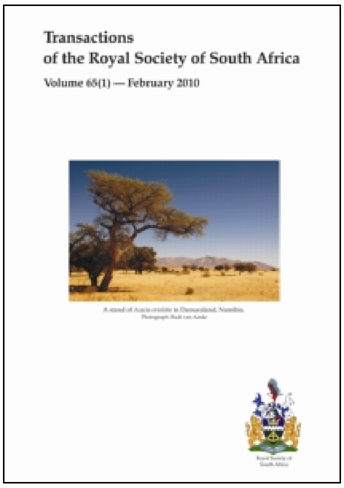

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The geomorphic provinces of South Africa, Lesotho and Swaziland: A physiographic subdivision for earth and environmental scientists

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The geomorphic provinces of South Africa, Lesotho and Swaziland: A physiographic subdivision for earth and environmental scientists

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This work has drawn upon previous attempts to define geomorphic provinces, but also on more recent work on the geological and geomorphological evolution of southern African fluvial systems. It has also used Digital Terrain Model (DTM)-derived data and statistical techniques to determine 34 geomorphic provinces and 12 sub-provinces within South Africa, Lesotho and Swaziland. Ninety-nine main stem river longitudinal profiles and valley cross-sectional profiles were generated from the DTM-derived data, and a statistical technique, the Worsley likelihood ratio test (WLRT), was applied to define statistically significant changes in slope and valley cross-sectional width along the river continuum. This isolated 471 macro-reaches for the 99 main stem rivers. Each macro-reach was then analysed using a variety of descriptors including shape, best fit curve, slope, sediment storage potential and valley width. Principal component analysis was applied to the data set to determine whether significant groupings existed, indicating significant similarities in the data by way of area, and conversely, whether distinct differences between groups of data were evident. The scores for the whole data set showed a large grouping around the origin with some scatter along the PC1 axis. Distinct groups were, however, evident for macro-reaches within each province. These reflect the extent of uniformity in the slopes, valley widths, altitudes and shape descriptors of each province. A description of each of the 34 provinces and 12 sub-provinces is presented.

Keywords: geomorphic provinces, South Africa, Lesotho, Swaziland, conservation planning, rivers.

INTRODUCTION

On a global scale, freshwater ecosystems are experiencing a significant loss of biodiversity due to human impact (Klaphake *et al.*, 2001). There is a growing recognition that this loss is not sustainable in the long-term because functioning aquatic ecosystems deliver significant economic and social benefits to society (Costanza *et al.*, 1997). Progressive legislation has been promulgated in some countries to ensure that freshwater ecosystems are protected [e.g., South African National Environmental Management: Biodiversity Act (No. 10 of 2004)], and that a balance is achieved between using freshwater as a resource (rivers and other surface and groundwater bodies) and protecting it [e.g., the South African National Water Act (No. 36 of 1998)]. In addition to nation-state initiatives, there are numerous international conventions that seek to conserve aquatic ecosystem diversity [e.g., Convention on Biological Diversity (CBD), Ramsar Convention].

One of the main objectives in protecting freshwater ecosystems is to ensure the long-term survival of native species and community types through the design and conservation of portfolios of landscape-scale spatial units (*cf.* Groves *et al.*, 2000). The identification and selection of representative spatial units that conserve the diversity of communities and ecological systems represents a significant challenge and various solutions have been offered [e.g., Omernik, 1987; Roux *et al.*, 2002; Kleynhans *et al.*, 2005). Conventional wisdom has it that a portfolio of representative spatial units/sites is needed to help set conservation targets and goals (Nel *et al.*, 2007). The targets are set at multiple spatial scales and levels of organisation to ensure the protection of all communities and ecosystems and not just the rare ones.

South African context

In 2002 the then South African National Department of Water Affairs and Forestry (DWAF), the Council for Scientific and Industrial Research (CSIR) and the Water Research Commission (WRC) embarked on a project to develop a policy and planning tool(s) for the systematic conservation planning of freshwater ecosystem biodiversity in South Africa (Nel *et al.*, 2005). Although a number of objectives were identified for this project, termed the Freshwater Biodiversity Initiative (FBI), two are relevant here:

- to identify those freshwater ecosystems best suited to receiving a high protection status; and

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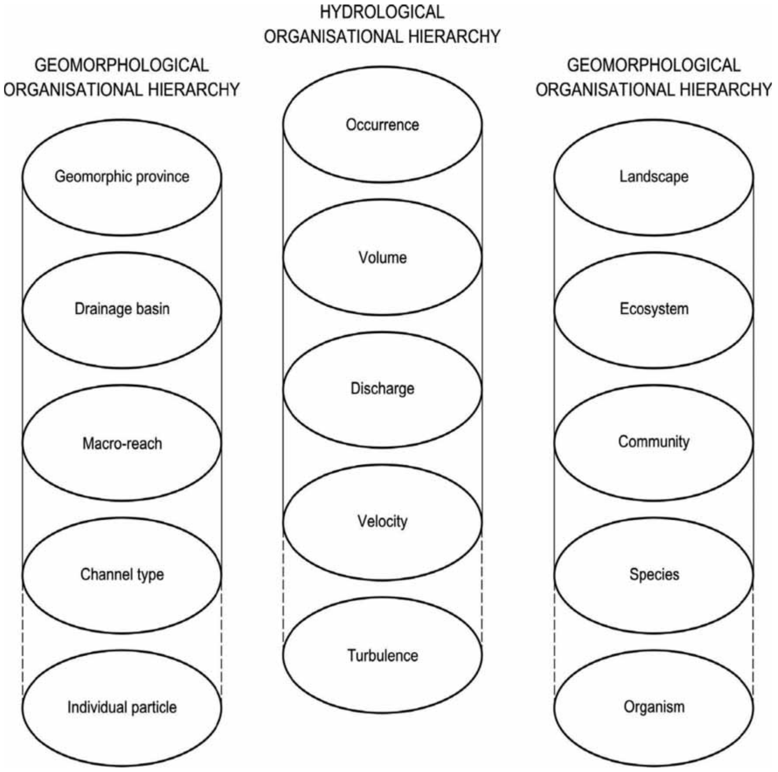

Figure 1. Hierarchical descriptions of levels of organisation (after Dollar *et al.* 2007).

- to develop methods and data layers for the spatial representation of both biodiversity pattern (so that a sample of all biodiversity can be conserved) and ecosystem processes (so that the processes that sustain biodiversity can be sustained). This needs to be done at scales that are appropriate to national and sub-national biodiversity planning initiatives.

To meet the second objective, an approach was developed that incorporated the notion of physical signatures as surrogates for biodiversity pattern. Although the concept of catchment signatures had been developed by King & Shael (2001), the concept of physical signatures for rivers was first applied as part of the Greater Addo Elephant National Park Conservation (GAENP) project (Roux *et al.,* 2002). The aim of the GAENP project was to conserve biodiversity and stimulate sustainable development in the region. This required the identification of options for expansion that would allow for the conservation of representative and viable biodiversity patterns and processes within the context of systematic conservation planning (*cf.* Margules & Pressey, 2000). As the biological information within the GAENP was limited, the study focussed largely on physical templates of the ecosystems. This involved delineating biodiversity patterns for rivers and streams using physical surrogates (e.g., geology, climate) and identifying the ecosystem processes that maintained biodiversity. Roux *et al.* (2002) made the point, as did Stanford (1998), that physical characteristics, such as geology and climate, control the biological attributes of rivers and streams. Roux *et al.* (2002) went on to argue that stream biota can be considered to be protected by conserving habitat heterogeneity or pattern. This approach was used for the GAENP study to construct 'signatures of physical pattern' with some success. Roux *et al.,* (2002) concluded that there was considerable scope for further development of physical signatures as surrogates for biodiversity in freshwater ecosystems.

The concept of physical signatures has recently been further developed for South African rivers; these advances are described in a companion paper (Dollar *et al.,* 2010). This article explains that the development of physical signatures is based on a theoretical framework for interdisciplinary understanding of rivers as ecosystems (Dollar *et al.,* 2007). Application of this framework requires, among other dimensions, a detailed description of the relevant levels of organisation that characterise different subsystem hierarchies (e.g., geomorphology, hydrology and ecology) of the river ecosystem. The highest level of organisation of the geomorphology hierarchy is represented by a geomorphic province (Figure 1). Geomorphic provinces are defined as similar land areas containing a limited range of recurring landforms that reflect comparable erosion, climatic and tectonic influences, and impose broad constraints on lower levels of organisation, e.g., drainage basins, macro-reaches, channel types (Figure 1) (Dollar *et al.,* 2007).

This article describes the process of revising the geomorphic provinces delineated by Lester C. King (1967) for South Africa, Lesotho and Swaziland, and presents a revised description of each of the provinces. These geomorphic provinces have been utilised in developing physical signatures for southern African rivers (see Dollar *et al.,* 2010) for the purposes of systematic conservation planning.

GEOMORPHIC PROVINCES

Lester C. King delineated 26 geomorphic provinces for southern Africa in 1942 (King, 1942). These were later rationalised to 16 in 1951 (King, 1951) and finally to 18 in 1967 (King, 1967). King's provinces incorporated work by Gevers (1942), Taljaard (1945), Wellington (1944; 1955) and Cole (1966). King (1967) described geomorphic provinces as regions of relatively uniform physiography that were more or less unique, although sometimes grading into one another. They were based on a hierarchy of criteria that included:

1. Geomorphic history.
2. Geological structure.
3. Climate.
4. Location.
5. Altitude.

Geomorphic provinces have been described elsewhere. In

Taiwan, for example, geomorphic provinces have been delineated on the basis of self-affinity dimensions of landscape surfaces and on the morphotectonic features of orogenic belts (Sung & Cheng, 2004). Yang *et al.* (2002) defined geomorphic provinces along the Keriya River in China based on the relationship between environmental change and landscape evolution. Similar concepts have been developed for systems in the United States (Montgomery & Buffington, 1998).

Delineating geomorphic provinces for South Africa, Lesotho and Swaziland

Advances in the fields of geology, remote sensing and geomorphology, the disciplines of stratigraphy, seismology, radiometric and isotopic dating, and current information generated from on- and off-shore exploration, require the revision of South Africa's, Lesotho's and Swaziland's geomorphic provinces[1] for the purposes of systematic conservation planning. The inductive approach adopted here has been to revise and refine the boundaries of earlier geomorphic provinces utilising the latest scientific literature and a statistical examination of 99 selected main stem river longitudinal and valley cross-sectional profiles generated from a Digital Terrain Model (DTM). This approach applies state-of-the-art views and methodology appropriate to the objectives of this new subdivision.

River longitudinal profiles have been utilised because they reflect the influence of lithological change, tectonics, river capture, climate change and historical changes in base-level; they also provide a common focal point for physical scientists and ecologists [e.g., through the river continuum concept (Vannote *et al.*, 1980; Brown & Magoba, 2009)] in selecting physical signatures as surrogates for freshwater ecosystem biodiversity at a scale appropriate to national and sub-national biodiversity planning initiatives. In southern Africa, these influences have resulted in many rivers being characterised by 'irregular' longitudinal profiles (Partridge & Maud, 2000). Such 'irregularities' mark natural boundaries along the profile continuum (e.g., knick-points, lithological changes) and these are also often the boundaries between geomorphic provinces. Accordingly, longitudinal profiles can be divided into homogenous zones or reaches (termed macro-reaches in this article) separated by longitudinal discontinuities (Dollar *et al.*, 2006). The delineation of macro-reaches for this purpose is not without precedent. Macro-reaches have been used, for example, to divide rivers into zones of similar form and response (*cf.* Rowntree & Wadeson, 1999; Rowntree, 2000; Heritage *et al.*, 2000; Baillie & Norbu, 2004). One of the assumptions underlying these divisions is that there is a relationship between the spatial organisation of ecosystems at the scale of a macro-reach and the physical template that the macro-reach provides (Dollar *et al.*, 2007). The macro-reach therefore becomes the spatial unit utilised in the systematic conservation planning process for aquatic ecosystems.

Valley cross-sectional characteristics have also been used in this process, as they have been demonstrated to exert an important control on channel type, sediment storage potential, flood hydraulics and floodplain development (*cf.* Warner, 1987; Miller, 1995; Thoms, 1999; Thoms *et al.*, 1999; Li *et al.*, 2001; Opluštil, 2002). Valley cross-sectional characteristics not only reflect longer term geological and geomorphological processes, but also influence the physical processes acting on the macro-reach template, and hence the spatial organisation of ecosystems.

Generating river longitudinal profiles and valley cross-sectional profiles

River longitudinal profiles were generated for 99 selected main stem rivers from a 20 m × 20 m resolution DTM produced by ComputaMaps and a drainage net originally captured at 1:500 000 scale whose spatial accuracy was corrected at the Directorate: Resource Quality Services at the DWAF to within 50 m of the 1:50 000 scale data (Silberbauer & Wildemans, 2001).

The DTM and the drainage net were used as input to produce an Arc/Info file of elevations at horizontal distance intervals along the length of each river (Moolman *et al.*, 2002). The resulting river profiles included a number of peaks, which are the result of differences in resolution (of the river and DTM data). These were removed by extracting the lowest points along the length of the profile, assumed to represent the valley bottom, and so creating a constantly decreasing profile (Moolman *et al.*, 2002).

The generation of river valley cross-sectional profiles was based on the same DTM and river input data used for the longitudinal profiles. A river course in the GIS is defined by a set of points (vertices) linked by lines. The midpoint of the line between each two vertices was obtained and a perpendicular line generated at this point. For the purposes of this study, the line was extended 2.5 km on either side of the river. An automated process was used to combine these lines with the DTM data to provide a set of perpendicular cross-sections. Based on the cross-sectional data this generated river valley width at 20 m above the lowest point in the valley.

Finding change points on the longitudinal profile: defining macro-reach boundaries

For each selected river, at every 10th inflection point along the longitudinal profile, the distance from the river source, height above mean sea level and valley width were computed. An automated version of the Worsley likelihood ratio test (WLRT, Worsley, 1979) was applied (see Dollar *et al.*, 2006) to the longitudinal profile slope to divide the river into macro-reaches. This method determined the most statistically valid change point in the data set of the river slope; it then split the data at that point and repeated the process on the two data portions as shown in Figure 2. This process was continued until the significance of levels of change points dropped below the values published by Worsley (1979) for 90% significance, or until the change point was closer than 5 km to one of higher rank, or was within three data points of one of higher rank.

Once the change point positions were identified, various descriptors could be derived for each macro-reach.

Macro-reach descriptors

Although all the river profiles under consideration were irregular, descriptors were required to compare the basic profile shapes. In order for these parameters to be comparable, all macro-reach profiles were normalised to unit lengths and heights (after Blight, 1994; Rădoane *et al.*, 2003).

Macro-reach convexity and concavity

The first descriptor derived was the longitudinal shape of the profile because this provides an indication of the down slope lithological variability as well as stage of the geomorphic evolu-

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[1] It is useful to consider recent work on the macro-scale geomorphic evolution of southern Africa, highlighting the evolution of fluvial systems. Work describing this can be found in Mayer (1973), Dingle *et al.* (1983), McCarthy (1983), Partridge & Maud (1987), Dardis *et al.* (1988), Maud & Partridge (1988), Thomas & Shaw (1988), Shaw (1989), Marshall (1988, 1990), Partridge *et al.* (1990), Wilkinson (1990), Nugent (1992), De Wit (1993), Hattingh (1996), Bootsman (1997), Smith *et al.* (1997), Zawada (1997), Dollar (1998), Partridge & Maud (2000), Moore & Larkin (2001) and McCarthy & Rubidge (2005).

Figure 2. Schematic of successive bifurcating at change points (after Dollar *et al.* 2006).

tion of the river system (Rădoane *et al.*, 2003). For example, convex profiles are often associated with recent tectonic uplift and/or dryland systems (*cf.* Marker, 1977a,b). Furthermore, slope steepness increases down channel in convex profiles, whereas in concave profiles, slope steepness diminishes down channel, and this affects sediment storage and transfer at lower levels of organisation. To compute profile shape, the longitudinal profile was normalised to unit lengths and heights (after Blight, 1994). The area under the normalised curve (i.e., the integral) was then calculated and expressed as a ratio of the area calculated when a straight line is used to join the beginning and end of the river. If the river profile is close to a straight line, then the value of concavity is close to 0.5. For L-shaped river profiles the value is closer to 0, while for very convex-shaped rivers the value tends toward 1 (Table 1).

Macro-reach best fit curves

Idealised shapes of river longitudinal profiles are logarithmic (Dollar *et al.*, 2006). Rice & Church (2001) have, however, demonstrated that exponential or quadratic functions best describe aggrading alluvial river systems where there is no significant lateral input of water or sediment. To describe the shape of a longitudinal profile, four functions (linear, exponential, power and logarithmic forms) were applied to the normalised profiles using least squares.

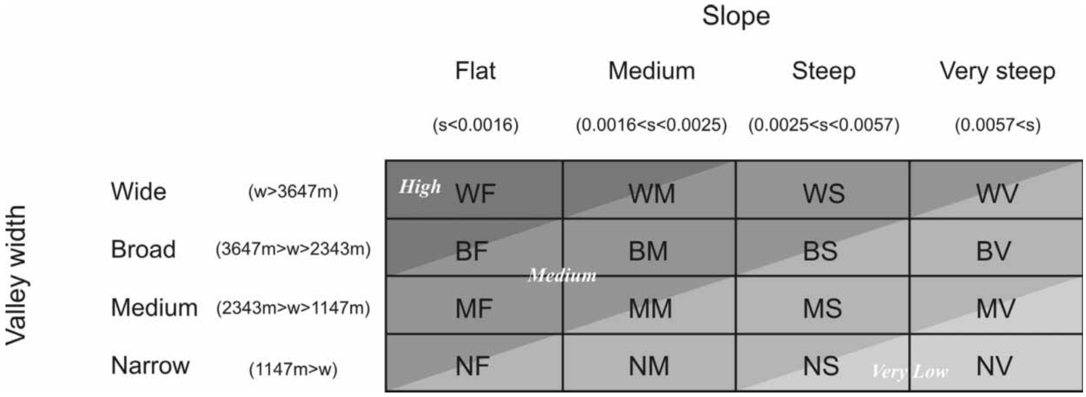
Table 1. Descriptors for macro-reach concavity based on the area under the normalised curve.

Ratio	Descriptor
$r \leq 0.100$	Extremely concave
$0.100 < r \leq 0.200$	Strongly concave
$0.200 < r \leq 0.300$	Averagely concave
$0.300 < r \leq 0.400$	Moderately concave
$0.400 < r \leq 0.497$	Mildly concave
$0.497 < r \leq 0.503$	Linear
$0.503 < r \leq 0.600$	Mildly convex
$0.600 < r \leq 0.700$	Moderately convex
$0.700 < r \leq 0.800$	Averagely convex
$0.800 < r \leq 0.900$	Strongly convex
$0.900 < r$	Extremely convex

Macro-reach sediment storage descriptors

For every macro-reach of each river a surrogate for the available area to store sediment within the macro-reach – the sediment storage surrogate – was generated using a matrix of average macro-reach valley width to average macro-reach slope (Table 2). The assumption is that macro-reaches characterised by steep slopes and narrow valleys have limited poten-

Table 2. Sediment storage surrogate descriptors.



Valley width		Slope Flat (s<0.0016)	Medium (0.0016<s<0.0025)	Steep (0.0025<s<0.0057)	Very steep (0.0057<s)
Wide	(w>3647m)	WF	WM	WS	WV
Broad	(3647m>w>2343m)	BF	BM	BS	BV
Medium	(2343m>w>1147m)	MF	MM	MS	MV
Narrow	(1147m>w)	NF	NM	NS	NV

Table 3. Sediment storage surrogate descriptors.

Storage class	Sediment storage surrogate
1 (High)	WF, BF, WM
2 (Medium)	MF, BM, WS, BF, WM, NF, MM, BS, WV
3 (Low)	NM, MS, BV, NF, MM, BS, WV, NS, MV
4 (Very low)	NV, NS, MV

Table 5. Load matrix.

Original variable	PC1	PC2
Average slope	0.821	0.175
Average valley width	–0.587	0.538
Average altitude	0.348	0.860
Area under normalised curve	–0.659	0.193

tial for sediment storage, while macro-reaches characterised by flat slopes and wider valleys have a greater potential for storage. Macro-reach sediment storage surrogate classes were derived for average macro-reach slopes and widths utilising the WLRT approach. Although shown as straight lines in Table 2, the divisions between these classes were log-linear, since the boundaries were not equidistant but were based on break points in the data.[2] From the average slope and width of macro-reaches, a sediment storage surrogate was derived for each. These classes were High, Medium, Low and Very Low (denoted 1 to 4, respectively, Table 3).

Delineation of geomorphic province boundaries

Following the separation of the 99 selected river longitudinal profiles into 471 macro-reaches, an iterative process was followed whereby King's 1967 geomorphic province boundaries were revised (on a GIS) utilising the macro-reach boundaries. This coarse delineation process not only shifted the position of the 1967 boundaries, but also identified a number of additional sub-province boundaries (described later in this article). Further boundary changes were made on the basis of recent literature on the macro-scale evolution of southern Africa (see Footnote 1). It is recognised that this further sub-division process is not replicable, as it was based only on 'expert judgement'. This was, to some extent, unavoidable given the process followed and the scale of analysis. The outcome of the process was, however, the delineation of 34 geomorphic provinces and 12 sub-provinces for South Africa, Lesotho and Swaziland (Map 1, pp. 12—13). A full description of these provinces is given later in the article.

PRINCIPAL COMPONENT ANALYSIS

As part of the process of defining the geomorphic province boundaries was inductive, a principal components analysis (PCA) was undertaken to assess whether the 34 geomorphic provinces and 12 sub-provinces do, in fact, reflect similar land areas. Accordingly, PCA was applied to determine whether groupings of data existed indicating spatial similarities, and, conversely, whether distinct differences between these groupings were evident. If data group together within province boundaries, then it is reasonable to assume that the provinces reflect discrete land areas and that the delineations are sensible.

Data from the 471 macro-reaches identified for the 99 selected longitudinal profiles using the WLRT method were collated and investigated using STATISTICA. For each macro-reach the average slope, valley width, altitude and area under the normalised curve were calculated. The geomorphic province through which the largest proportion (by length) of the macro-reach flowed was taken as characteristic of the macro-reach. The PCA was performed on a correlation matrix as the scale of parameters such as slope and altitude were of very different magnitudes. This had the effect of highlighting the contribution of the parameters to variations in the data set irrespective of scale. In fact, it amounted to performing the analysis on a standardised matrix (so as to have a zero mean and unit variance) (Galpin, 1997).

Only those principal components with eigenvalues greater than unity were extracted, as these explain more of the data variance than does a single original variable (Manly, 1986). Two principal components were obtained from this data set and the eigenvalues and explained variance are shown in Table 4.

The load matrix showing the relationship between the original variables and the constructed principal components is shown in Figure 3. The first component is dominated by the slope, since the loading is 0.82. This is balanced, in smaller measure, by the area under the normalised curve. The altitude of the macro-reaches dominates the second component. Although not dominating either of the components, the valley width has an influence on both.

The scores for the data from all 471 macro-reaches are shown in Figure 4. A strong grouping exists around the origin, with some scattering in the first and fourth quadrants (using Cartesian convention). A few outliers are evident in the first quadrant and one in the second quadrant. Although the data are grouped in Figure 4, distinct individual groupings are evident when the data relating to individual geomorphic provinces are displayed. These results are shown in Figures 5 to 19 (the figure numbering follows the order in which the geomorphic provinces are described later in the article).

The PCA shows that lower levels of organisation are constrained by the geomorphic provinces, as hypothesised. For example, Figure 5 shows the score plot of the Eastern and Western Limpopo Flats geomorphic sub-provinces. The data for the Western Limpopo Flats plot is a distinct group, predominantly in the second quadrant, while the Eastern Limpopo Flats data spread across the third and fourth quadrants. The distinct

Table 4. Eigenvalues and explained variance of principal components.

Principal component	Eigenvalue	% Total variance explained	Cumulative eigenvalue	Cumulative variance explained %
PC1	1.574	39.36	1.57	39.36
PC2	1.097	27.42	2.67	66.78

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[2] The boundary separating the Medium from the Low sediment storage class had three points for which slope and width coordinates were known from Table 2. A least squares best fit showed that the points were best described by a straight line if the slope values were transformed to natural logarithms. Sub-boundaries separating the Medium and Low classes had two defined coordinates. When straight lines were derived for these, the intersection coincided with the main boundary. This intersection point was used as a coordinate to fit the lines for the boundaries between the High and Medium classes and the Low and Very Low classes (Table 3).

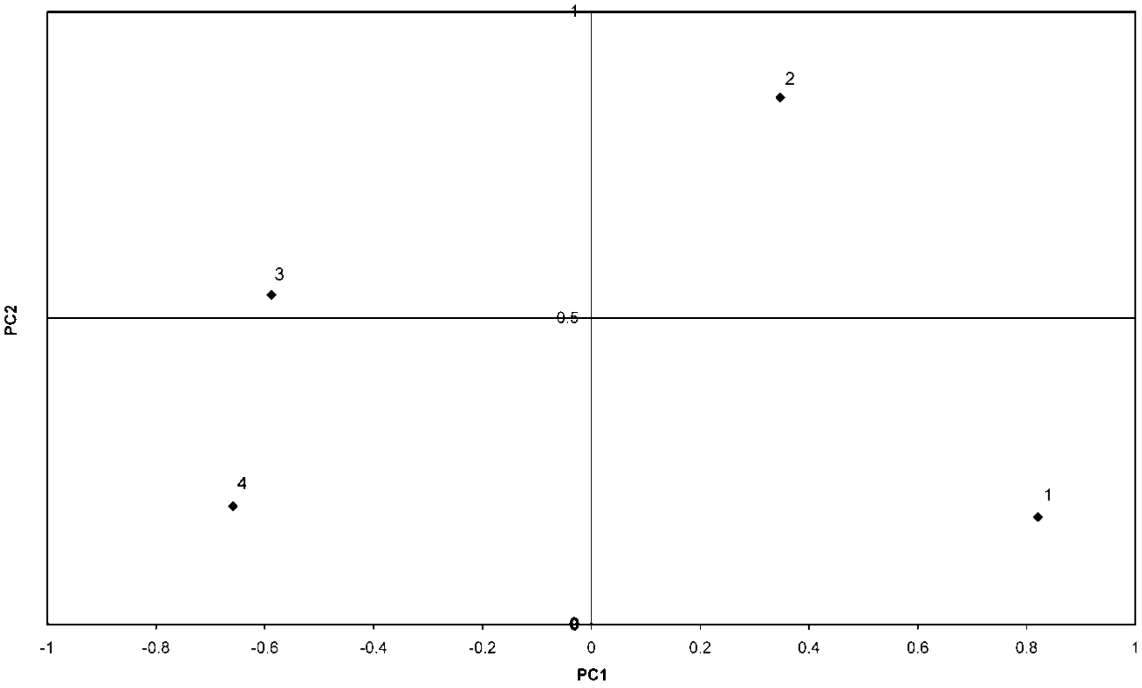

Figure 3. Load plot showing the relationship between the original variables and the extracted principal components where 1 = slope, 2 = average altitude, 3 = average valley width and 4 = area under the normalised curve.

differences between the two groups reflect the higher average altitude of the Western Limpopo Flats (838 m *vs* 484 m), its flatter slopes (0.0007 *vs* 0.0027) and its wider valleys (3934 m *vs* 1620 m), compared with the Eastern Limpopo Flats rivers. The average area under the normalised curve for the Western Limpopo Flats was 0.5 while for the Eastern Limpopo Flats it was 0.459.

A further example of this grouping is provided by the Great Escarpment geomorphic province. There are 31 macro-reaches within this province. With two exceptions, these have positive PC1 scores (Figure 7). With the exception of one macro-reach, the slopes are all in the Very Steep range and the average slope for the group is more than four times that of the whole data set. The valley widths are narrow and the altitudes above average, while the average shape descriptor is below the average for the full data set. In general, the macro-reaches are also short (average 31 km *vs* 62 km for the data set). The three outliers with high scores on both principal components are reaches of the Mkomazi, Mzimkulu and Thukela rivers. These reaches are very short (5.4 km, 5.1 km and 6.5 km, respectively) and represent the upper courses of these rivers where the slopes are very high (the highest three in the whole data set).

Northeast of the Great Escarpment province is the Lowveld geomorphic province. In contrast to the results for the Great Escarpment (Figure 7), only one of the scores for the Lowveld data set does not lie in the third quadrant (Figure 8). This 'outlier' is unique in having a low area under the normalised curve; all other macro-reaches are in the mildly concave, linear

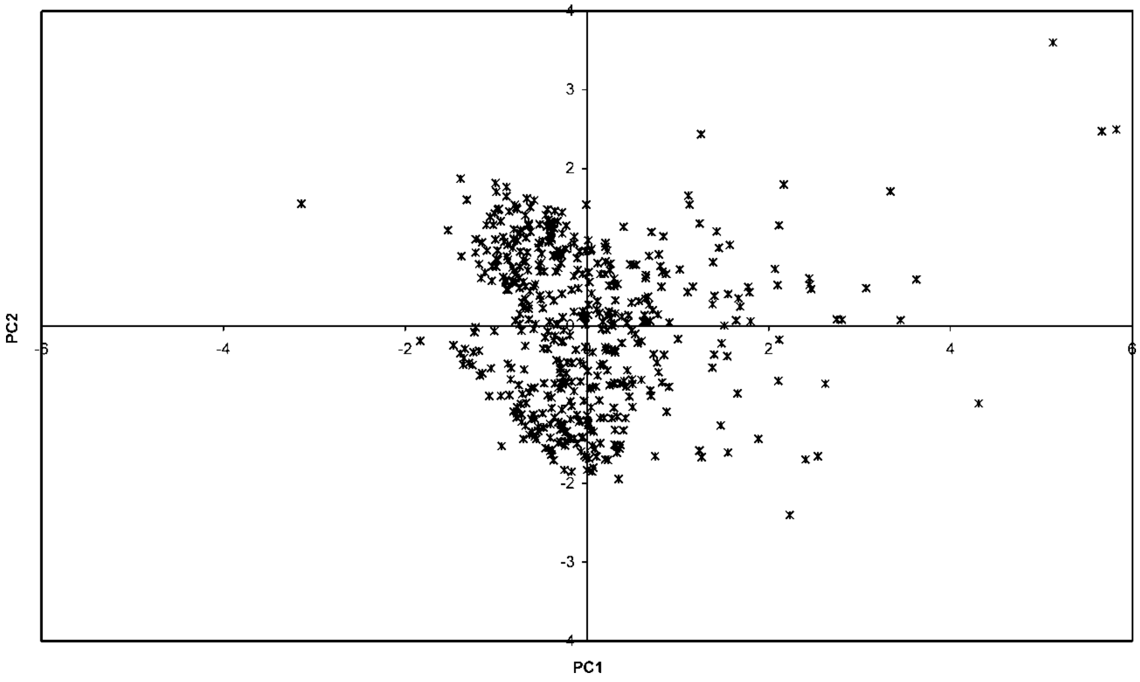

Figure 4. Score plot of all macro-reaches against extracted principal components.

