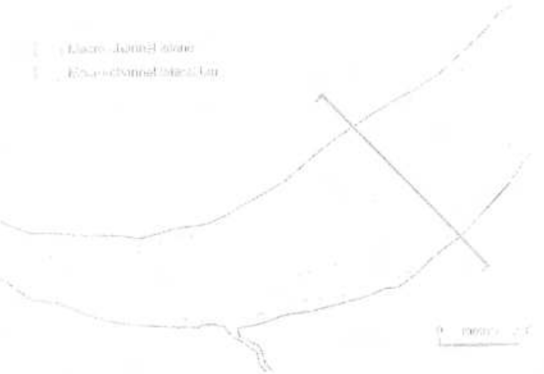


Fig. 17. Characteristic geomorphology of a mixed anastomosing channel type in the Sabie River.

The multi-thread channel alluviation pathway ranges between bedrock anastomosing, through mixed anastomosing channel types. Interpretation of the trends in geomorphological change indicates that bedrock core bars remain common as alluviation proceeds. Other alluvial features become progressively more common especially braid bars, lateral deposits and lee bars. Rock areas in pools remain prevalent since deposition within the active channel distributaries is not sufficient to bury these features. Away from the active channels alluvial backwaters increase at the expense of bedrock backwaters and macro-channel lateral deposits extend to cover areas of bedrock pavement, but isolated terrestrial rock outcrops remain common. Islands are recorded in mixed anastomosing channel types possibly as a result of the amalgamation of smaller alluvial deposits.

Progressive single-thread channel alluviation in pool-rapid channel types gives rise to mixed pool-rapid, braided and alluvial single-thread channels. The dominant features in these channel types are macro-channel lateral deposits, with very little bedrock pavement recorded. Occasional isolated bedrock outcrops have been observed in pool-rapid and braided channel types, but these disappear in fully alluvial single-thread areas. Backwater areas are uncommon due to the single-thread nature of these channel types. Bedrock pools are rare even in pool-rapid channels as most pools contain some alluvium, placing them in the mixed pool category. As sedimentation proceeds mixed pools are replaced by alluvial pools creating alluvial single thread channels. Rock rapids and bedrock core bars are lost as sediment cover increases, but isolated rocks in pools may persist in braided areas. Braid bars remain common but appeared to decline slightly in single-thread channels as they amalgamate with other deposits to form more extensive lateral features.

These changes to the geomorphological assemblages in anastomosing and pool-rapid channel types as a result of progressive sedimentation are summarised in Table 4.

Changes to a more alluviated state resulting from reduced flow frequency and magnitude and increased sediment outputs have also been recorded by Rountree *et al.* (*in press*). The aerial photographic interpretation of channel and vegetation change between 1986 and 1996 demonstrates a progression in terms of the accumulation of unconsolidated sand over bedrock which is later colonised by reed and shrub communities. Finer alluvium then accumulates due to the effect of the vegetation on flow and sediment transport processes creating more stable consolidated sedimentary deposits which appear then show a succession from reed-shrub communities to shrub-tree communities (Fig. 18).

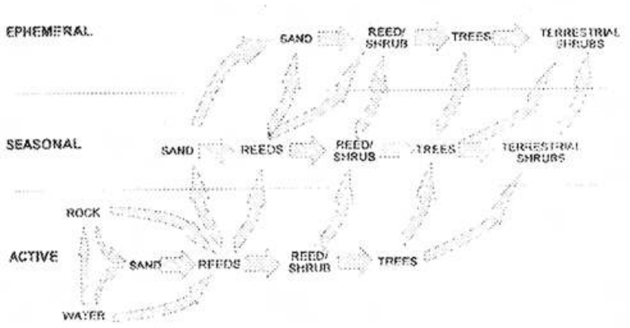


Fig. 18. Changes to the landscape states of the Sabie River in the Kruger National Park during a phase of sediment accumulation (after Rountree *et al. in press*).

Discussion

The Sabie River displays an extremely diverse geomorphology linked to the catchment control variables of geology and sediment dynamics. It is the variability between sediment transport ability and sediment delivery that determines the relative dominance of bedrock and sedimentary features (see Birkhead *et al. in press*). This variability is emphasised on the Sabie River by the incised nature of the macro-channel, confining all flows and deposits within its bounds, and the variable nature of the flow regime. Large infrequent flows may scour deposits in some areas and deposit sediments in others. Intermediate floods may redistribute sediments and perennial flows may further rework active channel deposits. Thus, bedrock dominated channel types may display areas of sedimentary influence giving the channel a 'mixed' bedrock-alluvial appearance.