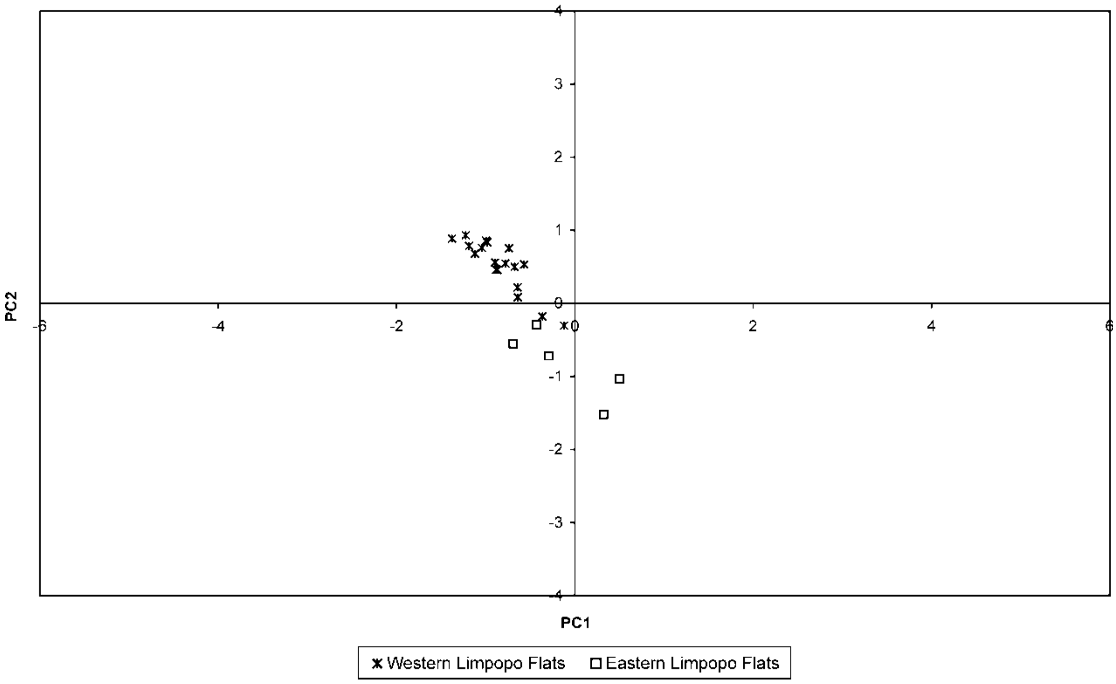

Figure 5. Score plot of the Western and Eastern Limpopo Flats geomorphic sub-provinces.

and mildly convex range. The negative scores on PC1 are indicative of below average slopes, above average widths and above average shape descriptors. The scores are also negative on PC2 primarily due to the low altitude. This distinct difference in score plots for adjacent geomorphic provinces indicates a significant difference between the two data sets, while there is similarity within the data sets reflecting similar features of slope, valley width and so on. Other geomorphic provinces in which the data show similarly distinct groupings are the Mpumalanga Highlands (Figure 9), Lower Vaal and Orange Rivers[3] (Figure 13), Eastern Escarpment Hinterland (Figure 14), Zululand Coastal Plain (Figure 14), Namib (Figure 15), Namaqua Highlands (Figure 15), Lesotho Highlands (Figure 16), Ladysmith Basin (Figure 16), Queenstown Basin (Figure 17) and East London Coastal Hinterland (Figure 17).

While PCA provides evidence for a clear distinction between many adjacent geomorphic provinces, there is a gradational change between others. For example, in the eastern part of southern Africa, many rivers that have their source on the Great Escarpment flow onto the South Eastern Coastal Hinterland geomorphic province (Map 1). Most scores for the South Eastern Coastal Hinterland province group slightly below the graph origin, with some scattering to the right (Figure 10). The points with high scores for PC1 are indicative of steep slopes.

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[3] The scores for this province are primarily grouped in the second quadrant (Figure 13), but data are found in all quadrants. Negative PC1 scores reflect below average slopes. The wider than average valleys influence both PC1 and PC2 values. The average shape descriptor value and altitude are the same as for the overall data set. Three outliers in the fourth quadrant reflect scores for macro-reaches that are steeper than the others in the geomorphic province and also have narrower valleys and relatively low altitudes.

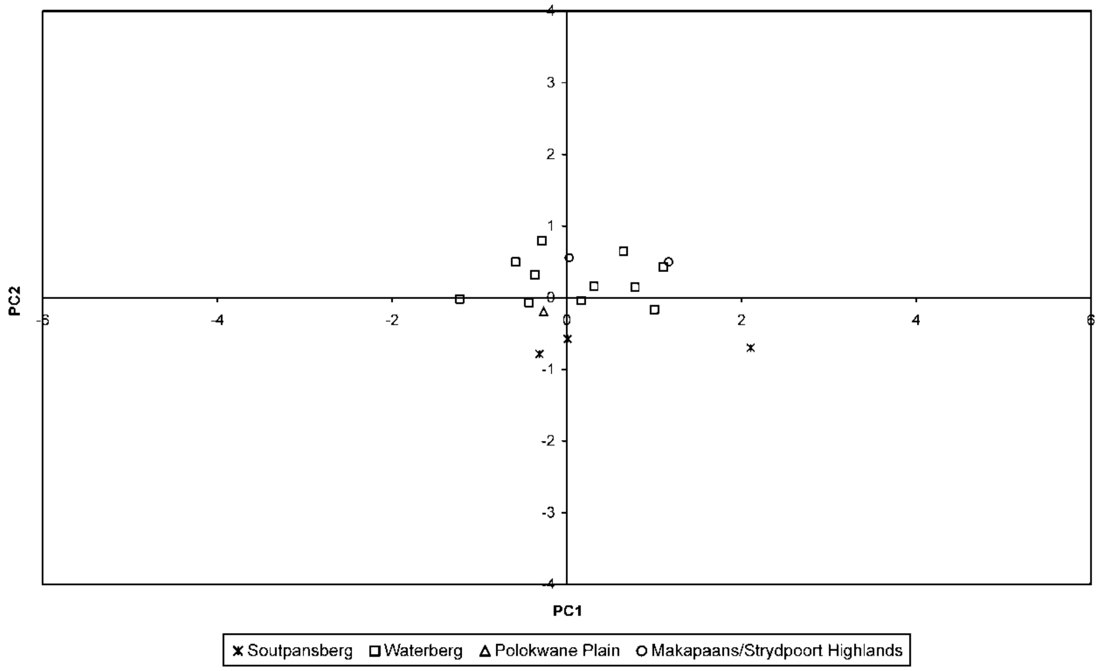

Figure 6. Score plot of the Soutpansberg, Waterberg, Polokwane Plain and Makapaans/Strydpoort Highlands geomorphic provinces.

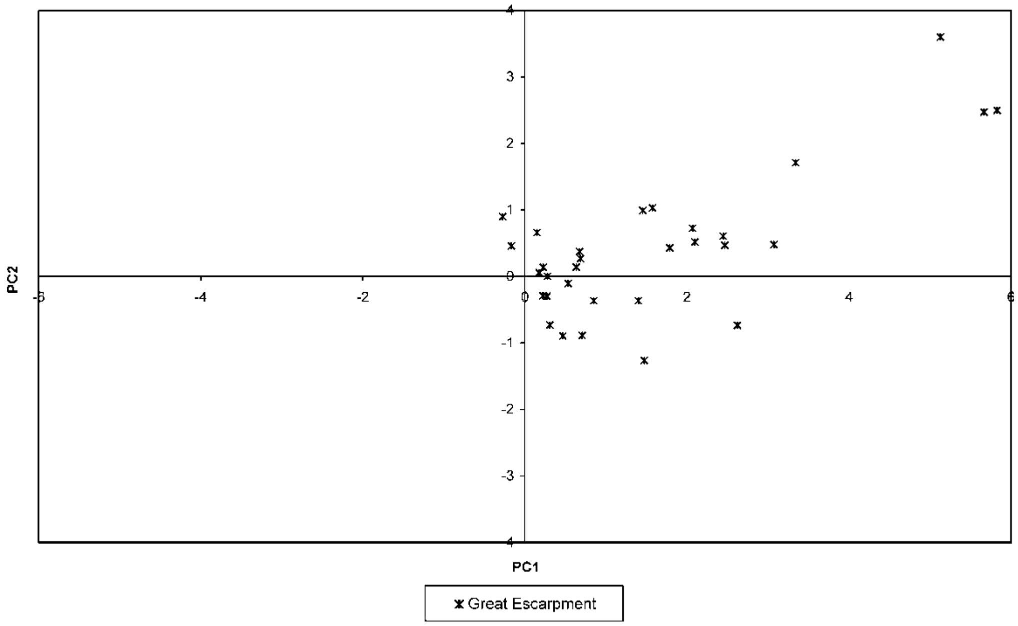

Figure 7. Score plot of the Great Escarpment geomorphic province.

The main group, however, has slopes ranging from flat to very steep, with most slopes above the average for the entire data set. The altitude is below average, as is the average valley width. The area under the normalised curve is very close to average. Although there is some overlap in the distribution of the scores from the two provinces, the data for them form distinct groups in different regions of the score plot, primarily as a result of differences in macro-reach slope and altitude.

An additional example of gradational change is evident between the Waterberg and the Makapaans/Strydpoort Highlands provinces (Figure 6) (although no rivers traverse both, these are adjacent provinces with similarities in macro-reach descriptors) and the Makapaans/Strydpoort Highlands and the Polokwane Plain provinces (Figure 6). This is also supported by the fact that only a single macro-reach occurred within the Polokwane Plain, indicating that this transition is not marked by a distinct change-point in the river longitudinal profile.

Similar gradational changes are reflected in the data for the Eastern and Western Transvaal Basins (Figure 9), Kalahari and Ghaap Plateau (Figure 11), Northeastern, Northwestern and Southern Highveld (Figure 12), Northern Cape Pan Veld and Upper Karoo (although the overlap is minor) (Figure 1), sub-provinces of the Cape Fold Mountains (Figure 18) and the Southern Coastal Lowlands, Southern Coastal Platform and the Swartland (Figure 19) provinces.

The score plots for the Southern Bankenveld (Figure 8) and Southern Kalahari (Figure 11) are difficult to interpret because limited data are available. For the first, two macro-reaches are representative, while for the second only a single macro-reach is representative. In both cases the scores for these plot separately from those for adjacent geomorphic provinces, indicating that the respective macro-reaches are distinctly different.

A number of geomorphic provinces or sub-provinces have been delineated, but are not reflected in the macro-reach data.

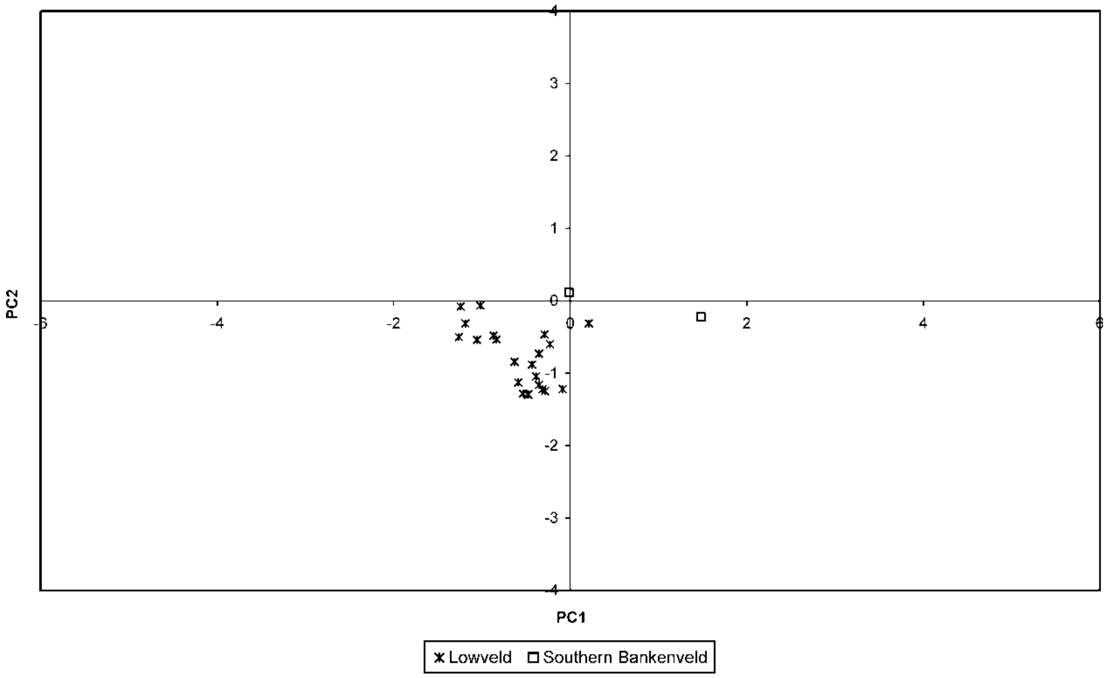

Figure 8. Score plot of the Lowveld and Southern Bankenveld geomorphic provinces.

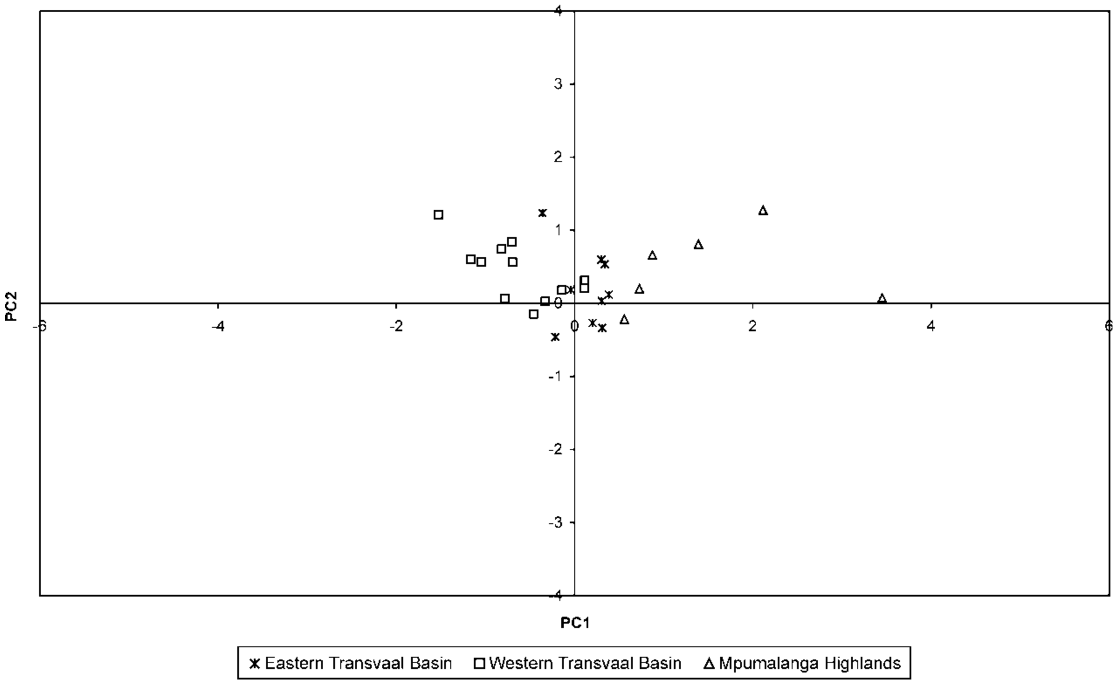

Figure 9. Score plot of the Western and Eastern Transvaal Basin and the Mpumalanga Highlands geomorphic provinces.

This is, in part, because none of the selected 99 rivers traversed the area e.g., the Tankwa Karoo and Roggeveld Karoo. The Lebombo Highlands, Northern Bankenveld and Southeastern Coastal Platform geomorphic provinces also had no representative macro-reaches. Where there was gradation in slope between the provinces or where the delineated geomorphic provinces were narrow, no macro-reach breaks defined these because the dominant geomorphic province was only traversed by a section of river. These delineations were, however, retained based on other evidence described later in this article.

A description of the 34 geomorphic provinces and 12 sub-provinces is presented in the remainder of this article. The provinces described in the following sections are based on a revision of King's (1967) provinces using the two sets of criteria already discussed, i.e., the macro-reach boundaries derived from the 99 selected river longitudinal profiles, and an 'expert approach' based on judgement and the most recent scientific literature. As already indicated, this approach is not repeatable in its entirety and some province boundaries may thus be open to dispute. Evidence from the PCA indicates, however, that the characteristics of the macro-reaches (as measured) within many of the geomorphic provinces are distinctly different from one another. This provides supporting evidence that the boundaries are sensible, although there are some exceptions. It is argued, however, that notwithstanding these limitations, there is reasonable evidence that the geomorphic province circumscribe land areas that are internally homogenous in that they contain a limited range of recurring landforms that reflect comparable erosional, climatic and tectonic influences.

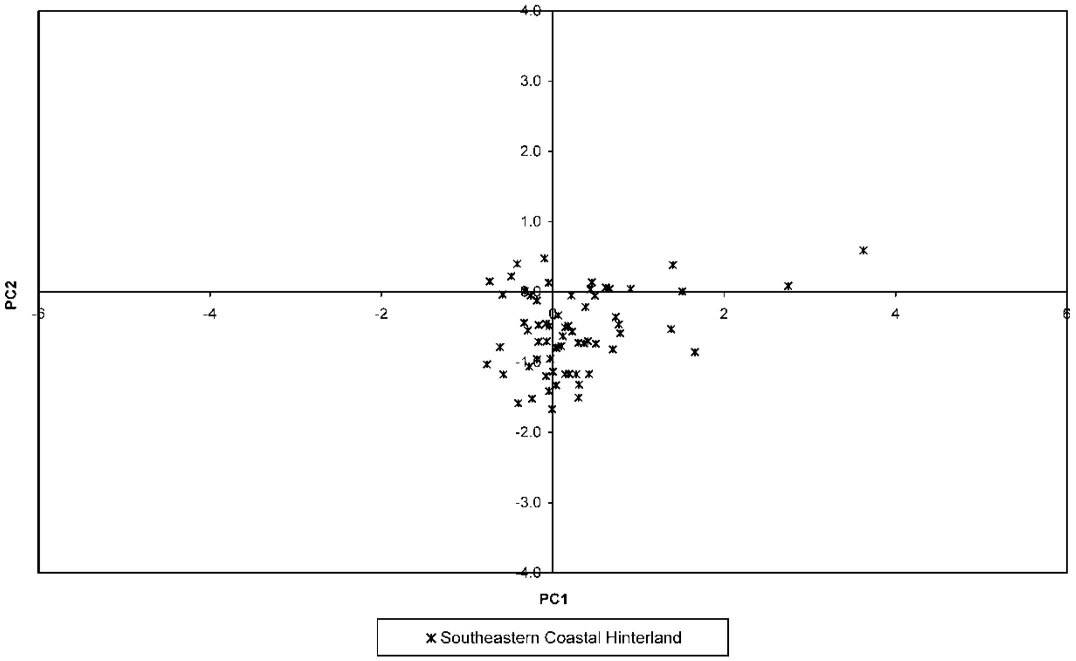

Figure 10. Score plot of the Southeastern Coastal Hinterland geomorphic province.

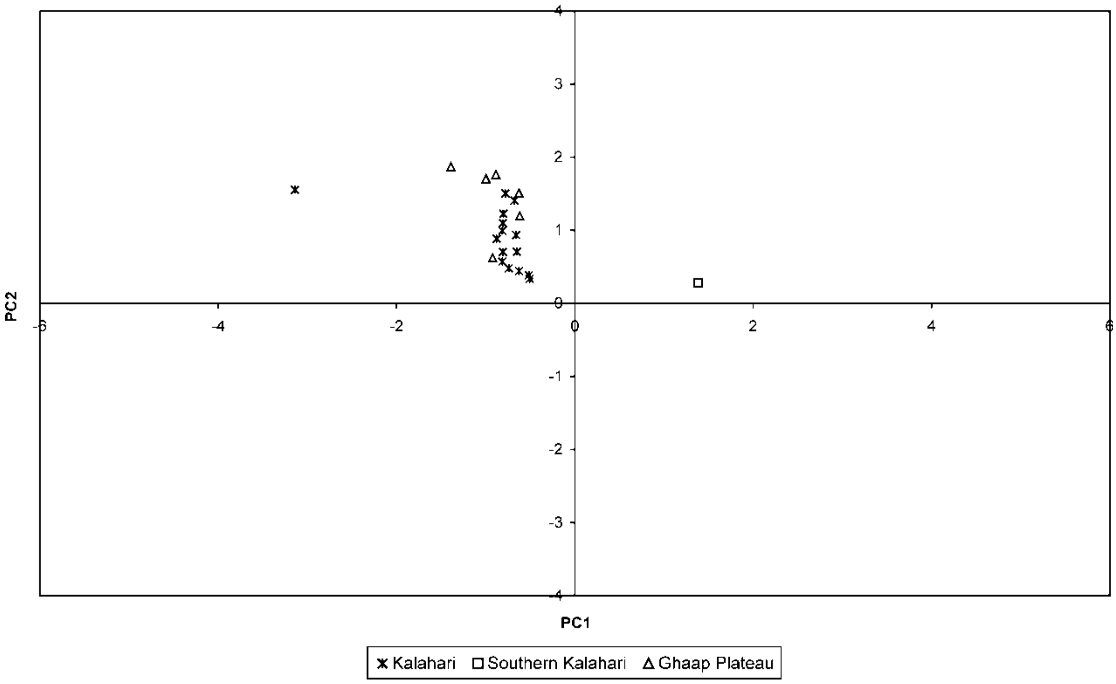

Figure 11. Score plot of the Kalahari, Southern Kalahari and Ghaap Plateau geomorphic provinces.

The descriptions presented below of each of the geomorphic provinces are ordered from northwest to southeast (Map 1).

DESCRIPTION OF THE GEOMORPHIC PROVINCES OF SOUTH AFRICA, LESOTHO AND SWAZILAND

Limpopo Flats

This province comprises the long valley (technically a fault-controlled trough) of the Limpopo River[4] (Map 1). It is generally an open inselberg-studded plain dominated by gentle slopes. In the Limpopo Flats much of the former soft Karoo cover has been removed, but in some areas these sediments have been preserved in down-faulted blocks. Although underlain by a wide variety of rock types, granites and gneisses are the most widespread substrates and, as a consequence, most of the rivers in the western Limpopo Flats meander freely on wide, sandy floors. However, in the central and eastern parts of the province, which are occupied by rocks of the Limpopo Belt, sinuous ridges and koppies are formed by the more resistant lithologies. These interruptions apart, the western part of the province is generally well planed and is dominated by the Early Miocene to Pliocene Post-African I erosion surface (Partridge & Maud, 1987). Only in the dissected, eastern part of the province are a few small remnants of the African surface preserved (e.g., the Malonga Flats). A number of active

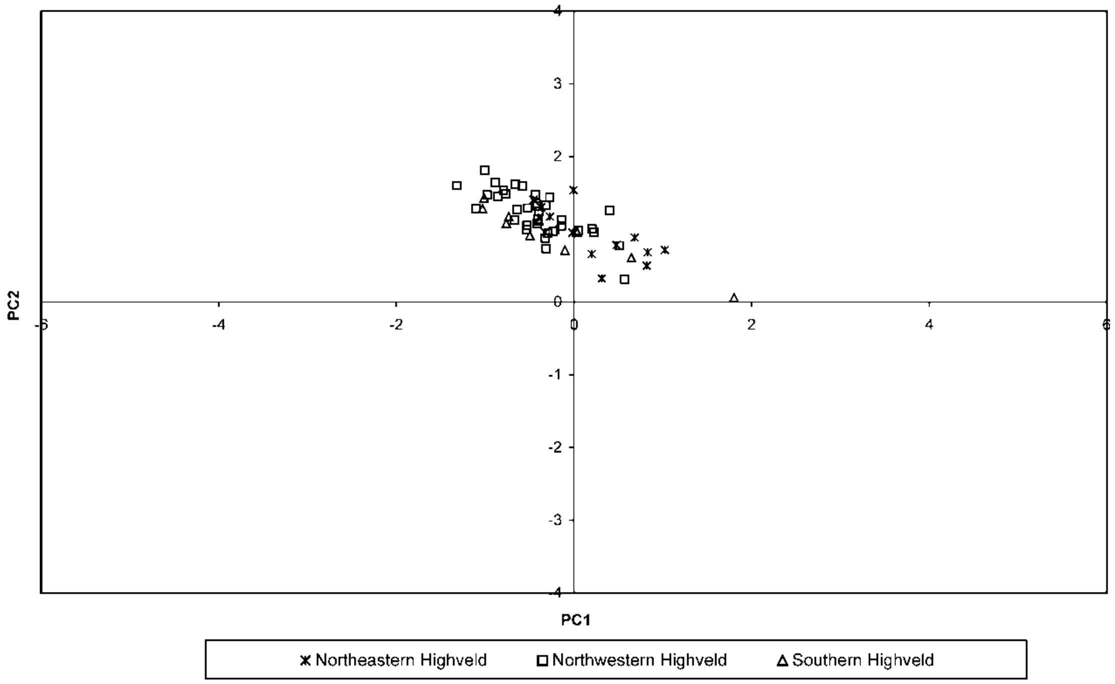

Figure 12. Score plot of the Northeastern, Northwestern and Southern Highveld geomorphic sub-provinces.

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[4] The Limpopo River developed along a rift formed at the time of the opening of the Mozambique Channel (McCarthy & Rubidge, 2005).

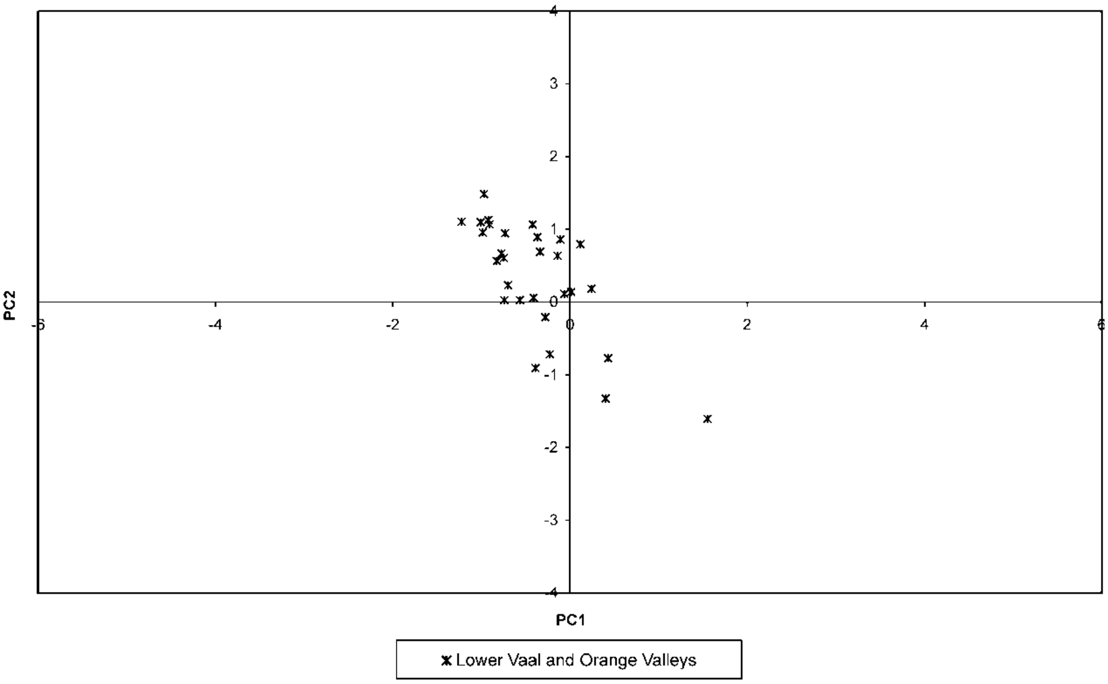


Figure 13. Score plot of the Lower Vaal and Orange Valleys geomorphic provinces.

faults and shear zones bear testimony to the significant influence that the Kaapvaal Craton-Limpopo Belt contact has on the province (Roering *et al.*, 1992). The rapid transition from the granite-greenstone terrain of the Kaapvaal-Craton to the granulite terrain of the Southern Marginal Zone of the Limpopo Belt helps to define the boundary between the Limpopo Flats and the Soutpansberg and Polokwane Plateau provinces.

The longitudinal profile of the Limpopo River can be described as averagely convex (Table 6). The profile is smooth and flat until just below the junction of the Lephalale River, whereafter the profile steepens, and immediately below the Mokgalakwena River a series of rapids has been cut into the more resistant lithologies of the Limpopo Belt. Overall, however, the valley cross-sectional profile is broad and the longitudinal profile flat, so that the sediment storage surrogate descriptor is BF, and the profile is best described by an exponential best fit curve (BFC) (Table 6). The tributaries joining the Limpopo River, although remarkably uniform in terms of their longitudinal profile characteristics (Figure 20), show a marked progression from west to east (Table 6), which is manifested in a distinct decrease in average valley cross-sectional width, as well as in an increase in slope (Table 6). This is coincident with, and the result of, the influence on the main stem Limpopo and its tributaries of resistant rocks of the Limpopo Belt.

There is justification, therefore, for dividing the Limpopo Flats into two sub-provinces, the Western and Eastern Limpopo Flats (the junction between the western and eastern groups lies just west of the Mokgalakwena/Limpopo confluence) (Map 1).

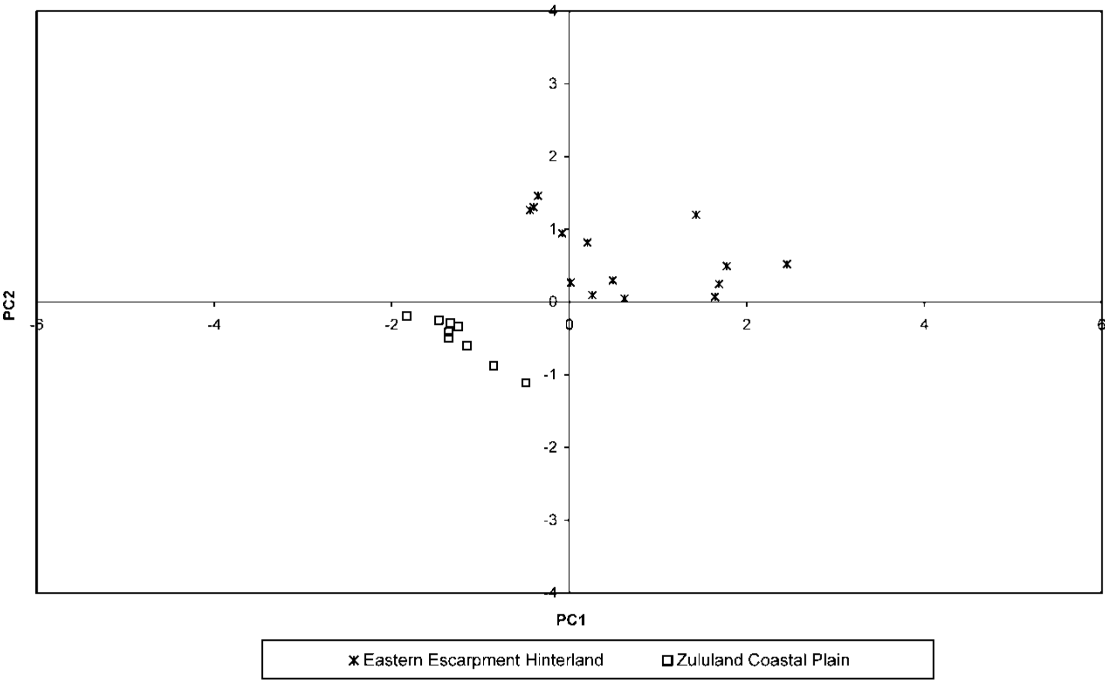
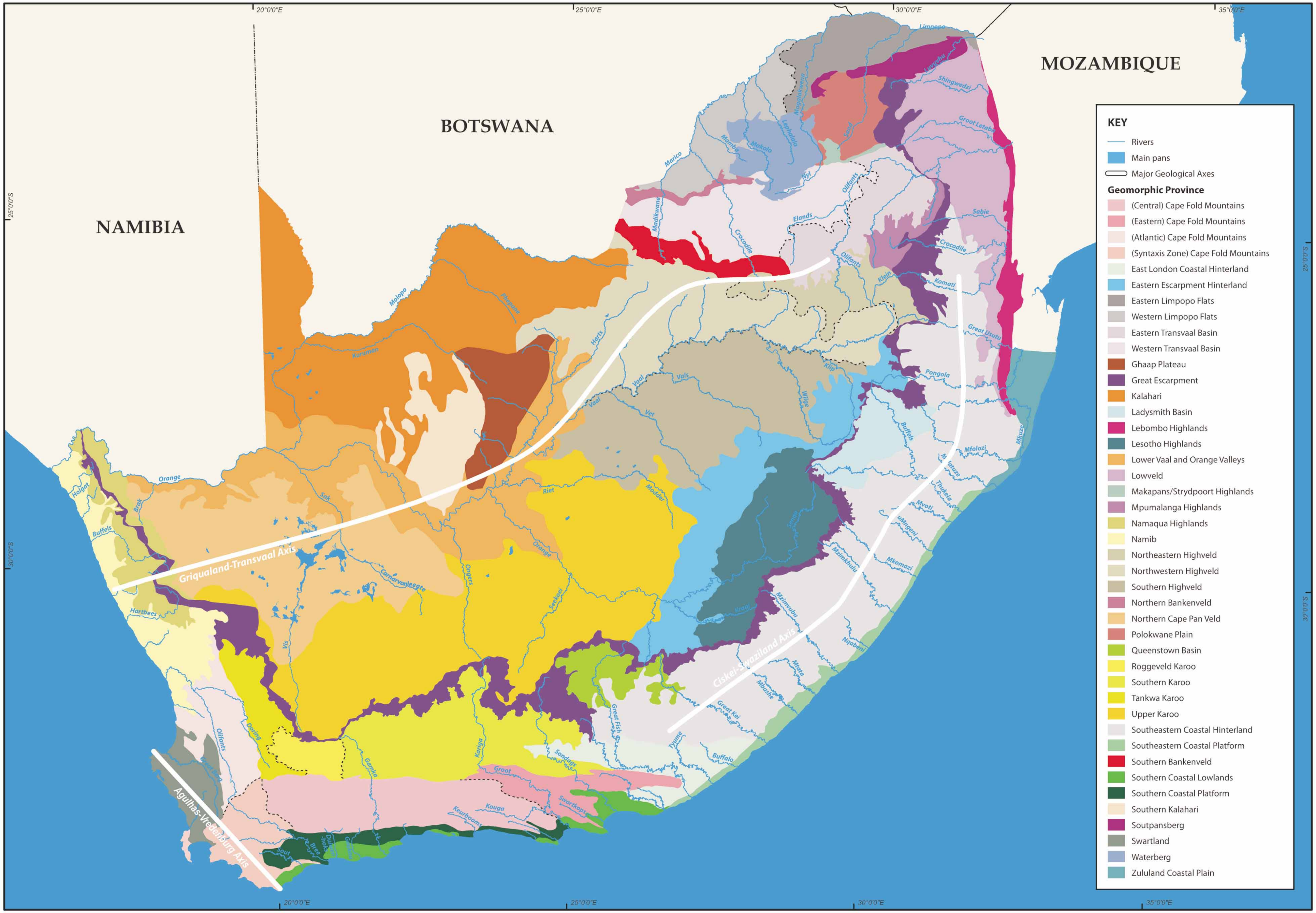


Figure 14. Score plot of the Eastern Escarpment Hinterland and Zululand Coastal Plain geomorphic provinces.



Map 1. Geomorphic provinces of South Africa, Lesotho and Swaziland.

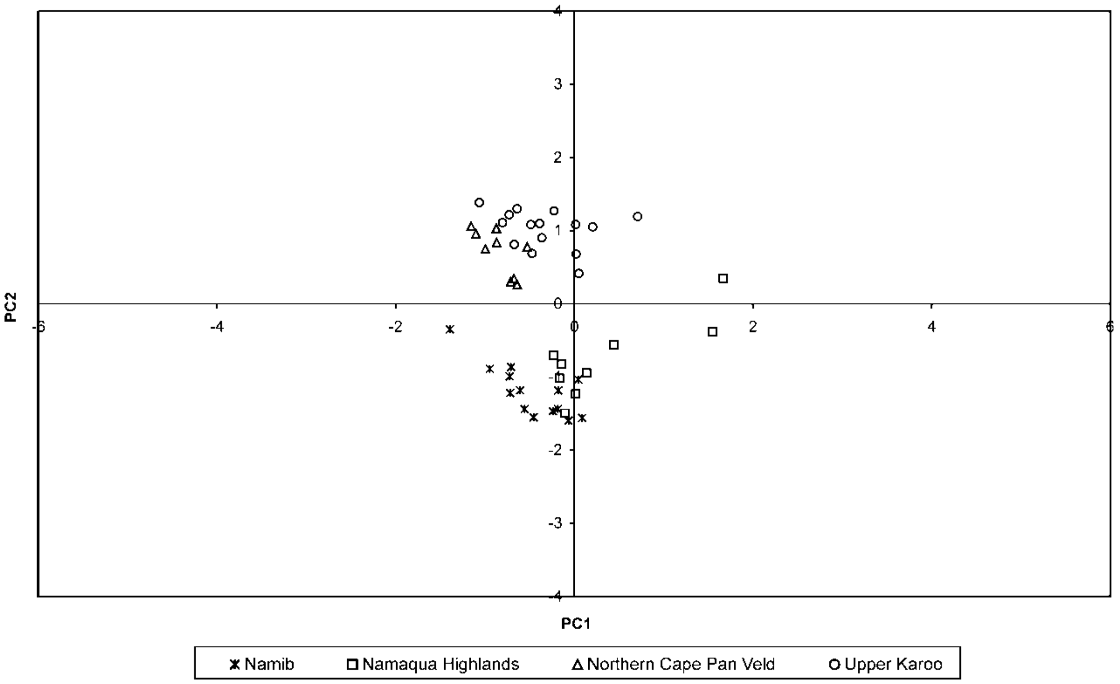


Figure 15. Score plot of the Namib, Namaqua Highlands, Northern Cape Pan Veld and Upper Karoo geomorphic provinces.

Sub-province Western Limpopo Flats

A western group of tributaries (Madikwane/Marico, Crocodile, Mamba, Mokolo, Lephalale and Mokgalakwena rivers), underlain mainly by granite-gneiss, flowing predominantly northwest into the Limpopo River (Map 1). These tributaries are characterised generally by concave, linear BFCs (the Crocodile and Mokolo rivers being the exceptions, as they are characterised by exponential and power BFCs, respectively), wide valley cross-sectional profiles and flat valley longitudinal slopes, so that the sediment storage surrogate descriptors are mainly WF (Table 6). The Limpopo Flats section of these systems is associated with significantly wider valley cross-sectional profiles and flatter slopes than the upstream provinces (Table 6). This section of the Limpopo Flats represents the well planed Post-African I surface (Partridge & Maud, 1987).

Sub-province Eastern Limpopo Flats

An eastern group of tributaries (Sand, Nzhelele and Luvuvu rivers) characteristically different from the western group.

These tributaries flow north and northwest across rocks of the Limpopo Belt, and while they are also characterised by linear BFCs, they are significantly narrower in valley cross-sectional profile and steeper in slope (Table 6); consequently all are characterised by the MS sediment storage surrogate descriptor (Table 6).

Soutpansberg

This province, underlain mainly by north-dipping, resistant Soutpansberg Group quartzites, comprises the Soutpansberg Mountain range the crest of which rises above the level of the African surface (Map 1). It is bounded by faults in the north and

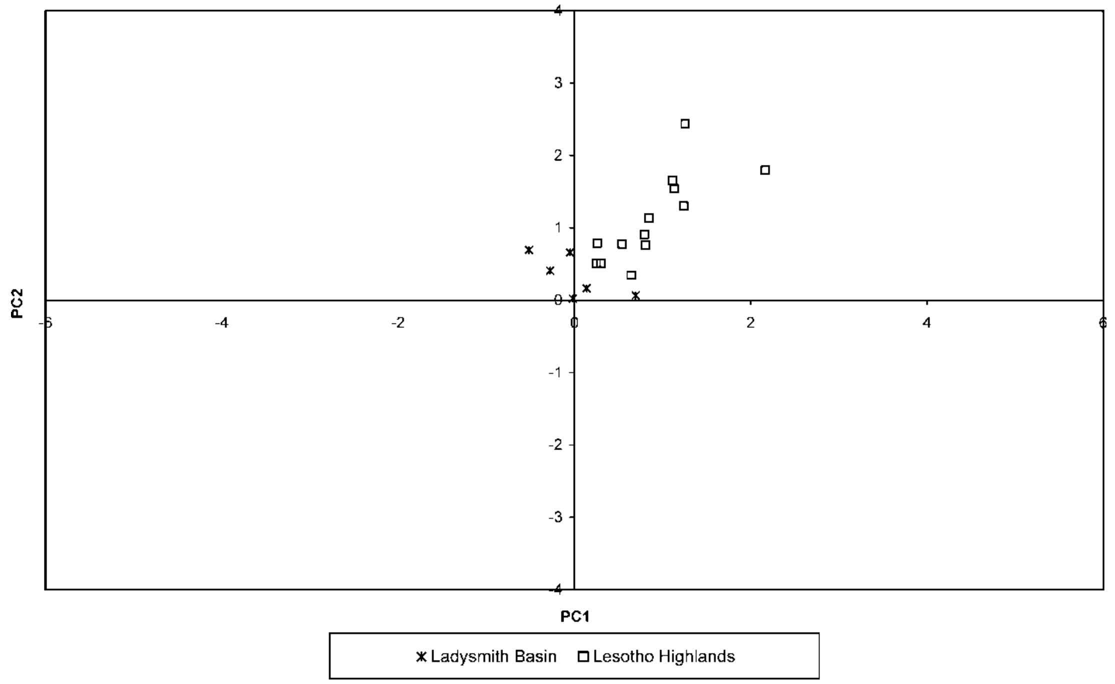


Figure 16. Score plot of the Ladysmith Basin and Lesotho Highlands geomorphic provinces.

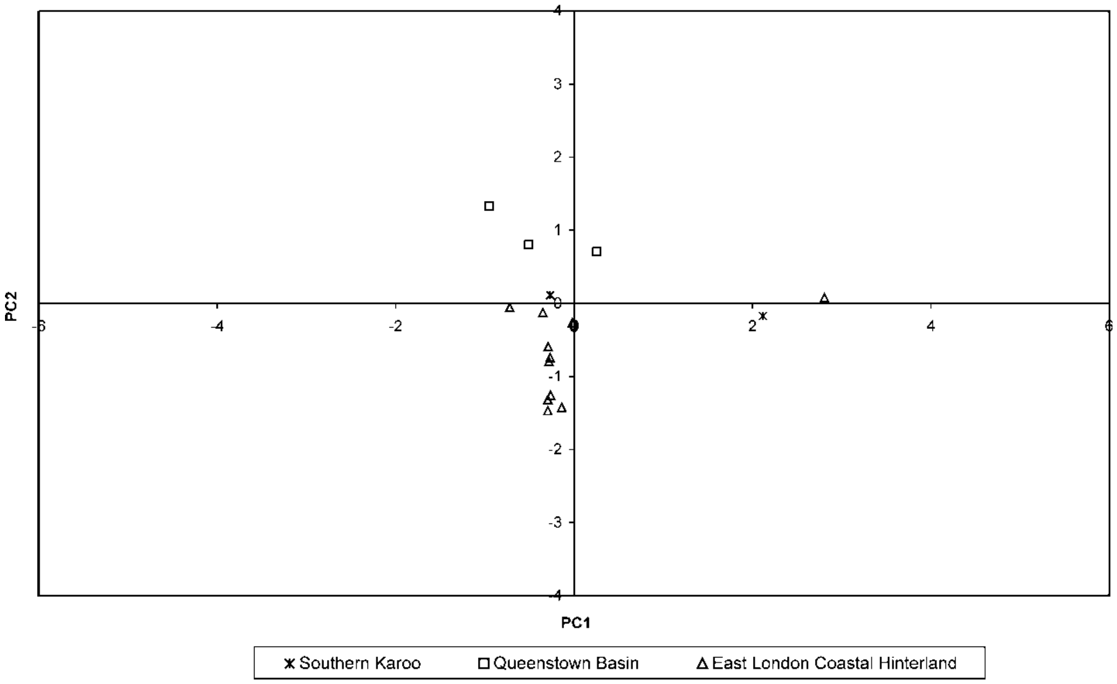


Figure 17. Score plot of the Southern Karoo, Queenstown Basin and East London Coastal Hinterland geomorphic provinces.

east and is transected by spectacular gorges (e.g., that cut by the Sand River). Strike-faulting has produced a repetition of strata and triplication of the ridges (King, 1942). Strike-transgressive drainage is a legacy of superimposition from pre-existing Karoo cover rocks. The north-northeasterly flowing Sand, Nzhelele, Mutale and Luvuvu rivers cross the intervening lava and shale in steep-sided, but often flat-floored, valleys. Tributaries invariably occupy narrow, steep valleys with irregular longitudinal profiles.

The four main stem rivers that drain this province are physically diverse, the Sand and Nzehele rivers (to the west) drain north into the Limpopo Flats, and the Mutale and Luvuvu rivers (to the east) drain north-northeast (also into the Limpopo Flats). The north-northeast draining Mutale and Levuvu rivers follow, in part, the active faults (King, 1967) within the province and are of more recent origin than the superimposed rivers to the west. Although these rivers are similar in terms of their valley longitudinal slopes and valley cross-sectional widths (Table 6) (so that their sediment storage surrogate descriptors are predominantly MS), they are characterised by distinctly different BFCs (Table 6).

Information Box 1

It is interesting to note that before the rifting of Gondwana, the Limpopo River was fed by the Zambezi and Okavango rivers and tributaries (Moore & Larkin, 2001). The offshore delta of the palaeo-Limpopo River is in fact larger than that of the present-day Zambezi River, and forms much of the present-day coastline between Maputo and Beira in Mozambique (McCarthy & Rubidge, 2005). Around 60 Ma, differential uplift along the Kalahari–Zimbabwe axis cut off the headwaters of the Limpopo River, significantly reducing its catchment area and discharge. Coeval with this event was the creation of the Kalahari Basin and the formation of large inland lakes such as Lake Makgadikgadi (*cf.* Partridge, 1998; Partridge & Maud, 2000).

Waterberg

This province is underlain almost exclusively by resistant Waterberg sandstones and conglomerates (and a few softer shale beds) and unlike the Soutpansberg, these are flat-lying, so that the province comprises a series of plateau remnants (pre-rifting residuals) separated by deeply incised (dissection of a variety of ages and ongoing), structurally-controlled valleys (Map 1). Some rivers occupy narrow gorges (e.g., reaches of the Mokolo River), while others have gentle, open, sandy floors that belong to the Post-African I surface (*cf.* Partridge & Maud, 1987). Waterfalls are common along tributary streams the steep, narrow valleys of which typically have stepped longitudinal profiles, while those of the larger rivers are less irregular. The rivers exit the Waterberg onto the Limpopo Flats via waterfalls and steep gorges.

Four main rivers drain the Waterberg; from west to east these are the Mamba, Mokolo, Lephalala and Mokgalakwena. Three (the Mamba, Mokolo and Lephalala rivers) are superimposed rivers imprinted onto the Waterberg from a pre-existing Karoo cover (King, 1967). All three rise within the Waterberg at altitudes of between 1500 and 1700 m and exit onto the Limpopo Flats at between 800 and 1000 m (Table 6). The Mamba River is the shortest of these, with only 20 or so kilometres of its course dissecting the Waterberg; consequently, the valley cross-sectional widths are narrow and the concave longitudinal profile very steep (Table 6). This is reflected in the sediment storage surrogate descriptor which is NV (Table 6). It is also the only river in this province characterised by a linear BFC (these characteristics are in strong contradistinction with the remainder of the rivers traversing the Limpopo Flats). The Mokolo River differs from the Mamba River in its broader valley cross-sectional profile and a flatter longitudinal slope, so that the sediment storage surrogate descriptor is MS (Table 6). However, from the Mokolo River eastwards there is a clear trend towards gentler slopes and broader valley cross-sectional forms (Table 6) as the province grades into the Polokwane Plain. It is interesting to note that the Mokolo and Mokgalakwena rivers are characterised by logarithmic BFCs, whereas the Lephalala is characterised by a power BFC (Table 6). Both these curve forms are poorly represented in the data set of southern African rivers.

The Mokgalakwena River rises on the southern flanks of the Waterberg flowing west–east (following the line of the active

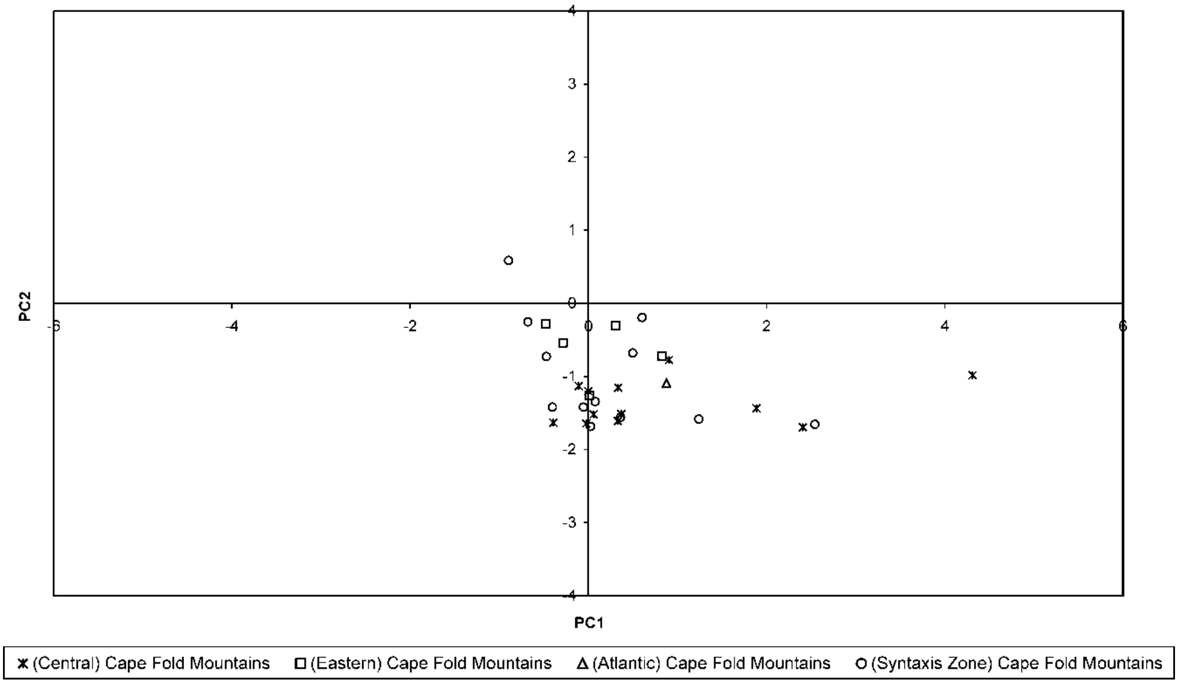


Figure 18. Score plot for the Cape Fold Mountains geomorphic province.

Thabazimbi/Murchison fracture) before making an orthogonal turn to the north as it crosses the Western Transvaal Basin. It then continues north-northwest back onto the Waterberg before exiting onto the Limpopo Flats. The longitudinal profile is considerably flatter (18% to 1100%, but due to the variations in slopes this is not statistically significant) and the valley cross-sectional profile broader (31% to 87%, significant at $\alpha = 0.05$ in an ANOVA comparison) than the other rivers of the province (Table 6) and as a consequence, the sediment storage surrogate descriptors are BS in the south and BM in the north (Table 6). In addition, the southern part of the Mokgalakwena River is characterised by a mildly convex longitudinal profile and a linear BFC, while in the north, the river is characterised by a logarithmic BFC and a concave longitudinal profile (Table 6).

Polokwane Plain

This province is underlain by granite-gneiss (with schist pods) and carries remnants of the early Cretaceous dissected African erosion surface on major interfluves (Partridge & Maud, 1987) (Map 1). The distinguishing feature of this province is the heavily etched surface (reworked in the Post-African I cycle) that is reflected in broad open valleys interspaced with numerous rocky koppies. The landscape is arched along a north–south axis, with the eastern limb being steeper than the western (King, 1967). On the eastern boundary the arching has deflected the north-flowing middle reaches of the Sand and the Mokgalakwena rivers to the northeast, while the northern headwaters of the Letaba and Pafuri rivers flow east off the Great Escarpment into the Lowveld. To the south, the headwaters of the north-bank tributaries of the

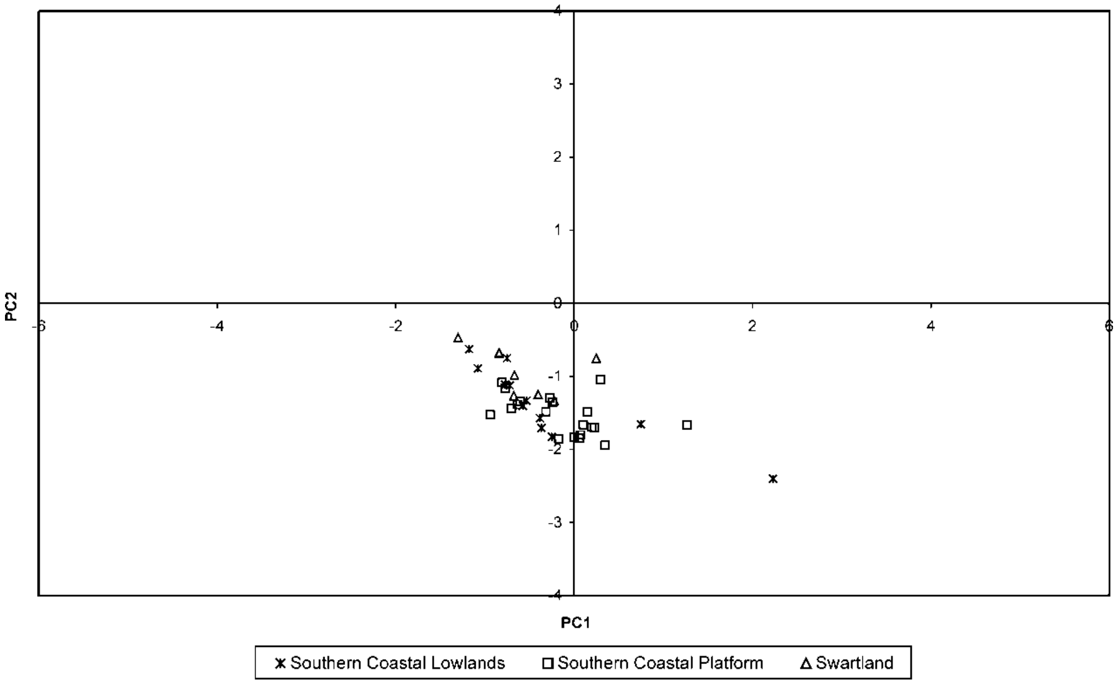


Figure 19. Score plot for the Southern Coastal Lowlands, Southern Coastal Platform and Swartland geomorphic provinces.

Olifants River flow southeast into the Western Transvaal Basin. These headwaters, however, occupy only very short sections of the province.

The two north-flowing rivers (the Mokgalakwena and Sand rivers) drain more than 95% of the Polokwane Plain, with the Sand River draining the largest area. Both the Mokgalakwena and Sand rivers are characterised by mildly concave longitudinal profiles and linear BFCs (Table 6). However, the Mokgalakwena River has a narrower valley cross-sectional profile and flatter slope than the Sand River, so that the sediment storage surrogate descriptors are BS and MF for the Sand and Mokgalakwena rivers, respectively (Table 6).

Makapaans/Strydpoort Highlands

This high relief mountainous province is underlain by quartzite and dolomite (Map 1). South of the province lies the Thabazimbi-Murchison lineament along which the Nylsvley wetland has developed. This fault is still active and has a significant impact on drainage in the region (McCarthy & Hancox, 2000). The summits of this province are above the level of the African surface (Partridge & Maud, 1987). Dissection through a pre-existing Karoo cover has meant that the superimposed rivers cut at right angles through the Strydpoort Range (e.g., the Hlakaro and Klipspruit rivers).

The province represents a significant watershed. To the north and west are the headwaters of the Sand River that follow northward courses across the Polokwane Plain. The short section of the Sand River within this province has cut a very steep, narrow valley (Table 6), so that the sediment storage surrogate descriptor is MV (Table 6). The longitudinal profile is best described as a averagely concave and logarithmic BFC (Table 6). To the south, the north bank tributaries of the Olifants River (e.g., Nkumpi, Klipspruit and Hlakaro rivers) drain south and southeast into the Western Transvaal Basin where they join the Olifants system. These occupy very short and steep valleys.

Great Escarpment

The Great Escarpment forms a continuous rampart-like step separating the coastal hinterland of southern Africa from the elevated interior plateau (Map 1). In some areas, the relief of the Great Escarpment is accentuated by local geology (e.g., in the Royal Natal National Park and Blyde River area). The province is underlain by a variety of rocks of different ages; in the northeast, for example, are granite-gneisses and sedimentary strata of the Transvaal Supergroup; in KwaZulu-Natal Karoo Supergroup sediments and lavas make up the escarpment, while on the west coast, erosion of the Cape Supergroup sediments and Namaqualand granite-gneisses create its topography. At its highest, in the Drakensberg of KwaZulu-Natal, the local relief within the province is as high as 2000 m, elsewhere total relief is mostly much lower, but is seldom less than 300 m.

The Great Escarpment owes its origin to the fragmentation of Gondwanaland in the late Jurassic and early Cretaceous (McCarthy & Rubidge, 2005)[5]. Rifting created a steep marginal escarpment, which was eroded back by rivers fed by the generally humid tropical climates of the Cretaceous. Most scarp recession occurred in the Cretaceous (Partridge & Maud, 2000). However, rates of recession slowed as climates became drier during the Cenozoic, but accelerated briefly in the Neogene following pulses of uplift which were largest in the South Eastern Coastal Hinterland (Partridge & Maud, 2000). This, together with the fact that there is no evidence of major fault control along its length, makes the Great Escarpment an erosion feature that has remained the most actively evolving segment of the southern African landscape since its formation. In some areas, such as Mpumalanga, KwaZulu-Natal and the Eastern Cape, the province is broad (up to 80 km) and is dissected by an intricate drainage network; here incision is usually deep, valley cross-sectional profiles narrow and longitudinal profiles very steep and irregular (stepped as hard barriers are crossed). Where the province is narrow, similar drainage geometries prevail, but the longitudinal profiles of rivers are everywhere very steep with numerous waterfalls. The province is also subject to a wide variety of climatic regimes, from humid tropical inland of the Lowveld to hyper-arid adjoining the Namaqua Highlands.

The Great Escarpment is a significant source of runoff for the majority of South Africa's and Swaziland's east flowing rivers. Twenty-two major east-draining rivers have their source in this province (Map 1). In the northeast, the province trends north to south in a narrow band approximately 20 km wide. Four major rivers traverse this region, the Luvuvu and Great Letaba which have their source in this province and flow east onto the Lowveld, and the Olifants and Blyde rivers which have their sources further west in the Mpumalanga Highlands and Highveld, respectively, and also exit across the Lowveld. Valley cross-sectional widths are predominantly narrow, becoming narrower from north to south (Table 7). Slopes are mainly very steep, so that the sediment storage surrogate descriptors range from MV to NV (Table 7). The profiles are characterised by both linear and exponential BFCs.

Information Box 2

The Olifants River has its source on the Highveld, with the major part of its drainage basin lying behind the Great Escarpment, a situation almost unique in the country (the Thukela, Bushmans, Great Fish, Gamtoos, Western Cape Olifants and Buffels rivers also display this characteristic, but the Olifants is the most prominent). This reflects a remarkable capture through the Great Escarpment (King, 1967).

To east of the Buffalo River in KwaZulu-Natal, the Great Escarpment widens to approximately 45 km. It is bounded in the east by the up-arched Southeastern Coastal Hinterland. The rivers flowing across this section of the province are characterised, in the main, by linear BFCs (the Pongola River being the exception) (Table 7). Valley cross-sectional profiles are broader than in the north, while slopes are similar (very steep), so that the sediment storage surrogate descriptors are equally distributed between NV and MV (Table 7). There is a clear relationship between narrower valleys and steeper slopes, and vice versa.