Despite the apparent diversity, observation of the association of morphological units along the river of the Kruger National Park has revealed that the channel may be zoned into a series of alternating channel types ranging from fully bedrock anastomosed and pool-rapid sections to fully alluvial braided and single-thread sections. The robustness of these observed channel types has recently been supported by an objective classification of selected mapped reaches using cluster and discriminate analysis (Heritage *et al. in press* a). Bedrock channel types dominate the steeper sections of channel upstream of Skukuza giving way to increasingly more alluvial reaches dominated by mixed anastomosed channel types.

The derived channel type structure of the Sabie River is differentiated on the basis of the five dominant channel types (bedrock anastomosing, mixed anastomosing, mixed pool-raid, alluvial single thread and alluvial braided). There are also a series of 'transition states', that exist between the major channel

Table 4

Changes to the geomorphological assemblage in anastomosing and pool-rapid channel types as a result of sediment accumulation

Increasing morphological features	Decreasing morphological features
Anastomosing channels	
Alluvial backwaters Macro-channel lateral deposits Braid bars, point bars, lateral bars	bedrock backwaters bedrock pavement bedrock pools
Pool-rapid channels	
Macro-channel lateral deposits remained dominant and stable	
Alluvial pools Point bars, lateral bars	bedrock pools, mixed pools bedrock core bars, braid bars, rock rapids

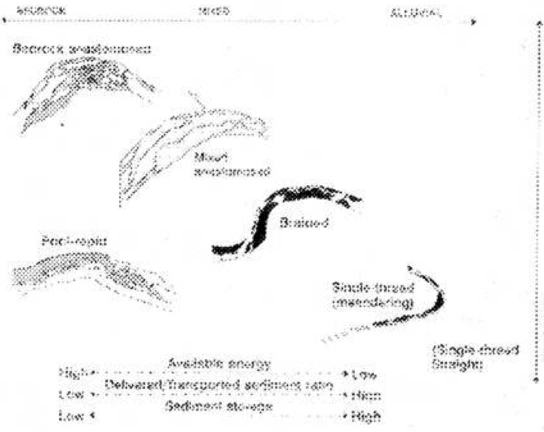


Fig. 19. The continuum of channel types observed on the Sabie River differentiated by planform and available energy levels.

types linking to form the continuum of channel form between bedrock and alluvial systems (Fig. 19). Examples of these less common or less well defined channel types observed on the Sabie River in the Kruger National Park include alluvial anastomosing (the final alluvial stage of bedrock anastomosing evolution), bedrock pool-rapid (the initial state in the sequence through mixed pool-rapid to mixed single thread/mixed braided), and finally alluvial single thread/alluvial braided.

The type of channel at any point on the river of the Kruger National Park is a function of two principal controls. The underlying geology plays a major role in defining the planform of the channel. In particular it is responsible for determining the single or multi-thread nature of the channel where the bedrock has not been buried by accumulated alluvium. Available energy is the second major control channel type, steeper channel segments are generally competent to transport more material than are those on a shallower gradient. Hence steeper reaches are characterised by a greater bedrock influence.

It is clear from several recent studies of channel and vegetation change on the Sabie River (Heritage *et al.* 1997; Rountree *et al. in press*) that there has been a trend towards increasing alluviation of the macro-channel regardless of channel type. Such a trend is probably related to the reduction in flow magnitude and frequency and the increased sediment inputs to the system from the degraded catchment to the west of the Kruger National Park. This would indicate that the system is moving towards a more sedimented state with bedrock influence and geomorphic diversity declining along many reaches of the river. Observations of the effects of the 1996 floods (2000 m^3s^{-1} in February) appear to indicate that this trend was halted and indeed reversed in some areas with considerable loss of consolidated sediment (Heritage *et al. in press* b).

From these data it is possible to conclude that the Sabie River demonstrates a state of episodic disequilibrium with long periods of sediment accumulation, enhanced by catchment degradation, followed by brief high magnitude flow events that remove part or all of the accumulated material. Other semi-arid rivers have also demonstrated this behaviour (see Nanson 1986).

The findings would indicate that alluviation is part of the natural channel change cycle on the Sabie River, however, it may be that with increasing catchment degradation that the rate of accumulation is increasing with bedrock influence being lost at a faster rate than was the case under natural conditions. Hence the river is likely to be in an alluviated state for longer periods than previously before bedrock is exposed by a high flow event. This, coupled with the reduced flow regime, may result in increased terrestrialisation of the system as noted by Rountree *et al.* (*in press*) if management action is not taken to prevent this.

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