To the west of the Mfolozi River, the Great Escarpment forms a narrow band, ~7 to 30 km wide, parallel to the present coastline. A group of rivers traversing the Great Escarpment, from the Buffalo River in the east to the Mbashe River in the west, show remarkably similar characteristics: all have their source in this province, and all are characterised by very steep longitudinal profiles and narrow valley cross-sectional profiles (Table 7). The sediment storage surrogate descriptors therefore are predominantly NV (this section of the Great Escarpment is marked by the narrowest valley cross-sectional profiles and steepest slopes of the entire province) (Table 7). The profiles are predominantly concave and best represented by exponential and linear BFCs (Table 7). Moreover, the rivers exit onto elevated platforms at between 1200 and 1700 m amsl (the Buffalo and Thukela rivers into the Ladysmith Basin; the Mzimkulu and

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[5] It has been suggested that the Great Escarpment was accentuated by the arching of the crust prior to rifting (McCarthy & Rubidge, 2005).

Table 6. Descriptor information for rivers by geomorphic province.

Geomorphic province	River (from north to south and then east to west)	River number	Geomorphic province starting altitude (m amsl)	Geomorphic province exit altitude (m amsl)	Geomorphic province length (km)	Total river slope (m/m)	River slope in geomorphic province (m/m)	Total river best fit curve	Total profile shape (area under curve)	Total profile shape descriptor (conc = concave; conv = convex)	Geomorphic province best fit curve	Geomorphic province shape	Geomorphic province shape descriptor (conc = concave; conv = convex)	Total profile average valley width (m)	Total profile sediment storage surrogate	Geomorphic province average valley width (m)	Geomorphic province sediment storage surrogate	Ratio total profile slope to geomorphic province slope	Ratio total profile width to geomorphic province width	Number of macro reaches
Limpopo Flats	Limpopo	A3	858	196	751	0.0009	0.0009	Exp.	0.79	Ave conv.	Exp.	0.79	Ave conv.	2851	BF	2851	BF	1.00	1.00	6
	Marico	A11	928	857	131	0.0020	0.0005	Exp.	0.20	Str. conc.	Lin.	0.38	Mod. conc.	3885	WM	4693	WF	3.63	0.83	3
	Crocodile_West	A12	898	858	105	0.0022	0.0004	Log.	0.22	Ave. conc.	Exp.	0.49	Mild. conc.	2716	BM	3893	WF	5.67	0.70	4
	Mamba	A14	995	835	123	0.0047	0.0013	Log.	0.17	Str. conc.	Lin.	0.40	Mild. conc.	3236	BS	3739	WF	3.57	0.87	3
	Mokolo	A15	1025	923	37	0.0026	0.0028	Pow.	0.28	Ave. conc.	Lin.	0.48	Mild. conc.	2515	BS	2370	BS	0.93	1.06	1
	Mokolo	A15	815	788	81	0.0026	0.0003	Pow.	0.28	Ave. conc.	Pow.	0.47	Mild. conc.	2515	BS	3861	WF	7.84	0.65	3
	Lephalala	A16	881	782	106	0.0042	0.0009	Log.	0.27	Ave. conc.	Lin.	0.46	Mild. conc.	2413	BS	3889	WF	4.54	0.62	2
	Mokgalakwena	A27	897	622	225	0.0018	0.0012	Lin.	0.36	Mod. conc.	Lin.	0.59	Mild. conv.	2970	BM	2861	BF	1.50	1.04	2
	Sand	A28	691	396	110	0.0041	0.0027	Pow.	0.37	Mod. conc.	Lin.	0.55	Mild. conv.	2033	MS	1170	MS	1.53	1.74	1
	Nzhelele	A29	595	373	76	0.0096	0.0029	Log.	0.17	Str. conc.	Lin.	0.48	Mild. conc.	1867	MV	1843	MS	3.27	1.01	1
	Luvuvu	A210	417	187	84	0.0036	0.0027	Exp.	0.34	Mod. conc.	Lin.	0.42	Mild. conc.	1614	MS	1316	MS	1.33	1.23	1
Soutpansberg	Sand	A28	827	703	32	0.0041	0.0039	Pow.	0.37	Mod. conc.	Pow.	0.52	Mild. conv.	2033	MS	1630	MS	1.04	1.25	1
	Nzhelele	A29	1232	615	11	0.0096	0.0584	Log.	0.17	Str. conc.	Log.	0.25	Ave. conc.	1867	MV	1943	MV	0.16	0.96	1
	Luvuvu	A210	820	420	137	0.0036	0.0029	Exp.	0.34	Mod. conc.	Exp.	0.35	Mod. conc.	1614	MS	1814	MS	1.24	0.89	2
Waterberg	Mamba	A14	1521	1071	22	0.0047	0.0206	Log.	0.17	Str. conc.	Lin.	0.40	Mod. conc.	3236	BS	431	NV	0.23	7.50	1
	Mokolo	A15	1505	1059	100	0.0026	0.0045	Pow.	0.28	Ave. conc.	Log.	0.35	Mod. conc.	2515	BS	2324	MS	0.58	1.08	3
	Mokolo	A15	908	818	44	0.0026	0.0020	Pow.	0.28	Ave. conc.	Log.	0.42	Mild. conc.	2515	BS	558	NM	1.28	4.51	3
	Lephalala	A16	1723	912	111	0.0042	0.0073	Log.	0.27	Ave. conc.	Pow.	0.40	Mod. conc.	2413	BS	937	NV	0.58	2.57	2
	Mokgalakwena	A27	1432	1151	213	0.0018	0.0025	Lin.	0.36	Mod. conc.	Log.	0.28	Ave. conc.	2970	BM	2730	BS	0.73	1.09	5
	Mokgalakwena	A27	1014	902	67	0.0018	0.0017	Lin.	0.36	Mod. conc.	Lin.	0.50	Mild. conv.	2970	BM	3388	BM	1.10	0.88	1
Polokwane Plain	Sand	A28	1206	839	118	0.0041	0.0031	Pow.	0.37	Mod. conc.	Lin.	0.49	Mild. conc.	2033	MS	2942	BS	1.31	0.69	1
	Mokgalakwena	A27	1057	1021	39	0.0018	0.0009	Lin.	0.36	Mod. conc.	Lin.	0.46	Mild. conc.	2970	BM	1693	MF	1.98	1.75	1
Makapaans/ Strydpoort Highlands	Sand	A28	1660	1225	37	0.0041	0.0116	Pow.	0.37	Mod. conc.	Log.	0.25	Ave. conc.	2033	MS	2056	MV	0.35	0.99	2

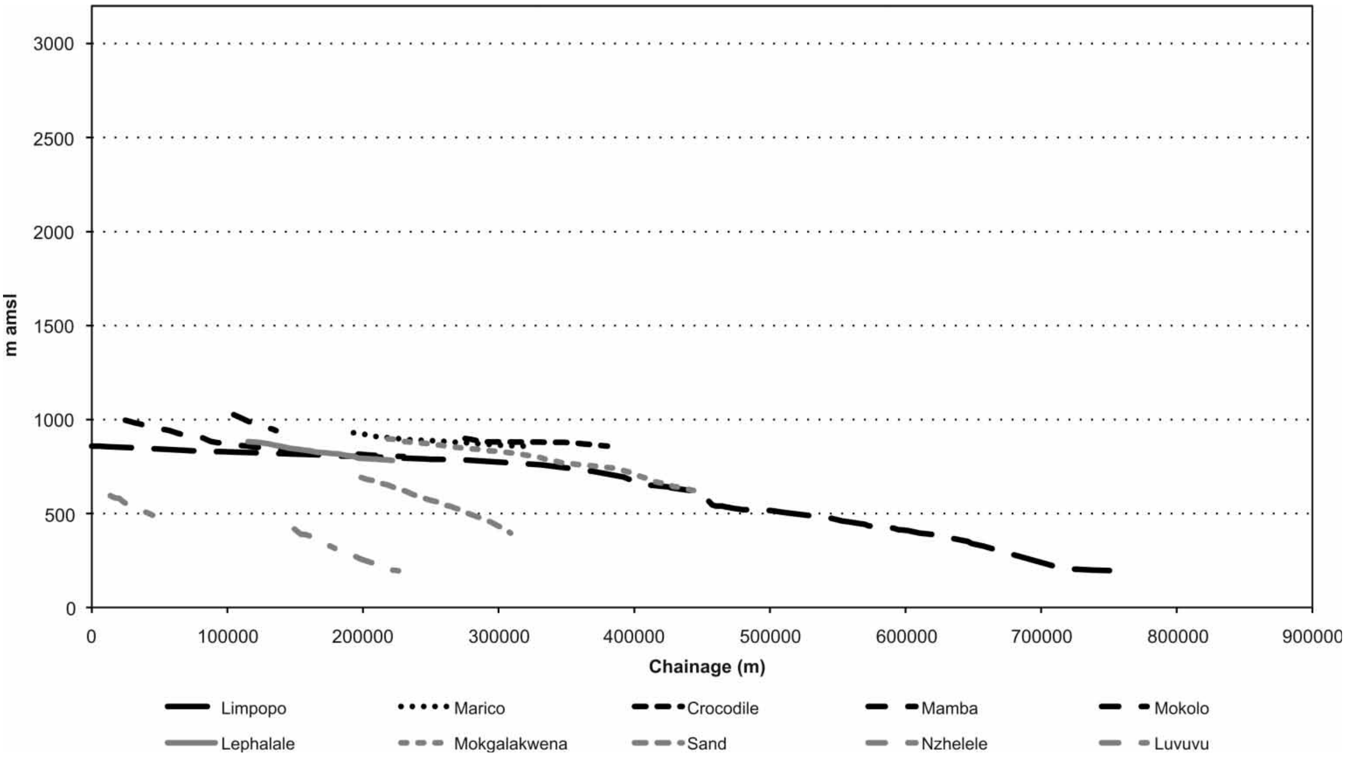

Figure 20. Longitudinal profiles of the rivers of the Limpopo Flats geomorphic province.

Mzimvubu rivers onto the flanks of the Cedarville Flats and the Kei River into the Queenstown Basin).

From the Kei River in the east to the Gourits River in the west, the elevation and width of the Great Escarpment declines. Simultaneously, valley slopes flatten and valley cross-sectional profiles widen. This is reflected in the sediment storage surrogate descriptor which ranges from NV in the east to BV in the west (Table 7). The BFCs for these rivers are distinctly different from those discussed previously, in that they have concave linear forms (Table 7).

Lowveld

This province extends from the Soutpansberg in the north, south through Swaziland into northern KwaZulu-Natal (Map 1). The Lowveld has been excavated by erosion between resistant uplands to the west and east (McCarthy & Rubidge, 2005). The province is characterised by low, undulating plains that are underlain mainly by granitic rocks in the north and exclusively by Karoo rocks (mainly basalt) in its narrow, southward extension. Occasional koppies occur in the granites and associated greenstone belts, but the remainder of the landscape is extensively pedimented. Planation has occurred mostly in the Post-African I cycle, but, immediately west of the Lebombo Highlands, the lowest lying areas represent the Post-African 2 surface (Lebombo Flats) (Partridge & Maud, 1987).

Ten major rivers traverse the Lowveld, flowing predominantly from west to east. The shapes of the river longitudinal profiles of this province show remarkable uniformity (Figure 21), with all rivers, except the Great Letaba, being characterised by linear BFCs (Table 7). This, however, belies other significant physical heterogeneity. To the north, the rivers are strongly controlled by the strike of the rocks, which are aligned southwest to northeast; otherwise structural control appears to be weak or localised. King (1967) has, in fact, suggested that the hydrography of the northern part of this province has retained its Tertiary form, while the southern part of the province has been influenced by Neogene tectonics. The northern rivers (Shingwedzi, Great Letaba and Olifants) follow a clear trend, with wide valley cross-sectional profiles and steep slopes grading to narrow valley cross-sectional profiles and medium slopes in the south (e.g., Olifants River) (Table 7). From the Blyde River south to the Komati River, however, the trend is in the opposite direction, with narrower valley cross-sectional profiles and steeper valley slopes in the north (e.g., Blyde River) trending to broad, flat valleys in the south (e.g., Komati River) (Table 7). These changes are reflected in the sediment storage surrogate descriptors which range from MS in the north to BF in the south (Table 7). From the Komati River south to the Mkuze River (southernmost extension of the province) the characteristics of the longitudinal profiles change again (e.g., Komati, Usutu and Mkuze rivers), with steeper slopes and wider cross-sectional profiles in the north (Table 7). As might be expected, these characteristics are reflected in the sediment storage surrogate descriptors which are MM (Table 7).

Lebombo Highlands

This province represents a continuous range (~ 500 km) of hills and low mountains dipping towards the east that extends from the Pafuri River in the north to Lake St Lucia in northern KwaZulu-Natal (Map 1). This feature has been preserved because it is formed by acid lavas (rhyolite) that are more resistant to weathering than the adjacent basalts (which underlie the Lebombo Flats which form part of the Lowveld). The Lebombo Highlands is unique in that rivers cross it orthogonally in narrow, deeply incised gorges. This unusual hydrography reflects the previously greater westward extent of the associated volcanic rocks and the existence at that time of a continuous pedimented surface (the African) between the crest of the Lebombo Highlands and the Great Escarpment to the west. Rounded gravels containing clasts of Great Escarpment rocks (now defined as the Cretaceous Malonga Formation) are preserved on the highest Lebombo Highlands summits (Partridge

Table 7. Descriptor information for rivers by geomorphic province.

Geomorphic province	River (from north to south and then east to west)	River number	Geomorphic province starting altitude (m amsl)	Geomorphic province exit altitude (m amsl)	Geomorphic province length (km)	Total river slope (m/m)	River slope in geomorphic province (m/m)	Total river best fit curve	Total profile shape (area under curve)	Total profile shape descriptor (conc = concave; conv = convex)	Geomorphic province best fit curve	Geomorphic province shape	Geomorphic province shape descriptor (conc = concave; conv = convex)	Total profile average valley width (m)	Total profile sediment storage surrogate	Geomorphic province average valley width (m)	Geomorphic province sediment storage surrogate	Ratio total profile slope to geomorphic province slope	Ratio total profile width to geomorphic province width	Number of macro reaches
Great Escarpment	Luvuvu	A210	1033	873	7	0.0036	0.0241	Exp.	0.34	Mod. conc.	Lin.	0.53	Mild. conv.	1614	MS	1468	MV	0.15	1.10	1
	Great Letaba	B6	1400	653	10	0.0048	0.0711	Log.	0.18	Str. conc.	Exp.	0.25	Ave. conc.	2738	BS	1132	NV	0.07	2.42	1
	Olifants	B1	598	510	48	0.0019	0.0018	Lin.	0.44	Mild. conc.	Lin.	0.54	Mild. conv.	1844	MM	332	NM	1.05	5.56	1
	Blyde	B5	1088	619	27	0.0111	0.0173	Lin.	0.33	Mod. conc.	Exp.	0.43	Mild. conc.	814	NV	204	NV	0.64	3.98	3
	Sabie	X3	1085	530	45	0.0102	0.0124	Exp.	0.19	Str. conc.	Lin.	0.58	Mild. conv.	983	NV	608	NV	0.83	1.62	2
	Crocodile	X2	1273	757	80	0.0059	0.0065	Exp.	0.28	Ave. conc.	Lin.	0.51	Mild. conv.	1285	MV	1457	MV	0.91	0.88	1
	Komati	X1	1425	936	77	0.0035	0.0064	Lin.	0.42	Mild. conc.	Lin.	0.49	Mild. conc.	1914	MS	1098	NV	0.56	1.74	1
	Usutu	W5	1397	902	30	0.0043	0.0166	Exp.	0.31	Mod. conc.	Lin.	0.54	Mild. conv.	2304	MS	802	NV	0.26	2.87	1
	Pongola	W4	2007	1222	27	0.0051	0.0296	Exp.	0.27	Ave. conc.	Exp.	0.26	Ave. conc.	1678	MS	1419	MV	0.17	1.18	2
	Mfolozi	W2	1444	1108	21	0.0035	0.0160	Exp.	0.33	Mod. conc.	Lin.	0.39	Mod. conc.	1639	MS	2198	MV	0.22	0.75	1
	Buffalo	V2	1589	1235	32	0.0039	0.0110	Exp.	0.44	Mild. conc.	Lin.	0.47	Mild. conc.	1636	MS	415	NV	0.36	3.94	2
	Thukela	V1	3142	1437	12	0.0059	0.1434	Log.	0.20	Ave. conc.	Exp.	0.37	Mod. conc.	1163	MV	870	NV	0.04	1.34	2
	Mkomazi	U1	3112	1552	12	0.0106	0.1279	Log.	0.21	Ave. conc.	Exp.	0.32	Mod. conc.	467	NV	147	NV	0.08	3.17	2
	Mzimkulu	T5	3051	1797	12	0.0081	0.1013	Lin.	0.27	Ave. conc.	Exp.	0.26	Ave. conc.	980	NV	606	NV	0.08	1.62	2
	Mzimvubu	T3	2641	1532	16	0.0070	0.0681	Exp.	0.26	Ave. conc.	Exp.	0.29	Ave. conc.	448	NV	166	NV	0.10	2.69	1
	Mbashe	T1	2113	1322	41	0.0060	0.0192	Exp.	0.27	Ave. conc.	Pow.	0.15	Str. conc.	921	NV	1456	MV	0.31	0.63	2
	Great Kei	S1	1973	1492	7	0.0040	0.0689	Lin.	0.33	Mod. conc.	Exp.	0.39	Mod. conc.	1370	MS	340	NV	0.06	4.03	1
	Great Fish	Q1	1601	1254	39	0.0021	0.0088	Exp.	0.37	Mod. conc.	Lin.	0.49	Mild. conc.	1833	MM	1852	MV	0.24	0.99	1
	Little Fish	Q2	1820	1410	4	0.0060	0.1011	Log.	0.24	Ave. conc.	N/A	0.50	Lin.	1659	MV	650	NV	0.06	2.55	1
	Sundays	N1	1615	846	71	0.0034	0.0108	Exp.	0.29	Ave. conc.	Lin.	0.46	Mild. conc.	2288	MS	627	NV	0.32	3.65	1
	Groot	L1	1394	1226	25	0.0023	0.0068	Lin.	0.42	Mild. conc.	Lin.	0.48	Mild. conc.	2434	BM	3071	BV	0.34	0.79	1
	Gourits	J1	1690	1545	1	0.0050	0.1784	Log.	0.18	Str. conc.	Lin.	0.63	Mod. conv.	1438	MS	3250	BV	0.03	0.44	1

Continued on p. 21

Table 7 (*continued*)

Lowveld	Shingwedzi	B7	654	247	165	0.0024	0.0025	Lin.	0.36	Mod. conc.	Lin.	0.37	Mod. conc.	3871	WM	3889	WM	0.98	1.00	3
	Great Letaba	B6	629	206	228	0.0048	0.0019	Log.	0.18	Str. conc.	Exp.	0.39	Mod. conc.	2738	BS	2895	BM	2.59	0.95	2
	Olifants	B1	499	154	199	0.0019	0.0017	Lin.	0.44	Mild. conc.	Lin.	0.46	Mild. conc.	1844	MM	1101	NM	1.11	1.68	1
	Blyde	B5	592	387	49	0.0111	0.0042	Lin.	0.33	Mod. conc.	Lin.	0.52	Mild. conv.	814	NV	1429	MS	2.63	0.57	1
	Sabie	X3	435	158	109	0.0102	0.0025	Exp.	0.19	Str. conc.	Lin.	0.44	Mild. conc.	983	NV	2401	BS	4.01	0.41	1
	Crocodile	X2	333	128	135	0.0059	0.0015	Exp.	0.28	Ave. conc.	Lin.	0.41	Mild. conc.	1285	MV	1846	MF	3.90	0.70	3
	Komati	X1	326	152	139	0.0035	0.0013	Lin.	0.42	Mild. conc.	Lin.	0.51	Mild. conv.	1914	MS	3481	BF	2.83	0.55	6
	Usutu	W5	298	58	122	0.0043	0.0020	Exp.	0.31	Mod. conc.	Lin.	0.43	Mild. conc.	2304	MS	1172	MM	2.20	1.97	3
	Pongola	W4	314	159	72	0.0051	0.0022	Exp.	0.27	Ave. conc.	Lin.	0.46	Mild. conc.	1678	MS	1332	MM	2.36	1.26	1
	Mkuze	W3	278	74	84	0.0037	0.0024	Exp.	0.19	Str. conc.	Lin.	0.53	Mild. conv.	2691	BS	1444	MM	1.51	1.86	1
Lebombo Highlands	Shingwedzi	B7	243	243	1	0.0024	0.0001	Lin.	0.36	Mod. conc.	N/A	N/A	N/A	3871	WM	2660	BF	24.23	1.46	1
	Olifants	B1	137	135	7	0.0019	0.0003	Lin.	0.44	Mild. conc.	N/A	0.38	Mod. conc.	1844	MM	727	NF	7.55	2.54	1
	Sabie	X3	151	125	5	0.0102	0.0055	Exp.	0.19	Str. conc.	N/A	0.33	Mod. conc.	983	NV	1133	NS	1.86	0.87	1
	Komati	X1	150	140	4	0.0035	0.0026	Lin.	0.42	Mild. conc.	N/A	0.50	Lin.	1914	MS	2690	BS	1.36	0.71	1
	Usutu	W5	55	48	4	0.0043	0.0015	Exp.	0.31	Mod. conc.	N/A	0.53	Mild. conv.	2304	MS	480	NF	2.87	4.80	1
	Pongola	W4	153	121	10	0.0051	0.0031	Exp.	0.27	Ave. conc.	N/A	0.37	Mod. conc.	1678	MS	1573	MS	1.63	1.07	1
	Mkuze	W3	72	62	9	0.0037	0.0011	Exp.	0.19	Str. conc.	Lin.	0.50	Lin.	2691	BS	545	NF	3.33	4.94	1
N&S Bankenveld	Marico	A11	1495	1073	57	0.0020	0.0074	Exp.	0.20	Str. conc.	Exp.	0.31	Mod. conc.	3885	WM	983	NV	0.27	3.95	2
	Crocodile	A12	1356	1299	15	0.0022	0.0037	Log.	0.22	Ave. conc.	Lin.	0.46	Mild. conc.	2716	BM	1351	MS	0.60	2.01	1
	Marico	A11	953	933	19	0.0020	0.0010	Exp.	0.20	Str. conc.	Pow.	0.37	Mod. conc.	3885	WM	2440	BF	1.90	1.59	1
	Crocodile	A12	913	900	24	0.0022	0.0006	Log.	0.22	Ave. conc.	Log.	0.43	Mild. conc.	2716	BM	4147	WF	3.83	0.66	1
Western Transvaal Basin	Marico	A11	1053	955	106	0.0020	0.0009	Exp.	0.20	Str. conc.	Lin.	0.43	Mild. conc.	3885	WM	4574	WF	2.13	0.85	3
	Crocodile	A12	1298	916	187	0.0022	0.0020	Log.	0.22	Ave. conc.	Log.	0.31	Mod. conc.	2716	BM	2647	BM	1.08	1.03	3
	Elands	B3	1212	820	189	0.0032	0.0021	Exp.	0.30	Ave. conc.	Exp.	0.39	Mod. conc.	3102	BS	3227	BM	1.55	0.96	2
	Mokgalakwena	A27	1141	1061	76	0.0018	0.0011	Lin.	0.36	Mod. conc.	Exp.	0.35	Mod. conc.	2970	BM	4071	WF	1.73	0.73	2
	Olifants	B1	918	707	191	0.0019	0.0011	Lin.	0.44	Mild. conc.	Lin.	0.43	Mild. conc.	1844	MM	2697	BF	1.74	0.68	3
Eastern Transvaal Basin	Elands	B3	1555	1240	34	0.0032	0.0092	Exp.	0.30	Ave. conc.	Lin.	0.46	Mild. conc.	3102	BS	2138	MV	0.35	1.45	1
	Olifants	B1	1395	919	129	0.0019	0.0037	Lin.	0.44	Mild. conc.	Exp.	0.42	Mild. conc.	1844	MM	751	NS	0.52	2.46	2
	Olifants	B1	703	602	65	0.0019	0.0016	Lin.	0.44	Mild. conc.	Lin.	0.50	Mild. conv.	1844	MM	824	NF	1.24	2.24	2
	Klein Olifants	B2	1556	1257	74	0.0034	0.0041	Lin.	0.53	Mild. conv.	Lin.	0.59	Mild. conv.	2272	MS	1786	MS	0.84	1.27	3
	Steelpoort	B4	1363	568	168	0.0047	0.0047	Lin.	0.42	Mild. conc.	Exp.	0.35	Mod. conc.	1510	MS	1366	MS	0.99	1.11	3

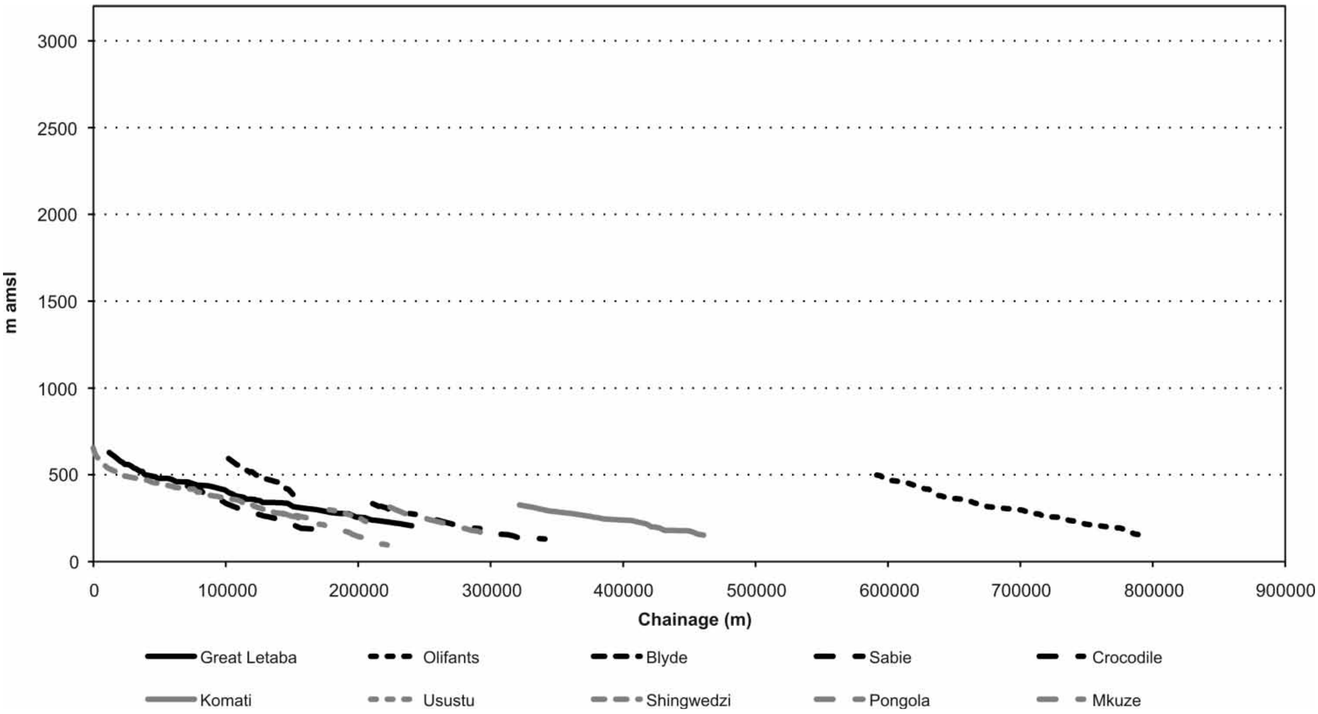

Figure 21. Longitudinal profiles of the rivers of the Lowveld geomorphic province.

& Maud, 2000) and attest to the existence of a drainage network at that level prior to the cycle of erosion that produced the Lowveld.

The seven main fluvial systems that dissect the Lebombo Highlands (from north to south, respectively) are the Shingwedzi, Olifants, Sabie, Komati, Usutu, Pongola and Mkuze rivers. The sections of river that traverse this province are short (~1 to 15 km), valley gradients are remarkably gentle (mainly flat) and the valley cross-sectional profiles range from broad, to narrow/medium (Table 7). The BFCs were not computed for this province as the rivers sections were too short to give meaningful results.

Northern and Southern Bankenveld

This province is characterised by northern and southern arms separated by the Western Transvaal Basin (Map 1). It is made up of cuestas formed by parallel quartzite ridges (e.g., Magaliesberg, Daspoort and Timeball Hill) and shale-filled valleys the existence of which is controlled by the contrasting resistance of strata within the Pretoria Group of rocks. The crests of the ridges probably belong to the African surface, while the valleys are Post-African I surfaces (Partridge & Maud, 1987). The ridges are asymmetrical with dip slopes towards the centre of the Western Transvaal Basin.

Two main river systems, the Marico and Crocodile, cut orthogonally through the Northern and Southern Bankenveld as a result of superimposition from an original Karoo covering. A trellis drainage pattern is evident due to the erosion of the softer sediments in the valleys. The west–east orientation of the province and the north-south traverse of the rivers means that the extent of these rivers across the province is short (~15 to 57 km). The sections that traverse the Southern Bankenveld are significantly steeper and narrower than in the northern section (Table 7). The rivers traversing the Southern Bankenveld have narrow and medium valley cross-sectional profiles and very steep to steep slopes (Table 7), while the rivers of the Northern Bankenveld are characterised by broad and wide valley cross-sectional profiles and flat slopes (Table 7). As might be expected, this is reflected in the sediment storage surrogate descriptors which are NV and MS in the south and BF and WF in the north (Table 7). The Southern Bankenveld rivers are also associated with exponential and linear BFCs (Table 7), while the Northern Bankenveld rivers have power and logarithmic BFCs (Table 7).

Western Transvaal Basin

This province represents that western part of the Transvaal Basin which has been intruded by the rocks of the Bushveld Complex (mainly norite, granite and felsite) and as a consequence, the province is characterised by considerable topographical diversity (Map 1). The centripetal dip of these rocks was imparted by the emplacement of the igneous rocks that occupy much of the province's floor. Along parts of the rim, recent faults (Partridge, 1998), some still active today and many associated with thermal springs, show that the basin floor has subsided by as much as 400 m in places (particularly in the northeast) (McCarthy & Rubidge, 2005). Much of the floor has limited relief, the landscape being dominated by a sprinkling of steep hills separated by wide, gentle pediments. The relief is particularly subdued on the Springbok Flats, where the Bushveld rocks are overlain by Karoo basalt. This low-relief area coincides with the Post-African I erosion surface (Partridge & Maud, 1987). Here, both the valley cross-sectional and longitudinal profiles of rivers are very gentle. The flat, marshy valley of the Nyl River, with its underfit character, is partly the result of channel disruption through ongoing subsidence and partly the product of capture by the Mokgalakwena River (Partridge & Maud, 1987). During the Cretaceous, the Mokgalakwena River drained the northeastern escarpment zone to the west of the then Great Escarpment (around Tzaneen and Palaborwa). It flowed west approximately along the present-day course of the Olifants River before veering north at the point where the present-day Nyl River flows into the valley of the Mokgalakwena River (Partridge & Maud, 1987). The westward recession of the Great Escarpment in the warm and wet Cretaceous and the Tertiary subsidence of the Western Transvaal Basin disrupted the early drainage pattern, leading to the present day hydrography. These events also constrained

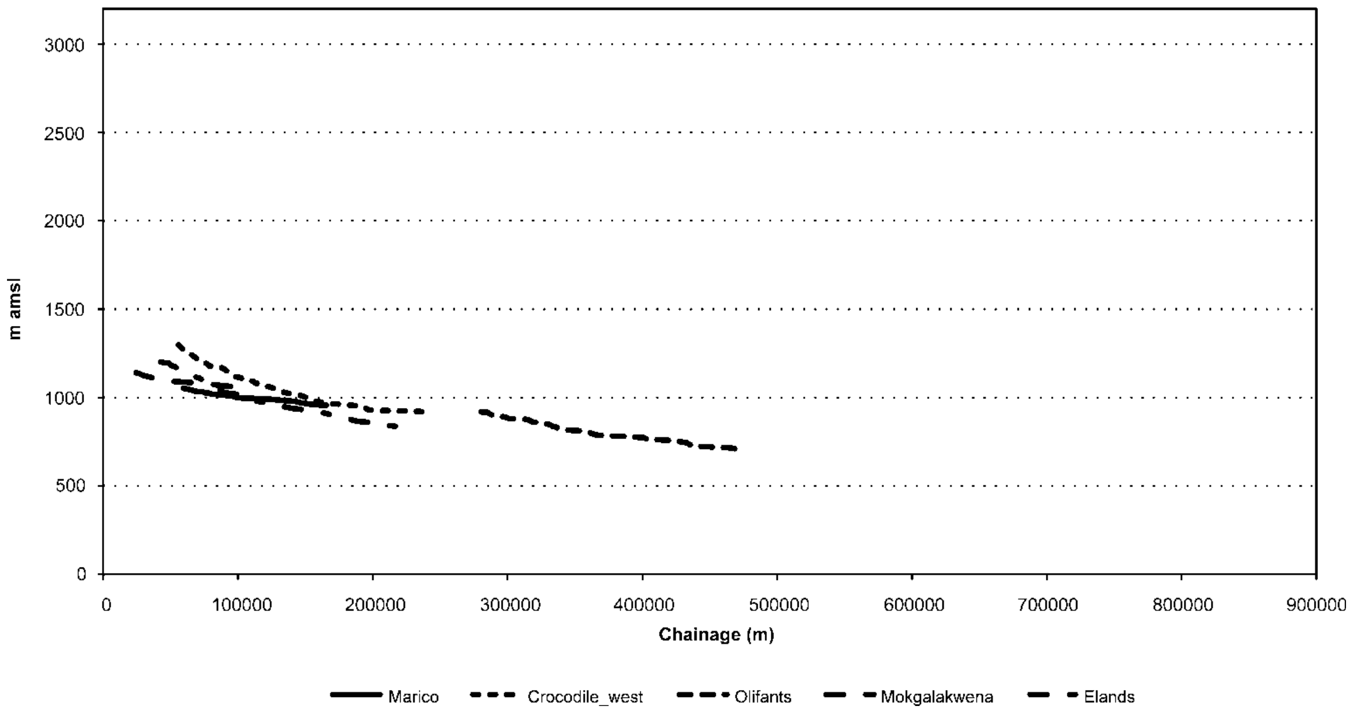

Figure 22. Longitudinal profiles of the rivers of the Western Transvaal Basin geomorphic province.

the hydrography of the Olifants River.

The concave longitudinal profiles of the five main river systems (Marico, Crocodile, Elands, Mokgalakwena and Olifants) that drain the Western Transvaal Basin reflect the imprint of lithology, structure and neotectonics. There is no clear trend from west to east or north to south, although in the extreme west of the basin, flatter slopes and broader valley cross-sectional profiles are evident (Table 7). However, the rivers are uniform in their longitudinal profile (Figure 22), with flat or medium slopes and wide or broad valley cross-sectional profiles (Table 5), so that the sediment storage surrogate descriptors are predominantly WF and BM (Table 7). However, there is significant heterogeneity in terms of the BFCs, with river longitudinal profiles displaying linear, logarithmic and exponential BFCs (Table 7).

Eastern Transvaal Basin

This province, representing the eastern, incised part of the Transvaal Basin, is underlain mainly by igneous rocks of the Bushveld Complex (Map 1). The layered, basic igneous rocks give rise to a series of arcuate parallel ridges of high relief. The main drainage lines (e.g., Olifants and Steelpoort valleys) are superimposed across these ridges. Remnants of summits above the African surface are evident, but the major part of the province belongs to the Post African I cycle of erosion (Partridge & Maud, 1987). As with the Western Transvaal Basin, there is strong structural and fault control on the rivers, for example, the Steelpoort lineament has determined much of the path of the Steelpoort River.

There are four main fluvial systems, the Elands, Olifants, Klein Olifants and Steelpoort rivers. The western section is drained by the Elands and Olifants rivers (the Elands being a tributary of the Olifants). These rivers are characterised by marginally flatter slopes and narrower valley cross-sectional profiles than are present to the northeast (9% flatter and 27% narrower on average, which is not statistically significant), which is drained by the Klein Olifants and Steelpoort rivers (Table 7). However, there is no clear north to south or east to west trend in terms of the physical characteristics of the rivers, and their longitudinal profiles are best described both by exponential and linear BFCs (Table 7). The river longitudinal profiles are generally concave, although the lower Olifants and Klein Olifants are convex in form (Table 7). The only unifying physical characteristic of the rivers of this province is that they are generally very steep to steep with narrow to medium valley cross-sectional profiles so that their sediment storage surrogate descriptors range from NS to MS (Table 7). In general, its rivers are notable for their physical heterogeneity.

Mpumalanga Highlands

This province is, in fact, part of the Eastern Transvaal Basin, but both overall elevations and local relief are significantly higher (Map 1). Extensive upland areas, which stand above the African erosion surface, are preserved in places (Partridge & Maud, 1987). The ridge-and-valley topography is imparted by lithological contrasts in the westward-dipping rocks of the Pretoria Group and Malmani dolomites, so that open strike valleys alternate with narrow gorges through quartzite ridges. This is an important watershed area which, because of its high rainfall, is source of a number of perennial rivers and also contains important wetlands.

Three main rivers traverse this province: the north-flowing Blyde and the east-flowing Sabie and Crocodile rivers. Longitudinal profiles are very steep (Table 8) and valley cross-sectional profiles narrow so that the sediment storage surrogate descriptors are in all cases NV (Table 8). The Blyde and the Sabie rivers share very similar physical characteristics; both have strongly concave longitudinal profiles with very steep slopes and narrow valley cross-sectional profiles and are characterised by exponential BFCs (Table 8). The Crocodile River has some characteristics in common with these two rivers, but has two significant differences: the profile is convex in form and is best described by a linear BFC (Table 8).

Southeastern Coastal Hinterland

This province stretches from the Great Kei River in the Eastern Cape to northern Swaziland (Map 1). It is underlain almost exclusively by Karoo rocks (Ecca and Dwyka Groups in the

Plate 1. The Mbashe River in the Southeastern Coastal Hinterland geomorphic province – incised meanders as a result of uplift along the Ciskei–Swaziland axis.

north and Beaufort Group further south), with hills in the southern area being capped by dolerite. A central core of granite-gneiss and schist and overlying Natal Group sediments (sandstones) has been exposed by erosion from north of the Thukela River to just north of the Mzimvubu River (King, 1967). Rivers flowing off the Great Escarpment cross the Southeastern Coastal Hinterland to the Indian Ocean in steep valleys. Significantly, the rivers flow orthogonal to many valley and ridge features and are therefore transverse to the structural and tectonic grain of the topography.

Perhaps the most significant constraint on the rivers of this province were two post-Cretaceous epeirogenic uplift events in the Neogene[6] (early Miocene uplift at ~20 Ma and Mio-Pliocene uplift at ~5 Ma) that were concentrated along an axis (the Ciskei–Swaziland axis)[7] some 80 km inland of the coast[8]. Uplift totalled between 800 and 1100 m[9] in an area where similarly pervasive structural and lithological controls are absent (Partridge, 1998). This uplift elevated the eastern part of the sub-continent (and much of the eastern Hinterland of Africa)[10], amplifying the relief between the province and the Great Escarpment. The uplift produced large-scale (asymmetrical) arching, steepening of the lower courses of rivers, while minor reverse warping in their upper reaches produced ponding (e.g., the Cedarville Flats in western KwaZulu-Natal). The net result was the creation of broad, upwardly convex, longitudinal profiles in most rivers and rapid down cutting and entrenchment of pre-existing meander systems, a spectacular example being the lower Mbashe River (Plate 1). As a result, many of the rivers in this province are deeply incised in their middle and lower reaches. The province has remnants of the African surface on the interfluves, and deep incision of the rivers into the Post-African I and II erosion surfaces (Partridge & Maud, 1987). Because of the presence of dolerite sills and other hard lithologies in an area of considerable geological diversity, longitudinal profiles are frequently stepped.

Nineteen major river systems traverse this province, from the Sabie River in the northeast to the Great Kei River in the southwest. What is remarkable is the dramatic effect of the differential uplift on the longitudinal profiles of the rivers (Figure 23). The majority of these are characterised by linear BFCs, with exponential BFCs occurring less frequently (Table 8). The valley slopes (steep and very steep) and valley cross-sectional profiles (mainly narrow, with some medium) are also remarkably uniform throughout the province, so that the sediment storage surrogate descriptors are mainly NS and NV (Table 8). There does appear to be a weak trend from east to west, with average valley cross-sectional widths slightly narrower and slopes slightly steeper in the east (Table 8). It is also interesting to note that, despite the presence of the axis of uplift, the only longitudinal profiles that show true convexity are the four northerly systems, the Sabie, Crocodile, Komati and Usutu rivers.

Kalahari

This province includes that portion of the Kalahari Basin falling within South Africa (Map 1). The basin is infilled with sediment (from Cretaceous to recent age) and its formation was a product of Neogene tectonics and Plio-Pleistocene aridification. It is covered by a discontinuous mantle of windblown sand, including several areas of well developed linear dunes interrupted by occasional rocky outcrops. The province was formed by differential marginal uplift, probably during the late Cretaceous, which reversed the flow of some southward-flowing rivers, causing the development of localised lakes. Subsequent sedimentation and aridification led to the diminution of surface fluvial activity and extensive dune formation during discrete intervals in the past. As a result, much of the Kalahari

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[6] For a full description and explanation of these events see Partridge & Maud (1987), Partridge (1998), Moore (1999), Partridge & Maud (2000), McCarthy & Rubidge (2005). Their dating has been revised somewhat over the years.

[7] Partridge (1998) makes the point that it is not coincidental that the majority of South Africa's hot springs are located close to this axis of uplift. It should be noted that the age and amplitude of these movements is constrained by a variety of evidence, not the least of which is the present occurrence of marine Pliocene sediments at elevations of up to 400 m within 15 km of the coast in the Eastern Cape.

[8] The uplift was accompanied by tilting to the west.

[9] Note that there was an almost simultaneous reactivation of the Griqualand–Transvaal axis and subsidence within the Western Transvaal Basin.

[10] Uplift also increased the height of the eastern Great Escarpment, thereby increasing the aridity of the interior and increasing the east to west rainfall gradient.

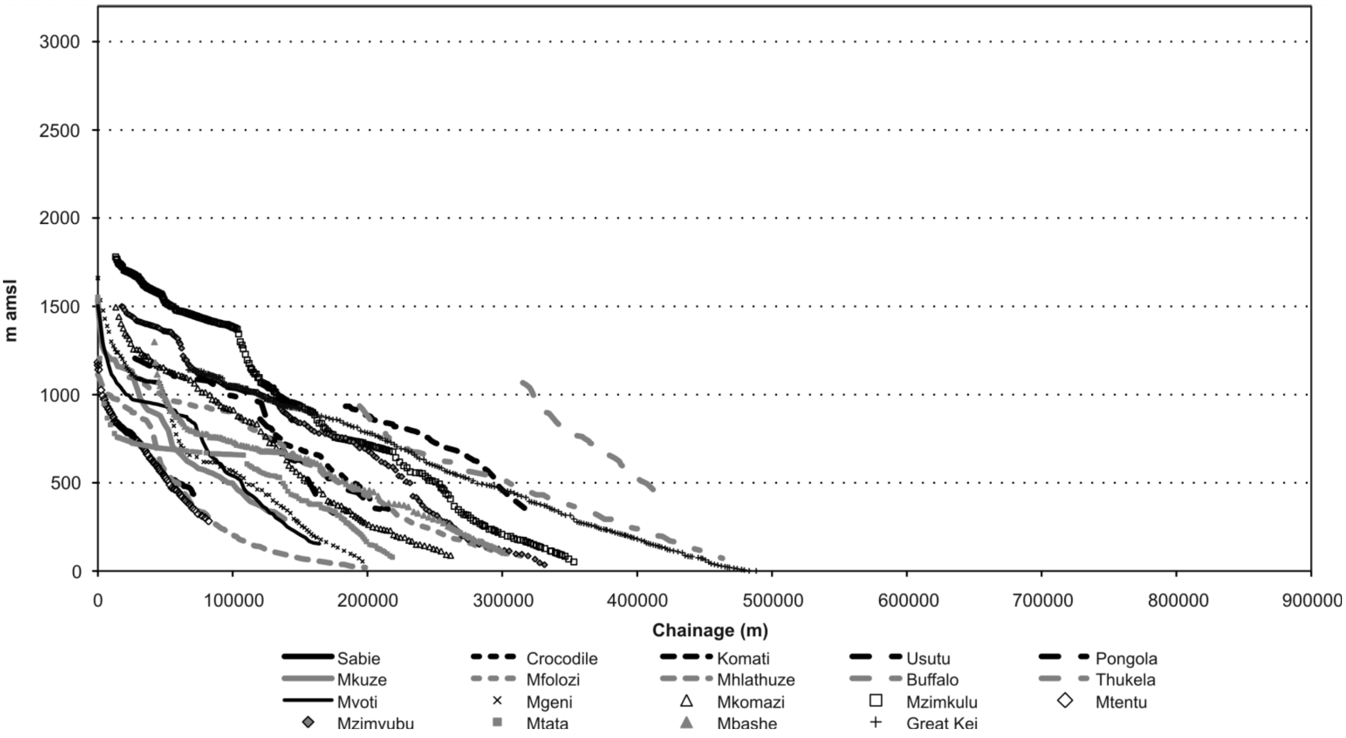

Figure 23. Longitudinal profiles of the rivers of the Southeastern Coastal geomorphic province.

consists of dry valleys and frequent pans so that drainage is essentially endoreic, with many rivers poorly defined and segmented between lines of dunes. Six major periods of dune activation have occurred over the last 115 000 years (Partridge, 2003), but these arid spikes probably occupied no more than 20% of this total period. During intervening times the dunes were stabilised by vegetation, as is the case today, except in those areas where disturbance has occurred. During one or more of the arid intervals dunes advanced across the lower course of the Molopo River, effectively cutting off flow from the lower reaches of this highly ephemeral system. The dry waterfall at Riemvasmaak, above its prior confluence with the Orange River, bears testimony to that event.

The main river system flowing east–west in this province is the Molopo. All other significant fluvial systems are south-bank tributaries of the Molopo. These include the Setlagole, Tlakgamenglaagte, Phepane, Ka Mogara, Moshwaeng and Kuruman rivers. The Nossob joins the now-defunct lower Molopo from the north-bank. These rivers have mainly flat, concave longitudinal profiles and wide valley cross-sectional profiles (Table 8). This is reflected in the sediment storage surrogate descriptors that include BF, WF and WM classes (Table 8). The Molopo longitudinal profile in this province is characterised by a logarithmic BFC, while the Phephane and Kuruman rivers are characterised by exponential and linear BFCs, respectively (Table 8).

Information Box 3

Towards the end of the Cretaceous, prior to the crustal upwarping that first formed the Kalahari–Zimbabwe and Griqualand–Transvaal axes and dismembered the palaeo-Limpopo River, a major drainage line; the palaeo-Kalahari River drained the western interior of southern Africa. A second major system, the palaeo-Karoo River drained the eastern highlands (termed the Cargonian Highlands) and flowed west, exiting near the present-day Olifants River mouth on the Atlantic coast (de Wit, 1993). Uplift along the Griqualand–Transvaal axis, together with the westward tilting of the interior, resulted in the capture of the upper reaches of the palaeo-Karoo River by the palaeo-Kalahari River, forming the present-day Orange River (McCarthy & Rubidge, 2005).

Highveld

The Highveld is an extensive grassland region occupying the eastern interior plateau at elevations from ~1200 to 1800 m (Map 1). Most of the province is drained by the tributaries and main stem of the Vaal River. South of the Vaal River the province is underlain by near-horizontal Karoo strata (intruded by dolerite dykes and sills), while north of the river Ventersdorp lavas and dolomite predominate. The older pre-Karoo landscape to the north of the Vaal has greater relief as a result of slight incision of the superimposed drainage. For example, near Middelburg and Heidelberg many of the rivers follow pre-Karoo lines (e.g., the Blesbokspruit); a major exception is the Suikerbosrand River that flows across a once buried ridge (King, 1967). Much of the province is, however, gently undulating and is dominated by the late Cretaceous African erosion surface, which remains intact on many of the broad interfluves (Partridge & Maud, 1987). The dominant drainage direction is westerly, partly because of the influence of the pre-Karoo topography, and partly because of warping along the Griqualand–Transvaal axis, whose activity was largely contemporaneous with uplift of the Ciskei–Swaziland axis (Partridge & Maud, 1987). The shallow, open valleys reflect minor incision in the early Miocene Post-African I cycle. Many of the Highveld rivers have incised their channel beds to just below the bedrock surface and are strongly influenced by the relationship between the softer Karoo shales and sandstones and the position and breaching of dolerite sills and dykes (Tooth *et al.*, 2004). Meandering patterns are typical within the sandstones and shales (above local hydraulic barriers usually dolerite dykes and sills), while straight channels occur where the rivers breach the dolerite (Tooth *et al.*, 2002, 2004).

Characteristics of this province are numerous palaeo-drainage features in the form of gravel bars (many now forming low ridges that host alluvial diamonds) and dry valleys

Table 8. Descriptor information for rivers by geomorphic province.

Geomorphic province	River (from north to south and then east to west)	River number	Geomorphic province starting altitude (m amsl)	Geomorphic province exit altitude (m amsl)	Geomorphic province length (km)	Total river slope (m/m)	River slope in geomorphic province (m/m)	Total river best fit curve	Total profile shape (area under curve)	Total profile shape descriptor (conc = concave; conv = convex)	Geomorphic province best fit curve	Geomorphic province shape	Geomorphic province shape descriptor (conc = concave; conv = convex)	Total profile average valley width (m)	Total profile sediment storage surrogate	Geomorphic province average valley width (m)	Geomorphic province sediment storage surrogate	Ratio total profile slope to geomorphic province slope	Ratio total profile width to geomorphic province width	Number of macro reaches
Mpumalanga Highlands	Blyde	B5	2057	1097	70	0.0111	0.0136	Lin.	0.33	Mod. conc.	Exp.	0.20	Str. conc.	814	NV	812	NV	0.81	1.00	3
	Sabie	X3	2043	1090	10	0.0102	0.0988	Exp.	0.19	Str. conc.	Exp.	0.30	Mod. conc.	983	NV	375	NV	0.10	2.62	1
	Crocodile	X2	2180	1293	46	0.0059	0.0192	Exp.	0.28	Ave. conc.	Lin.	0.57	Mild. conv.	1285	MV	874	NV	0.31	1.47	2
Southeastern Coastal Hinterland	Sabie	X3	518	436	15	0.0102	0.0055	Exp.	0.19	Str. conc.	Lin.	0.61	Mod. conv.	983	NV	659	NS	1.87	1.49	1
	Crocodile	X2	753	350	82	0.0059	0.0049	Exp.	0.28	Ave. conc.	Lin.	0.60	Mod. conv.	1285	MV	1117	NS	1.20	1.15	1
	Komati	X1	933	357	133	0.0035	0.0043	Lin.	0.42	Mild. conc.	Lin.	0.60	Mod. conv.	1914	MS	862	NS	0.82	2.22	2
	Great Usutu	W5	861	328	54	0.0043	0.0098	Exp.	0.31	Mod. conc.	Lin.	0.50	Lin.	2304	MS	831	NV	0.44	2.77	1
	Pongola	W4	1205	319	193	0.0051	0.0046	Exp.	0.27	Ave. conc.	Lin.	0.55	Mild. conv.	1678	MS	1372	MS	1.11	1.22	3
	Mkuze	W3	1535	295	139	0.0037	0.0089	Exp.	0.19	Str. conc.	Exp.	0.34	Mod. conc.	2691	BS	1113	NV	0.41	2.42	2
	Mfolozi	W2	1097	85	290	0.0035	0.0035	Exp.	0.33	Mod. conc.	Lin.	0.47	Mild. conc.	1639	MS	1187	MS	0.99	1.38	5
	Mhlathuze	W1	1112	19	198	0.0051	0.0055	Exp.	0.29	Ave. conc.	Exp.	0.31	Mod. conc.	1156	MS	999	NS	0.93	1.16	6
	Buffalo_KZN	V2	1066	447	98	0.0039	0.0063	Exp.	0.44	Mild. conc.	Lin.	0.46	Mild. conc.	1636	MS	408	NV	0.62	4.01	2
	Thukela	V1	935	72	269	0.0059	0.0032	Log.	0.20	Ave. conc.	Lin.	0.42	Mild. conc.	1163	MV	636	NS	1.85	1.83	2
	Mvoti	U3	1504	154	164	0.0069	0.0082	Lin.	0.34	Mod. conc.	Lin.	0.38	Mod. conc.	988	NV	982	NV	0.84	1.01	6
	Mgeni	U2	1662	54	196	0.0076	0.0082	Exp.	0.33	Mod. conc.	Exp.	0.35	Mod. conc.	1477	MV	1506	MV	0.93	0.98	6
	Mkomazi	U1	1496	89	248	0.0106	0.0057	Log.	0.21	Ave. conc.	Lin.	0.41	Mild. conc.	467	NV	492	NS	1.87	0.95	3
	Mzimkulu	T5	1780	52	340	0.0081	0.0051	Lin.	0.27	Ave. conc.	Lin.	0.45	Mild. conc.	980	NV	1023	NS	1.60	0.96	1
	Mtentu	T4	1182	282	82	0.0085	0.0110	Exp.	0.36	Mod. conc.	Lin.	0.38	Mod. conc.	609	NV	675	NV	0.78	0.90	3
	Mzimvubu	T3	1499	35	314	0.0070	0.0047	Exp.	0.26	Ave. conc.	Lin.	0.47	Mild. conc.	448	NV	476	NS	1.51	0.94	8
	Mtata	T2	1552	78	219	0.0061	0.0067	Lin.	0.30	Mod. conc.	Lin.	0.31	Mod. conc.	842	NV	872	NV	0.91	0.97	7
	Mbashe	T1	1299	105	259	0.0060	0.0046	Exp.	0.27	Ave. conc.	Lin.	0.36	Mod. conc.	921	NV	785	NS	1.30	1.17	3

Continued on p. 27

Table 8 (*continued*)

	Great Kei	S1	1140	42	388	0.0040	0.0028	Lin.	0.33	Mod. conc.	Lin.	0.49	Mild. conc.	1370	MS	1050	NS	1.43	1.31	1
	Buffalo	R2	1182	966	1	0.0094	0.2092	Log.	0.24	Ave. conc.	N/A	0.51	Mild. conv.	1006	NV	1160	MV	0.04	0.87	1
	Keiskamma	R1	1662	637	20	0.0067	0.0520	Log.	0.18	Str. conc.	Exp.	0.24	Ave. conc.	861	NV	460	NV	0.13	1.87	2
	Great Fish	Q1	957	774	78	0.0021	0.0023	Exp.	0.37	Mod. conc.	Lin.	0.48	Mild. conc.	1833	MM	2257	MM	0.91	0.81	1
	Little Fish	Q2	1333	1053	28	0.0060	0.0100	Log.	0.24	Ave. conc.	Lin.	0.44	Mild. conc.	1659	MV	1333	MV	0.60	1.24	1
Kalahari	Kuruman	D8747	1000	851	310	0.0014	0.0005	Exp.	0.23	Ave. conc.	Lin.	0.44	Mild. conc.	3785	WF	3366	BF	3.01	1.12	6
	Molopo	D8646	1440	803	1038	0.0009	0.0006	Log.	0.50	Lin.	Log.	0.28	Ave. conc.	3831	WF	3976	WF	1.41	0.96	5
	Phephane	D85	1347	956	196	0.0020	0.0020	Exp.	0.33	Mod. conc.	Exp.	0.33	Mod. conc.	4870	WM	4870	WM	1.00	1.00	1
Highveld	Komati	X1	1795	1437	103	0.0035	0.0035	Lin.	0.42	Mild. conc.	Lin.	0.36	Mod. conc.	1914	MS	2305	MS	1.02	0.83	2
	Steelpoort	B4	1732	1363	78	0.0047	0.0047	Lin.	0.42	Mild. conc.	Exp.	0.37	Mod. conc.	1510	MS	1870	MS	0.99	0.81	2
	Klein Olifants	B2	1765	1557	73	0.0034	0.0028	Lin.	0.53	Mild. conv.	Exp.	0.31	Mod. conc.	2272	MS	2625	BS	1.20	0.87	4
	Olifants	B1	1681	1399	144	0.0019	0.0020	Lin.	0.44	Mild. conc.	Lin.	0.40	Mod. conc.	1844	MM	2812	BM	0.98	0.66	4
	Usutu	W5	1779	1409	85	0.0043	0.0044	Exp.	0.31	Mod. conc.	Lin.	0.39	Mod. conc.	2304	MS	2324	MS	0.99	0.99	1
	Crocodile	A12	1697	1374	35	0.0022	0.0091	Log.	0.22	Ave. conc.	Lin.	0.41	Mild. conc.	2716	BM	790	NV	0.24	3.44	2
	Vaal	C117	1772	1190	1092	0.0006	0.0005	Lin.	0.44	Mild. conc.	Lin.	0.38	Mod. conc.	3221	BF	3246	BF	1.05	0.99	11
	Waterval	C12	1683	1487	140	0.0014	0.0014	Log.	0.30	Mod. conc.	Log.	0.30	Ave. conc.	3178	BF	3178	BF	1.00	1.00	1
	Blesbokspruit	C13	1692	1433	157	0.0016	0.0016	Lin.	0.33	Mod. conc.	Lin.	0.33	Mod. conc.	3099	BF	3099	BF	1.00	1.00	1
	Mooi	C25	1500	1280	123	0.0018	0.0018	Exp.	0.33	Mod. conc.	Exp.	0.33	Mod. conc.	3863	WM	3863	WM	1.00	1.00	1
	Skoonspruit	C24	1618	1291	148	0.0022	0.0022	Lin.	0.33	Mod. conc.	Lin.	0.33	Mod. conc.	4149	WM	4149	WM	1.00	1.00	1
	Bamboespruit	C26	1504	1221	102	0.0028	0.0028	Lin.	0.45	Mild. conc.	Lin.	0.45	Mild. conc.	4795	WS	4795	WS	1.00	1.00	1
	Harts	C37	1500	1258	269	0.0010	0.0009	Lin.	0.43	Mild. conc.	Lin.	0.36	Mod. conc.	4505	WF	4702	WF	1.11	0.96	3
	Dry Harts	C38	1318	1219	41	0.0016	0.0024	Exp.	0.35	Mod. conc.	Exp.	0.38	Mod. conc.	4079	WM	4746	WM	0.68	0.86	1
	Molopo	D8646	1462	1445	6	0.0009	0.0028	Log.	0.50	Lin.	Log.	0.53	Mild. conv.	3831	WF	5000	WS	0.31	0.77	1
	Klip	C11	1678	1512	147	0.0020	0.0011	Exp.	0.22	Ave. conc.	Exp.	0.24	Ave. conc.	2450	BM	2629	BF	1.75	0.93	2
	Wilge	C116	2043	1594	128	0.0011	0.0035	Log.	0.17	Str. conc.	Log.	0.16	Str. conc.	1811	MF	1277	MS	0.32	1.42	1
	Vals	C215	1577	1249	313	0.0025	0.0010	Exp.	0.18	Str. conc.	Exp.	0.38	Mod. conc.	2550	BM	2703	BF	2.34	0.94	2
	Vet	C213	1431	1221	342	0.0015	0.0006	Log.	0.15	Str. conc.	Exp.	0.32	Mod. conc.	4094	WF	4137	WF	2.37	0.99	5
	Modder	C314	1325	1219	124	0.0011	0.0009	Exp.	0.38	Mod. conc.	Lin.	0.50	Lin.	4071	WF	4222	WF	1.27	0.96	1
Southern Kalahari	Klein Riet	C311	1693	1515	9	0.0067	0.0201	Lin.	0.53	Mild. conv.	Exp.	0.34	Mod. conc.	4065	WV	612	NV	0.33	6.64	1
Ghaap Plateau	Korobela	C39	1427	1260	43	0.0041	0.0039	Lin.	0.47	Mild. conc.	Exp.	0.39	Mod. conc.	3896	WS	4731	WS	1.05	0.82	1
	Kuruman	D8747	1456	1003	109	0.0014	0.0042	Exp.	0.23	Ave. conc.	Lin.	0.46	Mild. conc.	3785	WF	4297	WS	0.34	0.88	2
	Boetsap	C310	1531	1315	82	0.0043	0.0026	Lin.	0.65	Mod. conv.	Lin.	0.56	Mild. conv.	4885	WS	5000	WS	1.63	0.98	2
	Klein Riet	C311	1475	1326	69	0.0067	0.0022	Lin.	0.53	Mild. conv.	Lin.	0.53	Mild. conv.	4065	WV	4892	WM	3.06	0.83	1
	Campbell	C312	1433	1340	35	0.0061	0.0027	Lin.	0.60	Mild. conv.	Lin.	0.60	Mild. conv.	4781	WV	5000	WS	2.28	0.96	1

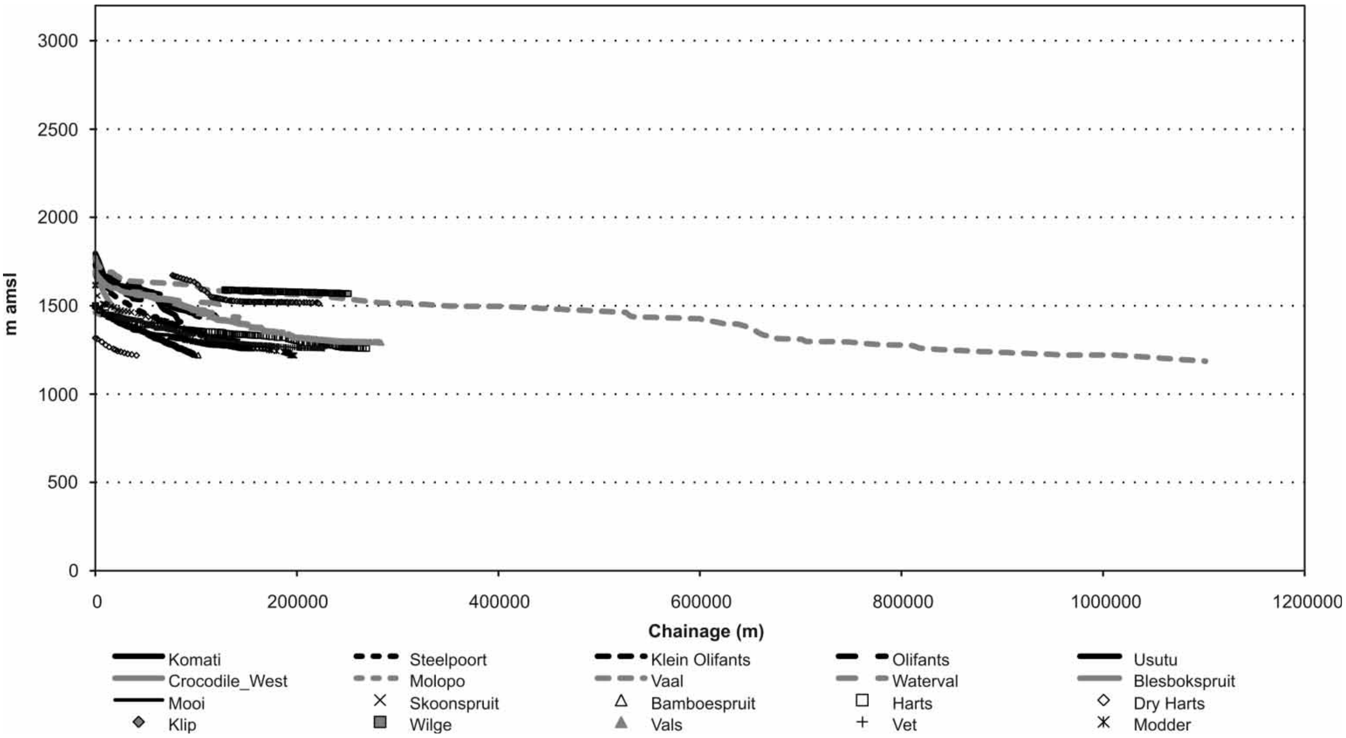

Figure 24. Longitudinal profiles of the rivers of the Highveld geomorphic province.

occupied by lines of pans. These are frequent, especially in the northwest where they represent right-bank tributaries of the palaeo-Vaal River (Marshall, 1988; 1990). In some areas, there are so many pans that they have redirected the original drainage into contiguous, small endoreic basins.

The Highveld province can be divided into three distinct sub-provinces:

Sub-province Northeastern Highveld

Six main easterly-flowing rivers traverse this sub-province (Komati, Steelpoort, Klein Olifants, Olifants, Great Usutu and Crocodile). These rise from the outcrop of Karoo Supergroup sediments at elevations around 1800 m amsl (Table 8), and are characterised by moderately concave longitudinal profiles and linear and exponential BFCs (Table 8). Average longitudinal slopes are mainly steep and valley cross-sectional profiles predominantly broad to medium, so that the sediment storage surrogate descriptors are mainly MS (Table 8). The exception is the Crocodile River which has a narrow valley cross-section profile and a very steep slope, so that the sediment storage surrogate descriptor is NV (Table 8). The Northeastern Highveld, as explained earlier, represents an exhumed pre-Karoo landscape that has imparted greater relief to the sub-province; consequently, the morphology of its rivers is distinctly different from the flatter longitudinal profiles (Figure 24) and broader valley cross-sectional profiles of the Northwestern Highveld.

Sub-province Northwestern Highveld

This is drained by north-bank Vaal River tributaries, and is underlain mainly by Ventersdorp rocks and dolomite. The rivers (Waterval, Blesbokspruit, Mooi, Skoonspruit, Bamboespruit, Harts, Dry Harts, Molopo and Vaal River main stem) flow in valleys with broad and wide cross-sectional profiles and flat to medium slopes so that the sediment storage surrogate descriptors are predominantly BF and WM (Table 8). There is a clear east to west trend, with an increase in valley cross-sectional profile widths and a concomitant increase in slope in that direction (Table 8). With the exception of the Waterval and Molopo rivers (which have logarithmic BFCs) and the Mooi and Dry Harts rivers (which are characterised by exponential BFCs), the rivers have moderately concave longitudinal profiles and linear BFCs (Table 8).

Sub-province Southern Highveld

This is drained by south-bank Vaal River tributaries. The rivers rise in the Eastern Escarpment Hinterland in the south before flowing northwest into the Vaal River valley. The valley cross-sectional profiles are broader than in the Northeastern Highveld, but narrower than those of the Northwestern Highveld (Table 8). There is also a broad trend from north to south, with narrower valley cross-sectional profiles and flatter slopes in the north and broader valley forms and steeper slopes in the south (Table 8). Significantly, however, the average valley slopes are flatter than in the other two sub-provinces (Table 8). The sub-province is therefore characterised predominantly by BF and WF sediment storage surrogate descriptors (Table 8). With the exception of the Wilge River (which has a logarithmic BFC), the concave longitudinal profiles are predominantly exponential (Table 8).

Southern Kalahari

This province, lying within the Kalahari Basin, consists of a series of parallel ridges formed by resistant lithologies, including those of the Postmasburg and Kheis Groups (Map 1). The ridges are separated by flat-floored valleys covered by Kalahari sand in which linear dunes are frequent. Some pans are present, but there is no significant surface drainage, although buried valleys provide good aquifers locally. The erosion surface represented by the valleys grades from African in the east and north to Post African I adjacent to the valley of the Orange River (Partridge & Maud, 1987).

The rivers that drain this province tend to be very steep and narrow in cross-sectional form (e.g., Klein Riet) so that their sediment storage surrogate descriptors are NV (Table 8). These

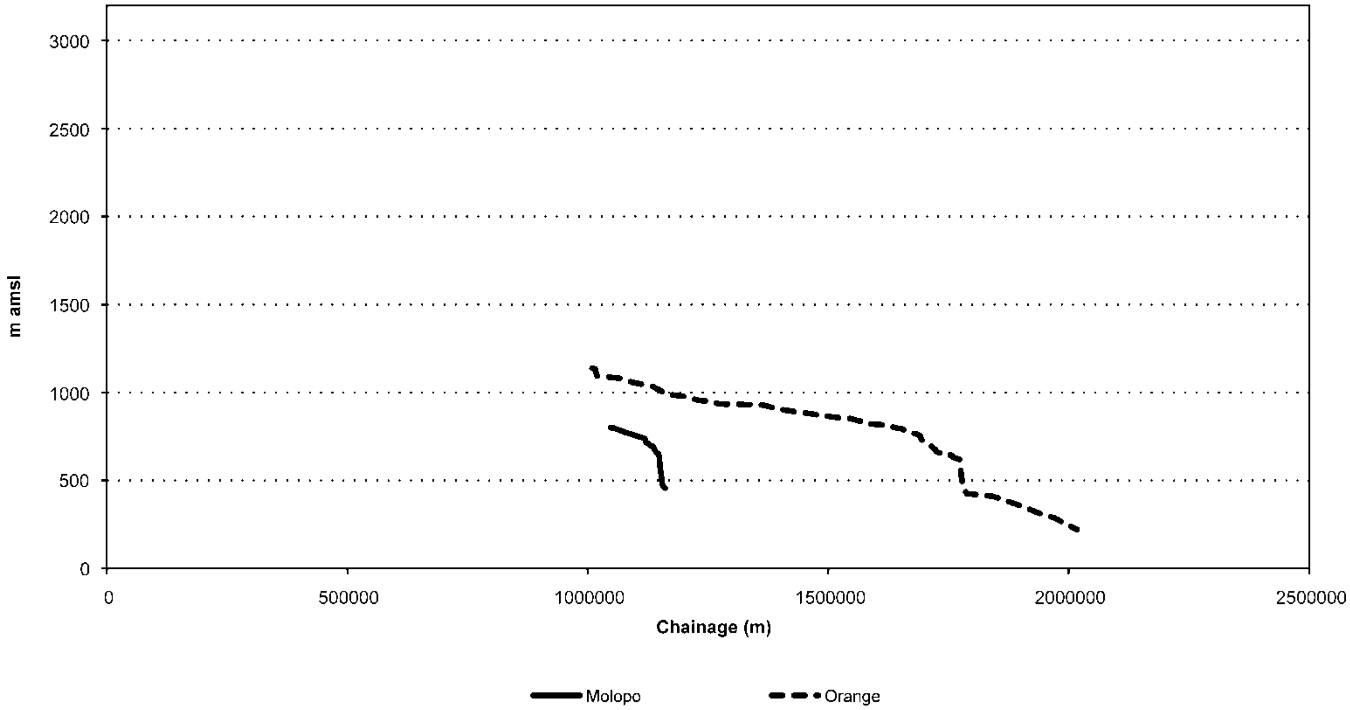

Figure 25. Longitudinal profiles of the Orange and Molopo rivers within the Lower Vaal and Orange Valleys geomorphic province.

physical characteristics are in sharp contrast to the surrounding provinces (see Kalahari, Ghaap Plateau and Lower Vaal and Orange Valleys provinces).

Ghaap Plateau

This elevated province (~1000 to 1500 m amsl) which is underlain by Campbell Rand dolomitic rocks is largely a watershed area (Map 1). It can be zoned from north to south. The north is characterised by sinkholes and sub-surface drainage, the south by intrusive dykes, transverse to the sub-surface drainage, that are expressed at the surface by lines of trees and bushes (King, 1967). Much of the province coincides with surviving areas of the African surface (Partridge & Maud, 1987) on which relief is extremely low. There is little surface drainage, partly as a consequence of the aridity of the area, and partly because of the presence of a well developed karst system which has favoured vertical infiltration and groundwater recharge. Remnants of palaeo-river channels dating to the late Cretaceous (e.g., at Mahura Mutla) indicate that, in the more humid past, larger rivers were able to maintain their flow (from north to south) across the dolomite. The importance of karst weathering and sub-surface flow is indicated by the presence of several large springs along the length of the Ghaap escarpment as well as relict tufa deposits (Marker, 1998).

Five main fluvial systems drain the Ghaap Plateau: the Kuruman River drains northwest into the Kalahari, the other rivers (Korobela, Boetsap, Klein Riet and Campbell) drain southeast into the Lower Vaal and Orange River Valleys. There is a clear north to south trend, with steeper slopes and narrower cross-sectional profiles in the north and flatter slopes and broader valley cross-sectional profiles in the south. The northern rivers (Korobela and Kuruman) are characterised by concave longitudinal profiles, whereas those in the south are characterised by convex longitudinal profiles (Table 8). Other than these differences, the rivers are physically remarkably uniform. The majority are characterised by linear BFCs, wide valley cross-sectional profiles and steep slopes, so that – other than in the Klein Riet – the sediment storage surrogate descriptors are all WS (Table 8).

Lower Vaal and Orange Valleys

This large province coincides with areas adjoining the Lower Vaal and Orange rivers that were incised in the Post-African I cycle and, below the Augrabies Falls, in the Post-African 2 cycle (Map 1). Below the Falls, incision has occurred into the ancient basement (mainly granitic) rocks (Partridge & Maud, 1987). To the northeast, the province is underlain mainly by Karoo rocks, with the Vaal River following the contact between the Karoo and Ventersdorp rocks. At Prieska, the valley turns northwest and incises into the ancient (Precambrian) rocks of the Transvaal Supergroup and the resistant lithologies of the Postmasburg and Kheis Groups. Just upstream of Upington, the valley swings west and is cut into Namaqualand gneiss for over 400 km, before heading north at Vioolsdrift (into the Richtersveld) through the resistant Kheis Group sediments.

The Augrabies Falls constitutes a major knick point in the Orange River, separating the two phases of down cutting (Miocene and Plio-Pleistocene). Downstream of Augrabies Falls, the topography becomes increasingly rugged, with frequent rocky koppies and mountain massifs which confine the Orange River. The longitudinal profile downstream of the Falls is smooth as it traverses the Namaqualand gneiss, before steepening as it traverses the stepped Namaqua Highlands. Upstream of Augrabies hard rock barriers create steps within a fairly flat, concave longitudinal profile (Figure 25). Tooth & McCarthy (2004) describe the 150 km reach above the Augrabies Falls as mixed bedrock-alluvial anabranching. Overall, however, the Orange River within this province is characterised by a mildly convex longitudinal profile and is best described by a linear BFC (Table 9). The average valley cross-sectional width of the Orange River is considerably narrower than its tributaries, but it is also significantly flatter, so that the sediment storage surrogate descriptor is MF (Table 9).

In the area above and below the Orange-Vaal confluence the present channels are strongly controlled by pre-Karoo valleys which are now being re-excavated. The lower course of the Harts River follows one such valley. Equally noteworthy is the presence, in some sectors, of well preserved sets of alluvial terraces (Helgren, 1979; Gibbon, 2009). Those near Kimberley (e.g., at Windsorton) and in the Richtersveld closer to the coast, are particularly well developed, with the highest terrace (60–100 m) being abandoned at ~19 Ma BP (Partridge & Brink, 1967); its crest is co-planar with the Post-African I surface (Partridge & Maud, 1987). The lower (~15 m) Rietputs terrace contains diamonds and important fossil and archaeological remains; it has been dated by the burial cosmogenic isotope method to 1.4 to 1.8 Ma (Gibbon, 2009).

Information Box 4

As mentioned in the previous information box, the capture of the upper reaches of the palaeo-Karoo River by the Palaeo-Kalahari River formed the present-day Orange River. The section of the Orange River from Prieska to its mouth is therefore a remnant of the palaeo-Kalahari River, while the Orange River upstream of Prieska is a remnant of the palaeo-Karoo River (McCarthy & Rubidge, 2005). The marked kink in the Orange River around Prieska marks the elbow of capture.

The main north bank tributaries of the province (Vaal, Harts, Dry Harts, Korobela, Boetsap, Klein Riet and Campbell rivers) are underlain mainly by Karoo and Ventersdorp rocks. These rivers are characterised by concave longitudinal profiles, with predominantly wide and broad valley cross-sectional profiles, but a variety of slope classes, ranging from flat to very steep (Table 9). Similarly, these rivers are best described by a range of BFCs (Table 9). There is a clear trend of increasing slope from northeast to southwest (Table 9). This reflects the exit of very steep north bank tributaries (Korobela, Boetsap, Klein Riet and Campbell rivers) from the Ghaap Plateau into this province. The sediment storage surrogate descriptors are BS, WV, BV and WV, respectively (Table 9). The overall profiles of these rivers (Boetsap, Klein Riet and Campbell) are convex, although this is not the case for all portions of the rivers that traverse the province (Table 9). The Vaal, Harts and Dry Harts rivers, which are re-excavating pre-Karoo valleys (Marshall, 1990), show concave, flat longitudinal profiles, but similar valley cross-sectional widths; thus the sediment storage surrogate descriptors are BF, WF and WF, respectively (Table 9).

The north bank Molopo River enters the province across Namaqualand gneiss. This tributary has an unusual longitudinal profile (Figure 25) and the section that traverses the province is narrower than those of other north bank tributaries (54% narrower than the average for the other north bank tributaries), with a sediment storage surrogate descriptor of MS (Table 9). It is also markedly convex and is characterised by a linear BFC (Table 9).

Four major south bank tributaries enter the Lower Vaal and Orange River province (Modder, Ongers, Vis/Hartbees and Brak rivers). These south bank tributaries are underlain mainly by Namaqualand gneiss in the south and by Karoo sediments in the north. With the exception of the Modder, they are mainly convex in form (Table 9) and have linear BFCs. Slopes are generally flat and valley cross-sectional profiles wide, so that the sediment storage surrogate descriptors are predominantly WF (Table 9). There is also a trend from north to south, with flatter slopes and broader valley cross-sectional profiles on the Karoo rocks in the north and steeper slopes and narrower valley cross-sectional profiles on the gneiss in the south.

Eastern Escarpment Hinterland

This high-altitude province represents the piedmont zone of the westward draining tributaries of the Vaal River (Map 1). It is underlain by the rocks of the upper part of the Karoo Supergroup, i.e., Upper Beaufort Group, Molteno, Elliot and Clarens Formations, together with a number of prominent dolerite sills. These predominantly flat-lying rocks give rise to recurrent elevated mesas and buttes that stand above the African erosion surface, which forms the floors of intervening valleys. The area is one of dissection within the currently active African cycle (Partridge & Maud, 1987). Contrasts in river longitudinal profiles and channel pattern exist as a result of the influence of different lithologies, notably dolerite and shales and sandstone (*cf.* Tooth *et al.*, 2002). This results in open meandering channel patterns on the shales and sandstones and narrow, steep channels across the dolerites. There are a number of important wetlands, notably those around Maclear and Ugie. This province also contains significant river capture sites across the Great Escarpment (e.g., the Buffalo River), as well as a number of incipient capture sites (e.g., the Wilge River).

Eight main systems drain this province (Buffalo, Klip, Wilge, Vals, Vet, Orange, Kraai and Stormbergspruit rivers). There is a trend from north to south, with slightly wider valley cross-sectional profiles and flatter slopes in the north and narrower valleys and steeper slopes in the south (Table 9). The six northern systems show remarkable uniformity (Figure 26), with mainly concave longitudinal profiles, logarithmic BFCs, medium valley cross-sectional profiles and very steep to steep slopes, so that the sediment storage surrogate descriptors are predominantly MV and MS (Table 7). The three southern systems (Table 9) are also uniform, but are marked by significantly narrower valley cross-sectional profiles, so that the sediment storage surrogate descriptors are NF, NM and MV (Table 9). Profiles are all concave, but are characterised by mainly exponential BFCs (Table 9).

Zululand Coastal Plain

This province is the most extensive coastal area in southern Africa and is underlain by young (Cretaceous to Miocene) marine sediments. It extends from Mtunzini in the south to Mozambique in the north (Map 1). The province is a marine platform (Maud & Partridge, 1988) exposed during eustatic sea-level decline (in the Palaeocene, the sea reached the eastern slopes of the Lebombo Highlands). Its surface, covered by redistributed sands, hosts a number of dune cordons which reflect pauses in the recession of the sea during the Cenozoic. Rivers crossing the province have been deflected and obstructed by the highest of the dune ridges close to the present coast, so that the rivers run parallel to the present shore line producing important wetland systems (e.g., the Kosi lakes, Lake Sibayi, the Mkuzi Swamps and Lake St Lucia). Apart from the Pongola River, drainage systems are fragmented and active faults have caused lineations and displacements (King, 1967).

Five main fluvial systems traverse this province; from north to south these are the Usutu, Pongola, Mkuze, Mfolozi and Mhlathuze rivers. All have wide valley cross-sectional profiles and flat concave longitudinal profiles, so that the predominant sediment storage surrogate descriptor is WF (Table 10). The three northern systems are marked by a variety of BFCs (linear, logarithmic and exponential, respectively), while the two southern systems have linear BFCs (Table 10). This province has is distinctively flat (Figure 27) in comparison to adjoining provinces (Table 10). The ratio of the total profile slope for these systems, compared to the slope of the province, ranges from 4.5 to >11 (Table 10). King (1967: 301) has also commented on this characteristic "A feature of this area is the manner in which the rivers that have boldly breached the Lebombo turn meekly parallel with the shore-line and flow along the length of the Coastal Plain."

Table 9. Descriptor information for rivers by geomorphic province.

Geomorphic province	River (from north to south and then east to west)	River number	Geomorphic province starting altitude (m amsl)	Geomorphic province exit altitude (m amsl)	Geomorphic province length (km)	Total river slope (m/m)	River slope in geomorphic province (m/m)	Total river best fit curve	Total profile shape (area under curve)	Total profile shape descriptor (conc = concave; conv = convex)	Geomorphic province best fit curve	Geomorphic province shape	Geomorphic province shape descriptor (conc = concave; conv = convex)	Total profile average valley width (m)	Total profile sediment storage surrogate	Geomorphic province average valley width (m)	Geomorphic province sediment storage surrogate	Ratio total profile slope to geomorphic province slope	Ratio total profile width to geomorphic province width	Number of macro reaches
Lower Vaal & Orange Valley Rivers	Orange	D28	1138	222	1008	0.0012	0.0009	Log.	0.33	Mod. conc.	Lin.	0.60	Mild. conv.	1416	MF	2315	MF	1.33	0.61	5
	Vaal	C117	1189	979	326	0.0006	0.0006	Lin.	0.44	Mild. conc.	Exp.	0.35	Mod. conc.	3221	BF	3117	BF	0.86	1.03	1
	Harts	C37	1252	1010	216	0.0010	0.0011	Lin.	0.43	Mild. conc.	Log.	0.23	Ave. conc.	4505	WF	4217	WF	0.89	1.07	3
	Dry Harts	C38	1208	1079	101	0.0016	0.0013	Exp.	0.35	Mod. conc.	Exp.	0.33	Mod. conc.	4079	WM	3805	WF	1.28	1.07	3
	Korobela	C39	1237	1125	27	0.0041	0.0042	Lin.	0.47	Mild. conc.	Lin.	0.45	Mild. conc.	3896	WS	2540	BS	0.97	1.53	1
	Boetsap	C310	1297	1029	32	0.0043	0.0084	Lin.	0.65	Mod. conv.	Lin.	0.49	Mild. conc.	4885	WS	4673	WV	0.51	1.05	2
	Klein Riet	C311	1318	1000	20	0.0067	0.0162	Lin.	0.53	Mild. conv.	Log.	0.37	Mod. conc.	4065	WV	3020	BV	0.41	1.35	2
	Campbell	C312	1320	979	35	0.0061	0.0097	Lin.	0.60	Mild. conv.	Exp.	0.34	Mod. conc.	4781	WV	4656	WV	0.63	1.03	1
	Molopo	D8646	800	456	113	0.0009	0.0030	Log.	0.50	Lin.	Lin.	0.77	Ave conv.	3831	WF	2295	MS	0.29	1.67	4
	Modder	C314	1102	995	112	0.0011	0.0010	Exp.	0.38	Mod. conc.	Log.	0.31	Mod. conc.	4071	WF	3703	WF	1.14	1.10	1
	Ongers	D711	982	934	62	0.0014	0.0008	Exp.	0.36	Mod. conc.	Lin.	0.58	Mild. conv.	4139	WF	4574	WF	1.86	0.90	4
	Vis/Hartbees	D5969	858	645	153	0.0014	0.0014	Exp.	0.38	Mod. conc.	Lin.	0.54	Mild. conv.	4396	WF	3941	WF	1.01	1.12	2
	Brak	D912	414	164	10	0.0124	0.0246	Lin.	0.54	Mild. conv.	Lin.	0.56	Mild. conv.	2537	BV	1509	MV	0.50	1.68	1
Eastern Escarpment Hinterland	Buffalo	V2	2069	1594	72	0.0039	0.0066	Exp.	0.44	Mild. conc.	Log.	0.25	Ave. conc.	1636	MS	1158	MV	0.60	1.41	1
	Klip	C11	1951	1678	74	0.0020	0.0037	Exp.	0.22	Ave. conc.	Log.	0.17	Str. conc.	2450	BM	2102	MS	0.53	1.17	4
	Wilge	C116	2043	1594	128	0.0011	0.0035	Log.	0.17	Str. conc.	Log.	0.16	Str. conc.	1811	MF	1277	MS	0.32	1.42	1
	Vals	C215	2107	1581	36	0.0025	0.0147	Exp.	0.18	Str. conc.	Log.	0.19	Str. conc.	2550	BM	1495	MV	0.17	1.71	2
	Vet	C213	1751	1440	20	0.0015	0.0156	Log.	0.15	Str. conc.	Log.	0.22	Ave. conc.	4094	WF	3594	BV	0.09	1.14	2
	Orange	D28	1506	1286	356	0.0012	0.0006	Log.	0.33	Mod. conc.	Lin.	0.43	Mild. conc.	1416	MF	643	NF	1.94	2.20	1
	Kraai	D11	1551	1290	162	0.0040	0.0016	Log.	0.22	Ave. conc.	Exp.	0.33	Mod. conc.	570	NS	718	NM	2.49	0.79	3
	Stormbergspruit	D22	1943	1417	86	0.0041	0.0061	Exp.	0.27	Ave. conc.	Exp.	0.30	Ave. conc.	1586	MS	1203	MV	0.66	1.32	2

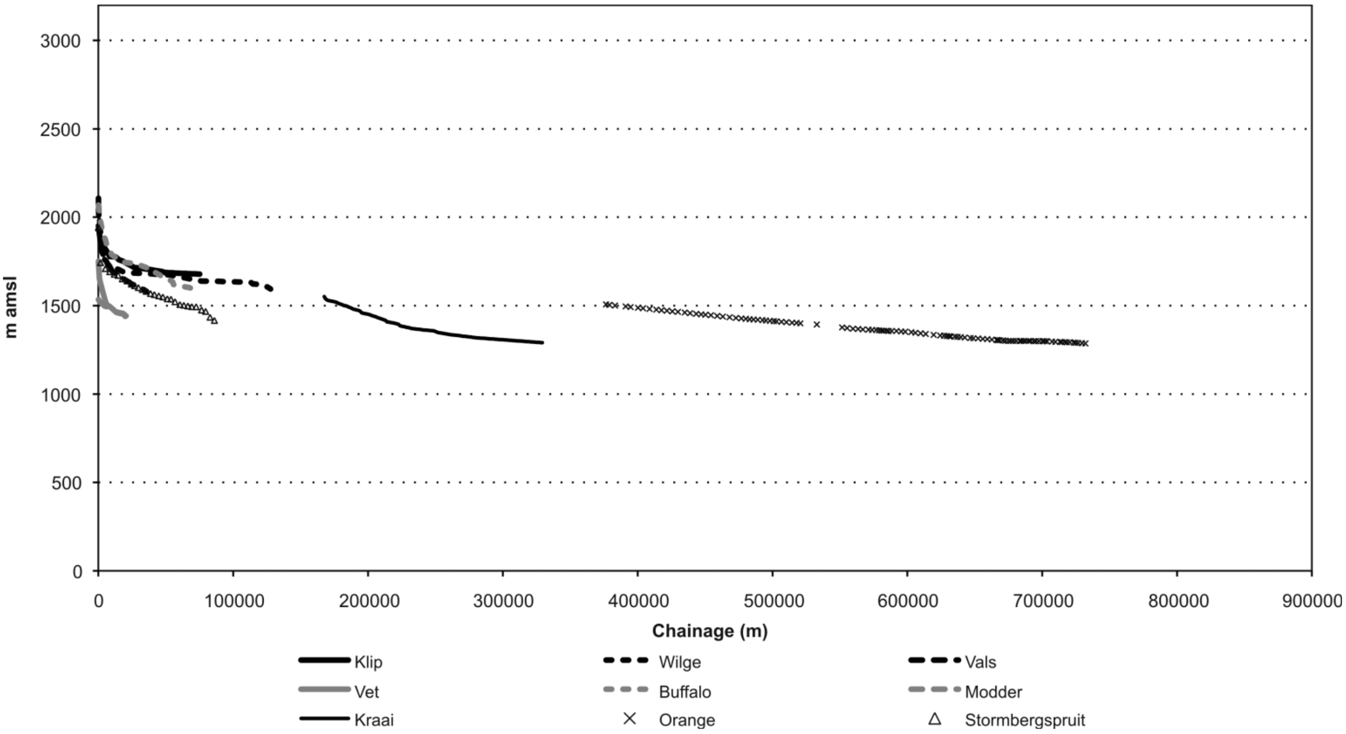

Figure 26. Longitudinal profiles of the rivers of the Eastern Escarpment Hinterland geomorphic province.

Namib

This province is an arid to hyper-arid (reflected in the widespread occurrence of calcrete and silcrete) coastal platform adjacent to the Atlantic Ocean south of the Orange River (Map 1). It is a southward extension of the Namib Desert of Namibia, a province created by the eastward recession of the western Great Escarpment. The province is underlain by Namaqualand gneiss and Nama Group sediments, which are mantled in places by recent (Cenozoic) sediments. In the south, Cape Supergroup rocks (Bokkeveld Group) extend into the province. The landscape is dominated by the Post-African I surface, with remnants of the African surface on the high-lying interfluves (Partridge & Maud, 1987). A prominent feature is an uplifted sea cliff of Miocene age (coeval with the Southern Coastal Platform) (Partridge & Maud, 1987) at an elevation around 90 m amsl; the lower reaches of the Namib rivers are moderately incised as a result of uplift in the Neogene. All rivers have in-filled valleys where they meet the sea. The steep rise to the base of the Namaqua Highlands that characterises the western part of the province means that the river longitudinal profiles are comparatively steep and flows are erratic, being limited by infrequent rains. A number of the rivers occupy

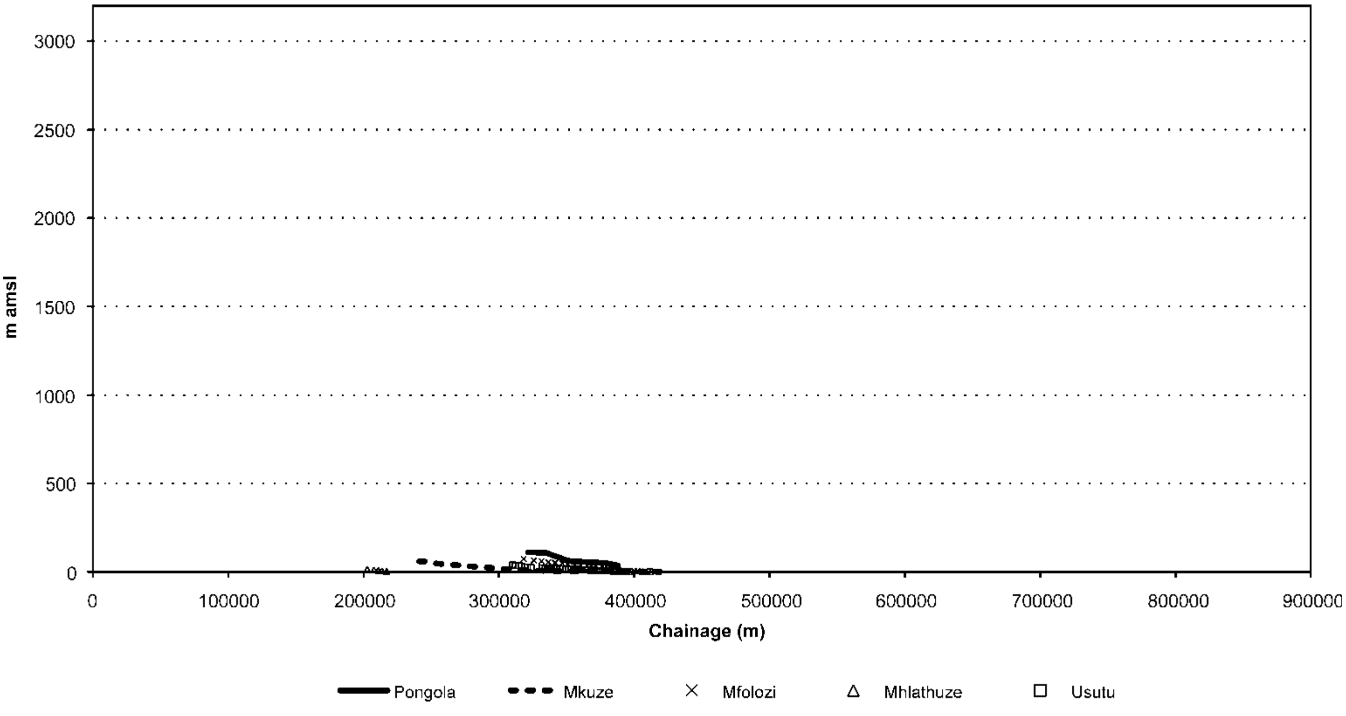

Figure 27. Longitudinal profiles of the rivers of the Zululand Coastal Plain geomorphic province.

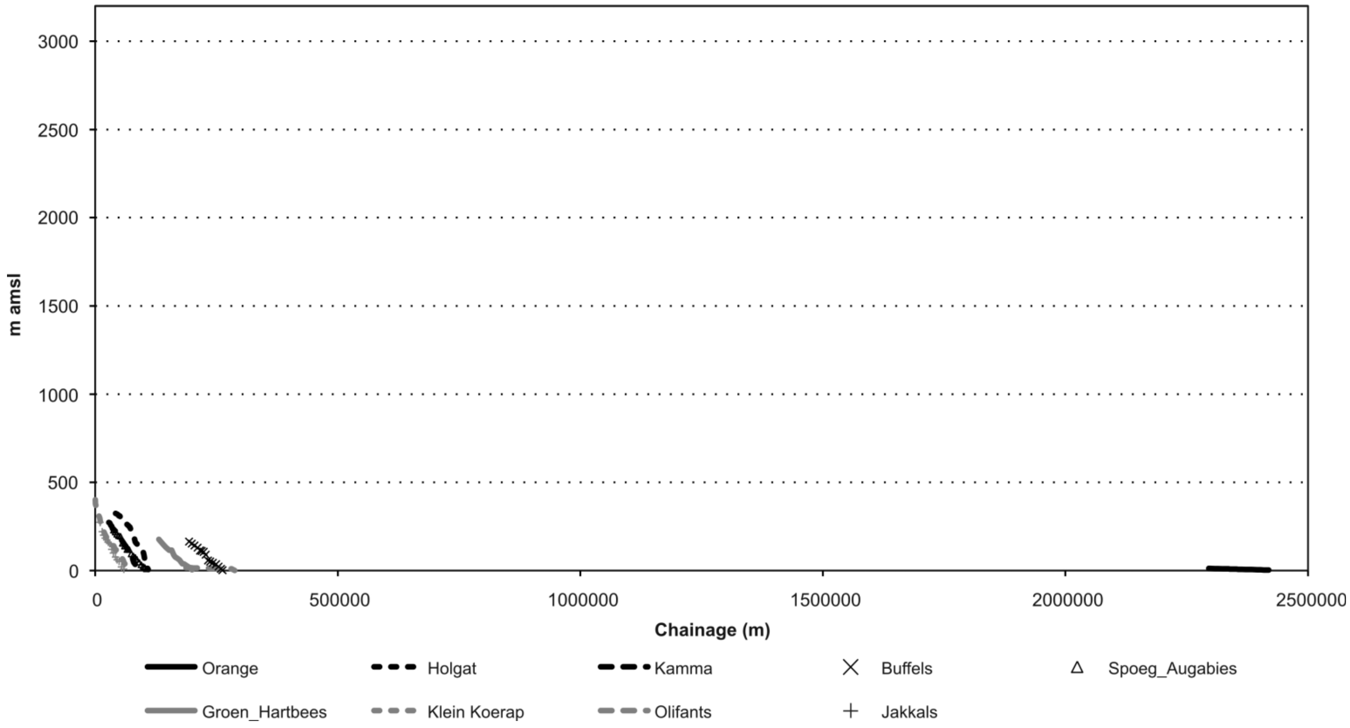

Figure 28. Longitudinal profiles of the rivers of the Namib geomorphic province.

shallow box-canyons typical of arid environments.

Ten main river systems traverse this province (Figure 28). Eight of them show remarkable uniformity (Holgat, Kamma, Buffels, Augabies, Hartbees, Klein Kgoerap and Jakkals rivers). These are characterised by steep longitudinal profiles, linear BFCs and medium valley cross-sectional profiles so that their sediment storage surrogate descriptors are mainly MS (Table 10). Three of these rivers, the Holgat, Kamma and Buffels, display convex longitudinal profiles (Table 10), reflecting the influence of Neogene uplift and arching and the fact that maximum uplift was in the north of the province.

The two largest rivers, the Orange River in the north and the Olifants River in the south, show significantly different physical characteristics from the other rivers in this province. Longitudinal profiles are significantly flatter (Table 10, approximately 3000% flatter, significant at $\alpha = 0.01$ level in ANOVA testing), and the ratio of the total profile slope to the province slope is 16 and 20 for the Orange and Olifants rivers, respectively (Table 10).

Namaqua Highlands

This province coincides with the Great Escarpment over a stretch extending from north of the Sout River, inland of the Atlantic coast, northwards into the Richtersveld (Map 1). The former area is underlain by rocks of the Namaqua Metamorphic Complex (mainly gneisses) which are capped, in places, by flat-lying sedimentary rocks of the Nama Group, but the Richtersveld shows much greater geological complexity. Much of the area lies above the level of the African surface (Partridge & Maud, 1987). Elevations have been increased by isostatic compensation since the rifting of Gondwanaland. Consequently, the valleys are deeply incised and longitudinal gradients are very steep. Uplift along an extension of the Griqualand–Transvaal axis has led to river capture in some places (e.g., the Buffels River).

The majority of rivers are ephemeral because of the semi-arid climate of the area. Seven main systems traverse this province (Orange, Holgat, Kamma, Buffels, Augabies, Hartbees and Brak rivers). Other than that of the Orange River, the longitudinal profiles are concave and have exponential BFCs (Table 10). Valley cross-sectional widths are mainly narrow, and slopes very steep, so that the sediment storage surrogate descriptors are mainly NV (Table 10). The longitudinal slopes and valley widths are markedly narrower (significant at $\alpha = 0.05$) and steeper (significant at $\alpha = 0.01$) than the adjoining province into which these systems exit, the Namib (Table 10). There is a weak trend within this province, for average slopes to steepen from north to south and this is accompanied by a small increase in average valley widths.

Northern Cape Pan Veld

The main feature of this province, which straddles the uplifted Griqualand–Transvaal axis, is the frequency of pans (some of vast size e.g., Verneukpan and Grootvloer) that are remnants of earlier (Cretaceous) drainage systems (De Wit, 1993) (Plate 2) (Map 1). The province is underlain by Karoo rocks (Ecca and Dwyka Groups) in the south and east and by Namaqua gneiss in the west and north. Each pan has its own endoreic drainage net and several are used for the evaporative production of salt. These pans can be regarded as discontinuous groundwater windows, in which the substantial excess of evaporation over precipitation under the prevailing hot, dry climate, leads to rapid concentration of dissolved solids within each discrete basin. Some of the pans are linked by now defunct palaeo-valleys which, under the more humid conditions of the Miocene, contained substantial rivers: the Koa Valley, Commissioner's Valley and Carnarvonleegte are among these relict features (Dollar, 1998). These drainage systems were disrupted both by progressive aridification and by uplift along the Griqualand–Transvaal axis, causing the dismembering of several (e.g., the Koa and Vis/Hartbees rivers) (Partridge & Maud, 2000). The province contains remnants of the African erosion surface along its western and eastern margins, but the surface is mainly Post-African I with some Post-African II incision near the Orange River (Partridge & Maud, 1987).

Four main drainage systems traverse this province; from east

Table 10. Descriptor information for rivers by geomorphic province.

Geomorphic province	River (from north to south and then east to west)	River number	Geomorphic province starting altitude (m amsl)	Geomorphic province exit altitude (m amsl)	Geomorphic province length (km)	Total river slope (m/m)	River slope in geomorphic province (m/m)	Total river best fit curve	Total profile shape (area under curve)	Total profile shape descriptor (conc = concave; conv = convex)	Geomorphic province best fit curve	Geomorphic province shape	Geomorphic province shape descriptor (conc = concave; conv = convex)	Total profile average valley width (m)	Total profile sediment storage surrogate	Geomorphic province average valley width (m)	Geomorphic province sediment storage surrogate	Ratio total profile slope to geomorphic province slope	Ratio total profile width to geomorphic province width	Number of macro reaches
Zululand Coastal Plain	Usutu	W5	40	0	101	0.0043	0.0004	Exp.	0.31	Mod. conc.	Lin.	0.35	Mod. conc.	2304	MS	4094	WF	11.02	0.56	4
	Pongola	W4	111	36	67	0.0051	0.0011	Exp.	0.27	Ave. conc.	Log.	0.48	Mild. conc.	1678	MS	4056	WF	4.50	0.41	3
	Mkuze	W3	60	0	178	0.0037	0.0003	Exp.	0.19	Str. conc.	Exp.	0.27	Ave. conc.	2691	BS	4650	WF	10.80	0.58	3
	Mfolozi	W2	73	0	100	0.0035	0.0007	Exp.	0.33	Mod. conc.	Lin.	0.43	Mild. conc.	1639	MS	2850	BF	4.69	0.57	1
	Mhlathuze	W1	16	2	14	0.0051	0.0009	Exp.	0.29	Ave. conc.	Lin.	0.53	Mild. conv.	1156	MS	3944	WF	5.56	0.29	1
Namib	Orange	D28	12	2	124	0.0012	0.0001	Log.	0.33	Mod. conc.	Lin.	0.50	Lin.	1416	MF	1660	MF	15.62	0.85	2
	Holgat	F1	323	5	67	0.0080	0.0047	Exp.	0.36	Mod. conc.	Lin.	0.61	Mod. conv.	1482	MV	1693	MS	1.69	0.88	2
	Kamma	F2	272	35	54	0.0086	0.0044	Exp.	0.30	Mod. conc.	Lin.	0.55	Mild. conv.	1200	MV	1770	MS	1.96	0.68	1
	Buffels	F3	163	1	69	0.0049	0.0023	Lin.	0.35	Mod. conc.	Lin.	0.51	Mild. conv.	1235	MS	1823	MM	2.08	0.68	1
	Augabies	F4	229	11	68	0.0112	0.0032	Exp.	0.23	Ave. conc.	Lin.	0.46	Mild. conc.	911	NV	819	NS	3.47	1.11	1
	Hartbees	F5	176	4	68	0.0078	0.0025	Exp.	0.27	Ave. conc.	Lin.	0.47	Mild. conc.	1157	MV	1328	MS	3.08	0.87	1
	Klein Kgoerap	F6	401	16	79	0.0048	0.0048	Exp.	0.33	Mod. conc.	Exp.	0.33	Mod. conc.	1234	MS	1234	MS	1.01	1.00	1
	Olifants	E1	16	0	101	0.0032	0.0002	Exp.	0.16	Str. conc.	Lin.	0.74	Ave conv.	1425	MS	2264	MF	20.08	0.63	2
	Jakkals	G3	273	7	49	0.0091	0.0054	Log.	0.29	Ave. conc.	Lin.	0.43	Mild. conc.	2082	MV	2189	MS	1.68	0.95	1
Namaqua Highlands	Orange	D28	213	15	263	0.0012	0.0008	Log.	0.33	Mod. conc.	Lin.	0.51	Mild. conv.	1416	MF	603	NF	1.59	2.35	1
	Holgat	F1	881	346	38	0.0080	0.0140	Exp.	0.36	Mod. conc.	Exp.	0.37	Mod. conc.	1482	MV	1201	MV	0.57	1.23	2
	Kamma	F2	741	291	26	0.0086	0.0176	Exp.	0.30	Mod. conc.	Exp.	0.29	Ave. conc.	1200	MV	512	NV	0.49	2.35	2
	Buffels	F3	1281	179	189	0.0049	0.0058	Lin.	0.35	Mod. conc.	Exp.	0.38	Mod. conc.	1235	MS	1052	NV	0.84	1.17	2
	Augabies	F4	1194	336	33	0.0112	0.0257	Exp.	0.23	Ave. conc.	Exp.	0.33	Mod. conc.	911	NV	1048	NV	0.44	0.87	2
	Hartbees	F5	1556	196	126	0.0078	0.0108	Exp.	0.27	Ave. conc.	Exp.	0.31	Mod. conc.	1157	MV	1061	NV	0.72	1.09	4
	Brak	D912	1193	940	11	0.0124	0.0234	Lin.	0.54	Mild. conv.	Log.	0.27	Ave. conc.	2537	BV	1713	MV	0.53	1.48	1
Northern Cape	Boesak	D510	1122	836	197	0.0023	0.0015	Exp.	0.30	Ave. conc.	Exp.	0.39	Mod. conc.	4598	WM	4730	WF	1.55	0.97	5

Continued on p. 35

Table 10 (*continued*)

Pan Veld	Vis/Hartbees	D5969	1088	867	279	0.0014	0.0008	Exp.	0.38	Mod. conc.	Exp.	0.39	Mod. conc.	4396	WF	4780	WF	1.78	0.92	2
	Brak	D912	936	460	56	0.0124	0.0085	Lin.	0.54	Mild. conv.	Lin.	0.62	Mod. conv.	2537	BV	3135	BV	1.46	0.81	3
Upper Karoo	Modder	C314	1534	1329	73	0.0011	0.0028	Exp.	0.38	Mod. conc.	Exp.	0.38	Mod. conc.	4071	WF	3525	BS	0.39	1.15	3
	Modder	C314	1218	1107	175	0.0011	0.0006	Exp.	0.38	Mod. conc.	Lin.	0.55	Mild. conv.	4071	WF	4886	WF	1.72	0.83	1
	Orange	D28	1285	1143	264	0.0012	0.0005	Log.	0.33	Mod. conc.	Lin.	0.50	Lin.	1416	MF	2806	BF	2.25	0.50	1
	Stormbergspruit	D22	1386	1279	74	0.0041	0.0015	Exp.	0.27	Ave. conc.	Lin.	0.48	Mild. conc.	1586	MS	1775	MF	2.79	0.89	1
	Seekoei	D24	1855	1128	264	0.0027	0.0027	Exp.	0.32	Mod. conc.	Exp.	0.32	Mod. conc.	3112	BS	3112	BS	1.02	1.00	1
	Ongers	D711	1360	982	235	0.0014	0.0016	Exp.	0.36	Mod. conc.	Exp.	0.36	Mod. conc.	4139	WF	3892	WM	0.89	1.06	4
	Boesak	D510	1381	1133	43	0.0023	0.0057	Exp.	0.30	Ave. conc.	Exp.	0.37	Mod. conc.	4598	WM	4201	WS	0.39	1.09	2
	Vis/Hartbees	D5969	1419	1093	85	0.0014	0.0038	Exp.	0.38	Mod. conc.	Lin.	0.45	Mild. conc.	4396	WF	2914	BS	0.37	1.51	2
Ladysmith Basin	Buffalo	V2	1232	1068	206	0.0039	0.0008	Exp.	0.44	Mild. conc.	Lin.	0.45	Mild. conc.	1636	MS	3168	BF	4.91	0.52	3
	Thukela	V1	1379	938	179	0.0059	0.0025	Log.	0.20	Ave. conc.	Exp.	0.31	Mod. conc.	1163	MV	1663	MM	2.40	0.70	3
Lesotho Highlands	Orange	D28	2915	1510	374	0.0012	0.0038	Log.	0.33	Mod. conc.	Exp.	0.27	Ave. conc.	1416	MF	334	NS	0.32	4.24	5
	Senqunyane	D13	2973	1510	181	0.0081	0.0081	Exp.	0.27	Ave. conc.	Exp.	0.27	Ave. conc.	180	NV	180	NV	1.00	1.00	4
	Kraai	D11	2611	1553	166	0.0040	0.0064	Log.	0.22	Ave. conc.	Exp.	0.22	Ave. conc.	570	NS	457	NV	0.63	1.25	4
Southeastern Coastal Platform	Thukela	V1	65	7	62	0.0059	0.0009	Log.	0.20	Ave. conc.	Exp.	0.42	Mild. conc.	1163	MV	879	NF	6.38	1.32	1
	Mvoti	U3	125	6	50	0.0069	0.0024	Lin.	0.34	Mod. conc.	Lin.	0.46	Mild. conc.	988	NV	1031	NM	2.88	0.96	1
	Mgeni	U2	28	2	19	0.0076	0.0014	Exp.	0.33	Mod. conc.	Exp.	0.30	Ave. conc.	1477	MV	1095	NF	5.59	1.35	2
	Mkomazi	U1	71	2	29	0.0106	0.0024	Log.	0.21	Ave. conc.	Exp.	0.40	Mod. conc.	467	NV	567	NM	4.43	0.82	1
	Mzimkulu	T5	22	0	20	0.0081	0.0011	Lin.	0.27	Ave. conc.	Exp.	0.34	Mod. conc.	980	NV	593	NF	7.36	1.65	1
	Mtentu	T4	257	6	53	0.0085	0.0047	Exp.	0.36	Mod. conc.	Lin.	0.54	Mild. conv.	609	NV	406	NS	1.81	1.50	1
	Mzimvubu	T3	18	0	38	0.0070	0.0005	Exp.	0.26	Ave. conc.	Exp.	0.30	Ave. conc.	448	NV	398	NF	14.9	1.13	2
	Mtata	T2	67	5	33	0.0061	0.0019	Lin.	0.30	Mod. conc.	Lin.	0.47	Mild. conc.	842	NV	609	NM	3.21	1.38	1
	Mbashe	T1	97	0	50	0.0060	0.0020	Exp.	0.27	Ave. conc.	Lin.	0.44	Mild. conc.	921	NV	501	NM	3.07	1.84	1
	Kei	S1	37	0	31	0.0040	0.0012	Lin.	0.33	Mod. conc.	Lin.	0.40	Mild. conc.	1370	MS	377	NF	3.35	3.64	1
	Buffalo	R2	31	0	10	0.0094	0.0031	Log.	0.24	Ave. conc.	N/A	0.50	Mild. conc.	1006	NV	1373	MS	3.04	0.73	1
	Keiskamma	R1	19	0	27	0.0067	0.0007	Log.	0.18	Str. conc.	Lin.	0.54	Mild. conv.	861	NV	1183	MF	9.24	0.73	1
	Great Fish	Q1	39	0	35	0.0021	0.0011	Exp.	0.37	Mod. conc.	Log.	0.36	Mod. conc.	1833	MM	309	NF	1.96	5.93	1
	Bushmans	P1	13	3	28	0.0025	0.0004	Exp.	0.32	Mod. conc.	Lin.	0.50	Lin.	1287	MS	1602	MF	6.96	0.80	1
Southern Karoo	Sundays	N1	808	229	245	0.0034	0.0024	Exp.	0.29	Ave. conc.	Lin.	0.46	Mild. conc.	2288	MS	3409	BM	1.45	0.67	2
	Groot	L1	1201	878	120	0.0023	0.0027	Lin.	0.42	Mild. conc.	Exp.	0.48	Mild. conc.	2434	BM	3059	BS	0.85	0.80	1
	Gourits	J1	1173	409	111	0.0050	0.0069	Log.	0.18	Str. conc.	Exp.	0.29	Ave. conc.	1438	MS	2379	BV	0.72	0.60	3
	Doring	E2	572	391	133	0.0021	0.0025	Lin.	0.44	Mild. conc.	Lin.	0.47	Mild. conc.	2071	MM	3236	BS	0.84	0.64	3
	Doring	E2	274	237	32	0.0021	0.0012	Lin.	0.44	Mild. conc.	Lin.	0.45	Mild. conc.	2071	MM	1252	MF	1.84	1.65	1

Plate 2. A typical pan in the Northern Cape Pan Veld geomorphic province.

to west these are the Boesak, Vis/Hartbees and Brak rivers. Those in the east (Boesak and Vis/Hartbees) display remarkable uniformity, with flat slopes, wide valley cross-sectional profiles, concave longitudinal profiles and exponential BFCs (Table 8). The sediment storage surrogate descriptors are consequently WF (Table 10). The rivers in the extreme northwest (e.g., the Brak) are, however, characterised by narrower valley cross-sectional profiles, steeper slopes, convex longitudinal profiles and linear BFCs (Table 10), so that their sediment storage surrogate descriptors become BV (Table 8). The Brak River in fact follows the Koa valley, the course of which was disrupted by uplift along the Griqualand–Transvaal axis which crosses it at right angles.

Upper Karoo

This extensive province is underlain predominantly by flat-lying sedimentary rocks of the Karoo Supergroup which have been intruded by innumerable sills and dykes of dolerite, some in the form of transgressive cone-sheets (Map 1). The relief associated with these lithologies ranges from tabular tafelkoppies (mesas) to sinuous, bouldery ridges and where dissection is advanced, steep-sided mountains such as the Kompasberg near Nieu Bethesda dominate the landscape. Much of the province consists of gentle, multi-concave pediments. To the west these have been planed in the Post-African I cycle, but towards the Great Escarpment in the south and the Lesotho Highlands in the east, the pediments represent partially complete planation in the African cycle (Partridge & Maud, 1987). The transition between these two surfaces is, in most places, gradational. Rivers rising within this province are mostly ephemeral, occupy broad, open valleys, and have braided floodplains and concave longitudinal profiles.

Seven main fluvial systems drain the Upper Karoo from the Modder River in the east to the Vis/Hartbees River in the west. Although the longitudinal profiles of these rivers show some uniformity, there is a clear trend from east to west, with flatter valley slopes and narrower cross-sectional profiles in the east, and marginally steeper slopes and wider valley cross-sectional profiles in the west (Table 10). This is reflected in the sediment storage surrogate descriptors which range from BF to MF in the east to WS and BF in the west (Table 10).

Ladysmith Basin

This province, like the Queenstown Basin (and possibly others), is a rain-shadow area below the Great Escarpment (Map 1). The province is underlain by Karoo sediments with dolerite intrusions and is dominated by the Post-African I erosion surface (Partridge & Maud, 1987). There is considerable structural control (*cf.* Matthews, 1969) that impacts on the province's hydrography and channel gradients are low as it lies inland of the hinge-line of the Ciskei–Swaziland axis (Map 1). In addition to this control, the Thukela River and its tributaries have yet to breach the dolerite barrier at Monte Christo and the province is therefore flat-lying and dry.

The Thukela River and its main tributaries drain the Ladysmith Basin (Buffalo, Klip, Mooi and Sundays rivers). The main stem Thukela River has a concave longitudinal profile, an exponential BFC, with a moderate valley slope and a medium valley cross-sectional profile so that the sediment storage surrogate descriptor is MM (Table 10). Its path is controlled largely by the Thukela fault. The eastern tributaries display linear BFCs, concave longitudinal profiles, broad valley cross-sectional profiles and flat slopes (Table 10).

Lesotho Highlands

This province includes the highest mountain massif in southern Africa, reaching elevations in excess of 3400 m amsl (Map 1). It stands above the African surface, and it is estimated

Plate 3. The Malibamats'o River at Paray, Lesotho Highlands geomorphic province.

that the crestal areas have been lowered by no more than 300 m since continental rifting (Partridge & Maud, 1987). The high-lying parts are underlain by Stormberg lavas (Drakensberg basalts) that reach thicknesses of up to 1300 m, but the valleys are often cut into lower Karoo sequences (e.g., Clarens sandstones) by the Senqu/Orange River and its tributaries. Valleys are deeply incised and steep-flanked, with steep longitudinal profiles, particularly in their upper reaches (Plate 3). Pronounced stepping of some profiles has been produced by the near-horizontal disposition of the strata both in the basalts which cap the higher ridges as well as in the underlying sandstone of the Clarens Formation. Deformations in the strata (particularly in the upper reaches) have influenced the hydrography of the two major rivers and their tributaries: the Senqu/Orange and Caledon flow in gentle synclines. Valley asymmetry has been attributed by some to the varying activity of freeze–thaw processes on slopes of different aspects (Meiklejohn, 1994). Active weathering and erosion have produced an abundance of colluvium which is transported readily in active mountain streams.

The high elevation (~3000 to 1500 m amsl) tributaries (e.g., Senqunyana, Malibamats'o and Kraai) and main stem Senqu/Orange River show many similarities (Map 1). All have averagely concave longitudinal profiles, exponential BFCs, narrow cross-sectional profiles and very steep slopes so that their sediment storage surrogates are predominantly NV (Table 10).

Southeastern Coastal Platform

This province, which is underlain mainly by Karoo rocks (Ecca and Dwyka Groups with some Table Mountain sandstones and granite-gneisses in the north and Beaufort Group sediments with dolerite intrusions in the south), represents a narrow coastal platform that strikes northeast to southwest from the Zululand Coastal Plain in the northeast to just east of Algoa Bay (Map 1). The province is fairly narrow, ranging in width from ~5 to 30 km and its elevation ranges from ~110 m amsl to a little above the present shoreline (Table 10). The province terminates sharply inland where it adjoins the Southeastern Coastal Hinterland and the East London Coastal Hinterland. The Platform is considerably more humid than its adjoining counterparts through a considerable range of latitudes (King, 1967). King (*ibid.*) has pointed out that the coastline of this province is slightly oblique to the strike of the country rocks and this is a result of differential uplift that has overridden the earlier structural grain. One of the impacts of this multi-cyclic, differential movement was to expose the adjoining continental shelf so that rivers extended their new courses straight across it to the new coastline, incising steep valleys in the process. A number of other features are of interest (King, 1967):

- the rivers assume straight courses in contrast to the tight meanders of the interior;
- the change occurs at a clearly defined scarp representing an ancient line of sea-cliffs; and
- smaller tributaries taking their rise off this province are swampy and river captures are common.

The general straightness of the coastline also bears testimony to tectonic control. Rivers crossing the hinterland were unable to widen their valleys in pace with rising sea-levels. The effects of sea-level rise can also be seen by the many drowned estuaries and river mouths (e.g., Mzimvubu), most of which contain significant thicknesses of sediment (*cf.* Dingle *et al.*, 1983).

Thirteen main systems traverse this province, from the

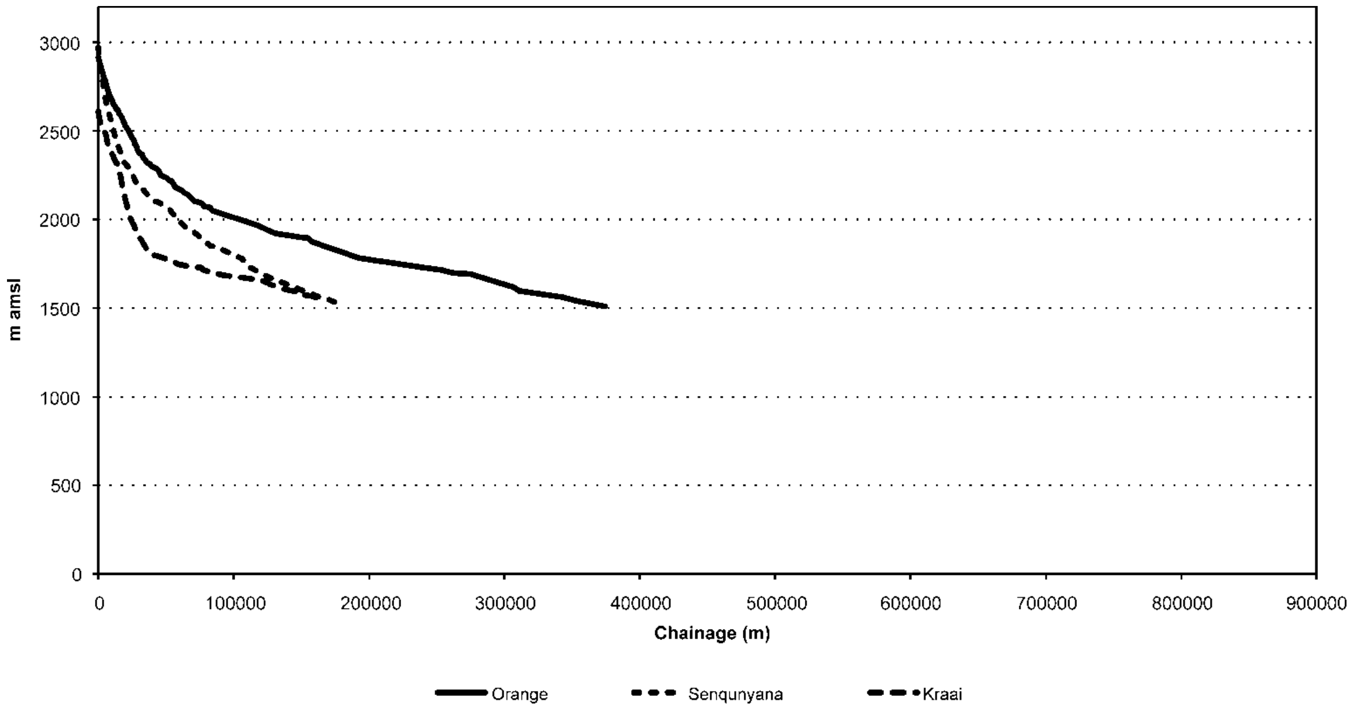

Figure 29. Longitudinal profiles of the rivers of the Lesotho Highlands geomorphic province.

Thukela River in the northeast to the Bushmans River in the southwest. Characteristic of the courses of these rivers over this province are flat to medium valley gradients and mainly narrow valley cross-sectional profiles (Table 10). A number of special features are present. First, the valley cross-sectional profiles are remarkably narrow (Table 10), a function of the recent uplift and subsequent incision. Second, there are possibly two groups of rivers within this province. The first, extending from the Thukela to the Kei, have narrower cross-sectional profiles than the second western group of rivers (Buffalo to Bushmans), which occupy broader valleys (average valley widths of 646 m and 1117 m, respectively) (Table 10). This is reflected in the corresponding sediment storage surrogate descriptors which are mainly NF and NM for the first group and MF for the second group (Table 10).

Southern Karoo

This arid province shares most of the characteristics of its counterpart (Upper Karoo), which occupies the interior plateau of South Africa (Map 1). The province lies between an area of summer rainfall in the north and winter rainfall in the south. It coincides with an area of fairly mature planation across flat-lying and, in the south, folded rocks of the Karoo Supergroup (Partridge & Maud, 1987). In contrast to the Upper Karoo province above the Great Escarpment, the sedimentary rocks of the Southern Karoo have undergone progressively more folding as the zone of influence of the Cape orogeny is approached. Dolerites are also noticeably fewer within this zone, so that the topography is more rolling than in the Upper Karoo. The surface is mainly lowered Post-African I, with the original surface retained on some of the interfluves (Partridge & Maud, 1987). As very little Neogene uplift affected this province, the rivers have not been deeply incised. Drainage lines are almost ubiquitously ephemeral, following broad open valleys. Close to the Great Escarpment, where local relief is significant, alluvial fans are common. A well developed trellis drainage pattern is present where folding has affected the Karoo strata.

The province has two distinct drainage patterns. In the east, the rivers drain south into the Cape Fold Mountains and thence to the Indian Ocean, while in the west, (which is drier than the east) the rivers (mainly the Doring River and its tributaries) drain northwest into the Atlantic Ocean. There is justification, therefore, for dividing the Southern Karoo into three sub-provinces:

Information Box 5

A Cretaceous river network transported significant portions of the original covering rocks of this province onto the continental shelf; as a consequence, the Outeniqua offshore basin (north of the Agulhas–Falklands Fracture Zone) contains sediment deposits up to up to 7000 m thick in places. Offshore oilrigs tap these deposits for gas (Dingle *et al.*, 1983).

Sub-province Southern Karoo

These eastern rivers are strongly influenced by the Cape Fold Mountains and are characterised by broad valley cross-sectional profiles and medium to very steep slopes (Table 10), with a clear trend towards wider valleys and flatter slopes in the east and narrower valleys and steeper slopes in the west (Table 10). The profiles are best described as linear BFCs in the east and exponential in the west (Table 10).

Sub-province Tankwa Karoo

These northwest draining rivers (mainly the Doring River and its tributaries) have broad, steep valleys in the inland section of the province grading to a narrower valleys, but flatter slopes nearer to the coast (Table 10). Consequently, the sediment storage surrogate descriptors are BS for the upper Doring and MF for its lower reaches (Table 10). The profiles are best described as linear BFCs (Table 10). The sub-province is hyperarid and is notable for the desert varnish on the gravels of its extensive gibber plains.

Sub-province Roggeveld Karoo

Although no rivers were selected from this sub-province for analysis, the elevated and dissected nature of this area

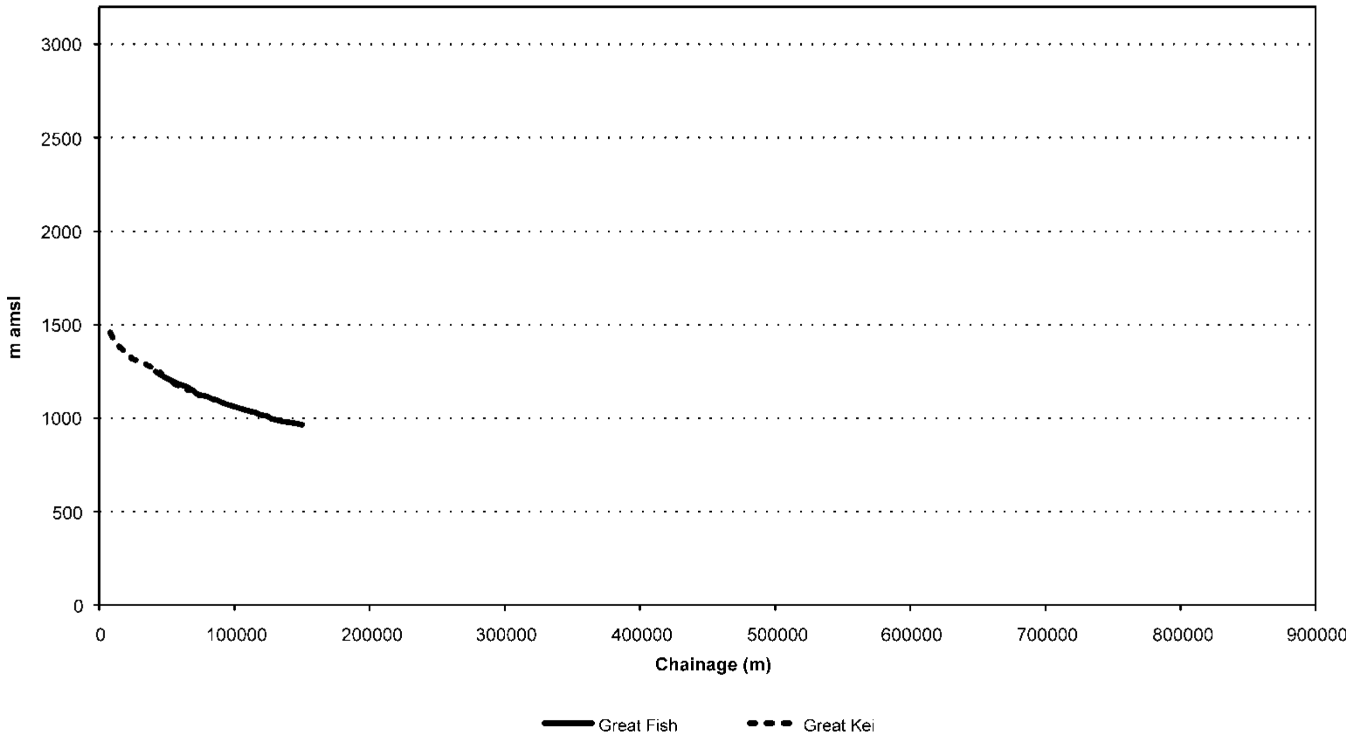

Figure 30. Longitudinal profiles of the rivers of the Queenstown Basin geomorphic province.

warrants the delineation of a separate sub-province. It also forms the watershed between the northwest draining rivers of the Tankwa Karoo and the east draining rivers of the Southern Karoo.

Queenstown Basin

This province is an analogue of the Ladysmith Basin (structural control by dolerites, a location inland of the hinge-line of the Ciskei–Swaziland axis resulting in flat-lying overall topography) (Map 1). Like the Ladysmith Basin, it is underlain by Beaufort Group sediments. However, the province occupies a pronounced rain shadow area because of orographic interception by the high mountains (Amatoles) that flank it to the south. The province is dominated by the Post-African I surface, with steep dolerite koppies rising above it (Partridge & Maud, 1987).

Two main systems drain this province: the Great Fish River in the west and the Great Kei River in the east. The longitudinal profiles of these systems show remarkable similarity, plotting almost as a single profile when superimposing the elevations at distances from the river sources (Figure 30). Both systems are characterised by mildly concave longitudinal profiles and linear BFCs (Table 11). The Great Kei has a narrower valley cross-section (32% narrower) and a steeper slope than the Great Fish (104% steeper); this is reflected in the sediment storage surrogate descriptors which are BS and WS, respectively (Table 11).

East London Coastal Hinterland

This province was distinguished on the basis of two main criteria. First, the province is coincidental with the eastern extension of the Cape Fold Mountains, and here, as in the Southern Karoo, the Karoo sediments have been folded in late phases of the Cape orogeny. This structural influence has deflected the rivers to the east (Map 1). Second, the influence of differential uplift along the Ciskei–Swaziland axis on the longitudinal profiles of the rivers is no longer evident (profiles and macro-reaches are concave, as opposed to the convex forms of Southeastern Coastal Hinterland rivers). There is thus a clear boundary with that province. In combination, these factors have produced characteristic linear longitudinal profiles (Figure 31). There are remnants of the African erosion surface on many of the interfluves, but there is also deep incision by rivers into the shoulders created by the Post-African I surface (Partridge & Maud, 1987).

Six main systems traverse this province; from east to west these are the Buffalo, Keiskamma, Great Fish, Little Fish, Bushmans and Sundays rivers. All have predominantly concave longitudinal profiles, and linear and exponential BFCs (Table 11). Profile shapes are range-bound between 0.41 and 0.51 (Table 11). Valley cross-sectional profiles are mainly narrow to medium, and, other than along the Great Fish and Bushmans rivers, slopes are steep so that the dominant sediment storage surrogate descriptors are NS and MS (Table 11).

Cape Fold Mountains

The Cape Fold Mountains province occurs as two distinct belts: a north–south trending Atlantic belt, predominantly anticlinal in the north (e.g., around Cedarberg) and synclinal in the south (e.g., Table Mountain); and an east–west trending southern belt (multiple anticlines overfolded to the north) (Map 1). Both coincide with the outcrop area of rocks of the Cape Supergroup, with the valleys being underlain mainly by Bokkeveld shales. The influence of active faulting (especially on the southern flanks of ranges in the southern belt) on the hydrography is apparent (e.g., Coega, Cango and Worcester faults). The high local relief is imparted both by intense folding and faulting, and the contrasting resistance of alternating arenaceous and argillaceous beds. The overwhelming influence of geological structure is apparent in the trellis drainage pattern that characterises this province (*cf.* Hattingh, 1996). Major rivers of the southern fold belt, however, follow north–south courses through all of the major ranges that parallel the Southern Ocean. These transgressive rivers were superimposed across the resistant quartzite ridges from a pre-existing cover of Karoo rocks and predate the onset of folding during the Triassic period (a fine example is the Sundays River that meanders through the

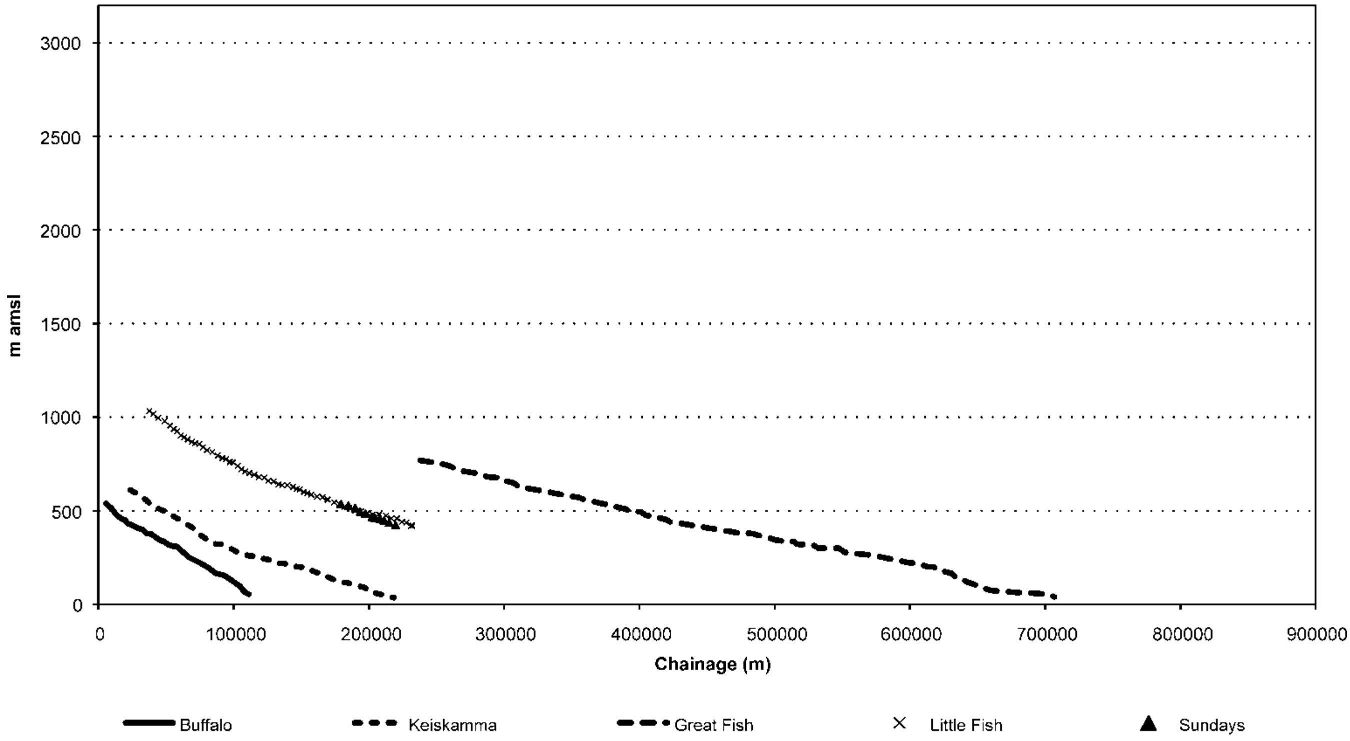

Figure 31. Longitudinal profiles of the rivers of the East London Coastal Hinterland geomorphic province.

Langeberg) (Hattingh, 1996). The high potential energy imparted to the rivers both by the relief and the abundant orographic precipitation has produced a number of river captures. For example, the capture of the former head of the Breede River by a tributary of the Great Berg River and the impressive poort of the Sandrifskloof River (Plate 4) that was beheaded by the Doring and Touws Rivers (King, 1967).

The province can justifiably be divided into four sub-provinces:

Sub-province (Eastern) Cape Fold Mountains

This sub-province runs east–west from the Bushmans River in the east to the Groot River in the west. Although the longitudinal profiles of these rivers range from medium to very steep and the valley cross-sectional profiles are medium to narrow (Table 9), the valley slopes are gentler[11] and valley cross-

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[11] Although the average slopes are 1480% flatter for the Eastern zone than the Central zone, there is no significant statistical difference at the $\alpha = 0.1$ level due to the variations of slopes within the data groups.

Plate 4. Sanddrifskloof River in the Sub-province Atlantic Cape Fold Mountains geomorphic province.

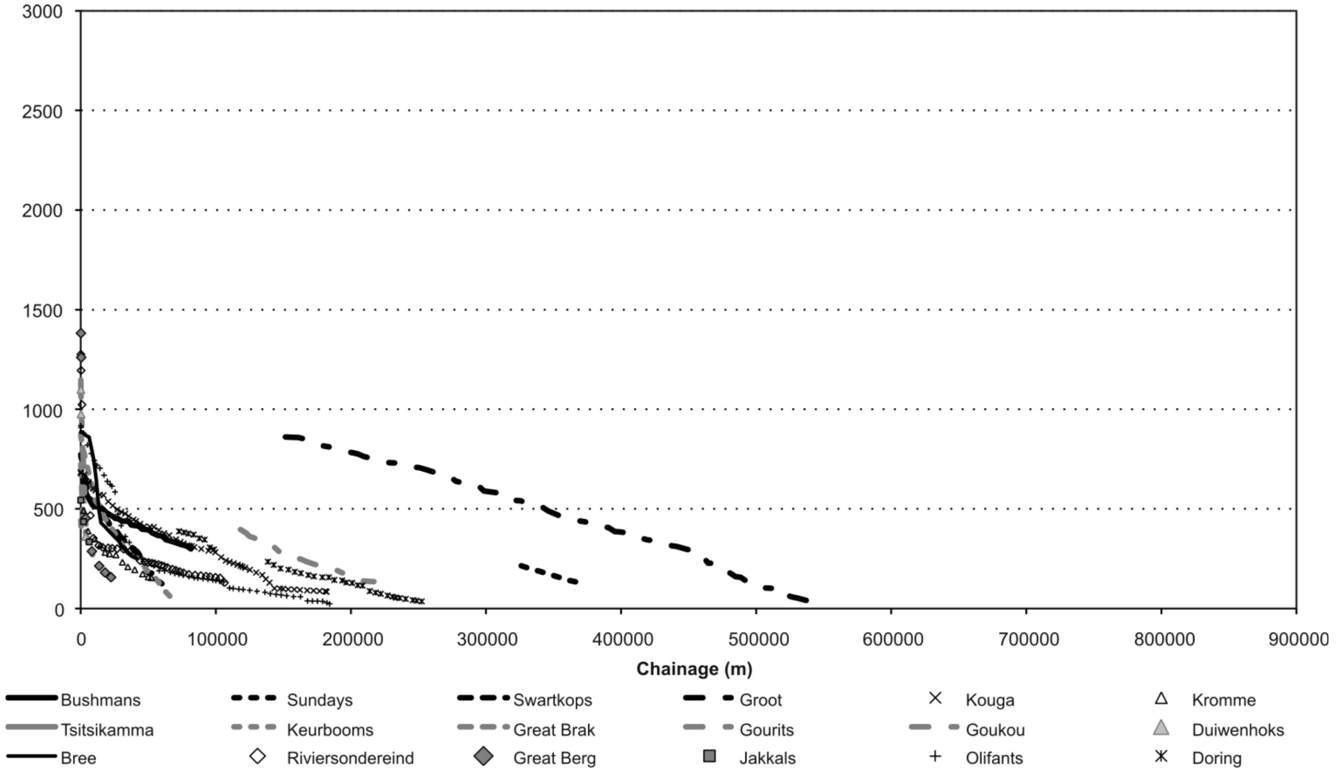

Figure 32. Longitudinal profiles of the rivers of the Cape Fold Mountains geomorphic province.

sectional profiles broader (68% broader and significant at $\alpha = 0.05$) (Table 11) than in the (Central) Cape Fold Mountains (Table 11 and Figure 32). This is reflected in the sediment storage surrogate descriptors which range from NV to MM (Table 11). The rivers are best described by both exponential and linear BFCs (Table 11).

Sub-province (Central) Cape Fold Mountains

This sub-province is bounded to the east by the Kouga River and to the west by the Duiwenhoks River. These rivers traverse short sections of the sub-province before exiting onto the Southern Coastal Platform. The longitudinal profiles are usually strongly concave (Figure 32), narrow in valley cross-

Plate 5. The Breede River in Sub-province Syntaxis Zone Cape Fold Mountains geomorphic province.

Table 11. Descriptor information for rivers by geomorphic province.

Geomorphic province	River (from north to south and then east to west)	River number	Geomorphic province starting altitude (m amsl)	Geomorphic province exit altitude (m amsl)	Geomorphic province length (km)	Total river slope (m/m)	River slope in geomorphic province (m/m)	Total river best fit curve	Total profile shape (area under curve)	Total profile shape descriptor (conc = concave; conv = convex)	Geomorphic province best fit curve	Geomorphic province shape	Geomorphic province shape descriptor (conc = concave; conv = convex)	Total profile average valley width (m)	Total profile sediment storage surrogate	Geomorphic province average valley width (m)	Geomorphic province sediment storage surrogate	Ratio total profile slope to geomorphic province slope	Ratio total profile width to geomorphic province width	Number of macro reaches
Queenstown Basin	Great Kei	S1	1457	1147	58	0.0040	0.0053	Lin.	0.33	Mod. conc.	Lin.	0.41	Mild. conc.	1370	MS	2751	BS	0.76	0.50	2
	Great Fish	Q1	1248	964	108	0.0021	0.0026	Exp.	0.37	Mod. conc.	Lin.	0.41	Mild. conc.	1833	MM	4032	WS	0.82	0.45	2
East London Coastal Hinterland	Buffalo	R2	539	54	106	0.0094	0.0046	Log.	0.24	Ave. conc.	Lin.	0.49	Mild. conc.	1006	NV	953	NS	2.05	1.05	2
	Keiskamma	R1	610	35	195	0.0067	0.0030	Log.	0.18	Str. conc.	Exp.	0.41	Mild. conc.	861	NV	870	NS	2.26	0.99	2
	Great Fish	Q1	769	39	469	0.0021	0.0016	Exp.	0.37	Mod. conc.	Lin.	0.48	Mild. conc.	1833	MM	1318	MF	1.38	1.39	2
	Little Fish	Q2	1032	419	194	0.0060	0.0032	Log.	0.24	Ave. conc.	Exp.	0.41	Mild. conc.	1659	MV	1761	MS	1.92	0.94	2
	Bushmans	P1	296	95	144	0.0025	0.0014	Exp.	0.32	Mod. conc.	Exp.	0.43	Mild. conc.	1287	MS	698	NF	1.79	1.84	1
	Sundays	N1	536	423	41	0.0034	0.0028	Exp.	0.29	Ave. conc.	Lin.	0.51	Mild. conv.	2288	MS	1575	MS	1.23	1.45	1
Cape Fold Mountains	Bushmans	P1	695	299	81	0.0025	0.0049	Exp.	0.32	Mod. conc.	Exp.	0.32	Mod. conc.	1287	MS	1577	MS	0.51	0.82	3
	Sundays	N1	214	123	48	0.0034	0.0019	Exp.	0.29	Ave. conc.	Lin.	0.47	Mild. conc.	2288	MS	653	NM	1.80	3.51	1
	Swartkops	M1	773	124	60	0.0064	0.0108	Exp.	0.26	Ave. conc.	Exp.	0.37	Mod. conc.	1012	NV	511	NV	0.60	1.98	2
	Groot	L1	860	28	393	0.0023	0.0021	Lin.	0.42	Mild. conc.	Lin.	0.54	Mild. conv.	2434	BM	2203	MM	1.08	1.10	1
	Kouga	L2	684	85	182	0.0033	0.0033	Exp.	0.37	Mod. conc.	Exp.	0.37	Mod. conc.	208	NS	208	NS	1.00	1.00	5
	Kromme	K4	977	154	52	0.0095	0.0157	Log.	0.17	Str. conc.	Log.	0.15	Str. conc.	867	NV	586	NV	0.60	1.48	2
	Tsitsikamma	K3	442	413	0	0.0137	0.1215	Exp.	0.26	Ave. conc.	N/A	0.50	Lin.	543	NV	120	NV	0.11	4.52	1
	Keurbooms	K2	875	27	71	0.0101	0.0120	Exp.	0.31	Mod. conc.	Exp.	0.35	Mod. conc.	544	NV	229	NV	0.84	2.38	2
	Great Brak	K1	723	270	9	0.0244	0.0524	Exp.	0.24	Ave. conc.	Log.	0.27	Ave. conc.	443	NV	157	NV	0.47	2.82	1
	Gourits	J1	397	135	99	0.0050	0.0026	Log.	0.18	Str. conc.	Lin.	0.41	Mild. conc.	1438	MS	689	NS	1.87	2.09	1
	Goukou	H4	1146	423	4	0.0176	0.1996	Exp.	0.06	Str. conc.	Exp.	0.43	Mild. conc.	786	NV	1033	NV	0.09	0.76	1
	Duiwenhoks	H3	1100	362	3	0.0163	0.2150	Exp.	0.09	Str. conc.	Exp.	0.28	Ave. conc.	467	NV	135	NV	0.08	3.45	1
	Breede	H1	887	251	41	0.0027	0.0154	Log.	0.16	Str. conc.	Exp.	0.37	Mod. conc.	1960	MS	2412	BV	0.17	0.81	3
	Great Berg	G1	1382	157	22	0.0049	0.0547	Pow.	0.05	Str. conc.	Exp.	0.16	Str. conc.	3142	BS	1029	NV	0.09	3.05	1
	Jakkals	G3	544	334	6	0.0091	0.0341	Log.	0.29	Ave. conc.	N/A	0.41	Mild. conc.	2082	MV	1587	MV	0.27	1.31	1

Continued on p. 43

Table 11 (*continued*)

	Olifants	E1	918	23	184	0.0032	0.0049	Exp.	0.16	Str. conc.	Exp.	0.23	Ave. conc.	1425	MS	1050	NS	0.66	1.36	4
	Doring	E2	387	296	26	0.0021	0.0035	Lin.	0.44	Mild. conc.	Lin.	0.64	Mod. conv.	2071	MM	587	NS	0.60	3.53	2
Southern Coastal Lowlands	Sundays	N1	113	4	92	0.0034	0.0012	Exp.	0.29	Ave. conc.	Exp.	0.32	Mod. conc.	2288	MS	3457	BF	2.87	0.66	3
	Swartkops	M1	112	0	58	0.0064	0.0019	Exp.	0.26	Ave. conc.	Exp.	0.32	Mod. conc.	1012	NV	1855	MM	3.35	0.55	3
	Groot	L1	21	0	59	0.0023	0.0003	Lin.	0.42	Mild. conc.	Exp.	0.24	Ave. conc.	2434	BM	2286	MF	6.66	1.06	2
	Gourits	J1	1	0	41	0.0050	0.0000	Log.	0.18	Str. conc.	Exp.	0.28	Ave. conc.	1438	MS	1494	MF	222.6	0.96	2
	Goukou	H4	89	0	37	0.0176	0.0024	Exp.	0.10	Extr.. conc.	Exp.	0.30	Mod. conc.	768	NV	483	NM	7.36	1.59	1
	Duiwenhoks	H3	76	0	36	0.0163	0.0021	Exp.	0.09	Str. conc.	Exp.	0.28	Ave. conc.	467	NV	343	NM	7.78	1.36	2
	Sout	G4	5	0	14	0.0018	0.0004	Exp.	0.34	Mod. conc.	Exp.	0.22	Ave. conc.	2026	MM	2875	BF	5.14	0.70	1
Southern Coastal Platform	Kromme	K4	145	0	48	0.0095	0.0030	Log.	0.17	Str. conc.	Exp.	0.34	Mod. conc.	867	NV	1114	NS	3.14	0.78	1
	Tsitsikamma	K3	248	0	29	0.0137	0.0084	Exp.	0.26	Ave. conc.	Log.	0.37	Mod. conc.	543	NV	608	NV	1.63	0.89	2
	Great Brak	K1	160	0	19	0.0244	0.0084	Exp.	0.24	Ave. conc.	Lin.	0.43	Mild. conc.	443	NV	693	NV	2.89	0.64	1
	Gourits	J1	107	14	74	0.0050	0.0012	Log.	0.18	Str. conc.	Lin.	0.40	Mod. conc.	1438	MS	528	NF	3.97	2.72	1
	Goukou	H4	224	94	17	0.0176	0.0076	Exp.	0.10	Extr. conc.	Exp.	0.33	Mod. conc.	768	NV	1203	MV	2.32	0.64	1
	Duiwenhoks	H3	197	79	21	0.0163	0.0055	Exp.	0.09	Extr. conc.	Log.	0.32	Mod. conc.	467	NV	817	NS	2.93	0.57	2
	Bree	H1	218	0	288	0.0027	0.0008	Log.	0.16	Str. conc.	Lin.	0.44	Mild. conc.	1960	MS	1827	MF	3.53	1.07	1
	Sout	G4	318	10	157	0.0018	0.0020	Exp.	0.34	Mod. conc.	Exp.	0.36	Mod. conc.	2026	MM	1973	MM	0.93	1.03	2
Swartland	Great Berg	G1	142	0	259	0.0049	0.0005	Pow.	0.05	Str. conc.	Exp.	0.27	Ave. conc.	3142	BS	3316	BF	8.85	0.95	4
	Diep	G2	415	0	86	0.0048	0.0048	Log.	0.19	Str. conc.	Log.	0.19	Str. conc.	2229	MS	2229	MS	1.00	1.00	3

sectional profile and mainly very steep in slope (Table 11), so that the sediment storage surrogate descriptors are predominantly NV (Table 11). The rivers are also best described by exponential and logarithmic BFCs (Table 11).

Sub-province (Syntaxis Zone) Cape Fold Mountains

This sub-province, which represents the zone of convergence between the north–south trending Atlantic belt and the east–west trending southern belt, is characterised by broad valleys (Plate 5) (on Bokkeveld shales), concave longitudinal profiles (Figure 32) and exponential BFCs (Table 11). The sediment storage surrogate descriptors are mainly BV and NV (Table 11). The main stem rivers that traverse this sub-province include the Breede and Riviersondereind rivers (flowing southeast into the Indian Ocean) and the Great Berg (flowing northwest into the Atlantic Ocean).

Sub-province (Atlantic) Cape Fold Mountains

This sub-province drains the older north–south trending Atlantic belt. The rivers flow north to south in sympathy with the folding before exiting onto the Namib province whence they flow into the Atlantic Ocean. The main stem rivers of this province (Jakkals, Olifants and Doring) generally display narrower valley cross-sectional profiles and steeper slopes than the Syntaxis Zone sub-province (although this is not statistically significant) (Table 11). The Jakkals and Olifants rivers are characterised by concave longitudinal profiles with exponential BFCs, while the Doring River has a remarkably narrow, deeply incised valley, a linear BFC and a convex form (Table 11). This sub-province also shows a weak, progressive trend from south to north, from broader valley cross-sectional profiles and steeper slopes in the south to narrower valley cross-sectional profiles and gentler slopes in the north. This is reflected in the sediment storage surrogate descriptors which are MV in the south and NV in the north (Table 11).

Southern Coastal Lowlands

This province, which occupies a number of separate areas along the Southern Ocean coastline, is underlain by Neogene marine and coastal aeolian sediments, including old dune lines and shoreline ridges (Dingle *et al.*, 1983) (Map 1). Individual areas include the Algoa Bay embayment, the Gamtoos embayment, the Keurbooms embayment, small areas around Mossel Bay, as well as the area between the Gourits River mouth and Walker Bay, which includes the Agulhas/Stilbaai Plain. There are a number of unique features that identify this as a discrete (but disjunct) province. First, the province consists of exposed, young marine sediments that bear the imprint of sea-level oscillations. Second, the flatness of the province, particularly in the west, results in frequent flooding and therefore flood damage. Third, many of the rivers do not have functional exits to the sea, as the mouths of the rivers have been drowned and subsequently filled with sediment (e.g., the Sout River) (Plate 6). Fourth, dune ridges formed during high sea-stands commonly deflect rivers, leading to the formation of coastal lagoons behind them (e.g., at Sedgefield and Kleinmond); and finally, around Arniston and Stilbaai, the soluble marine limestones that underlie coastal areas are associated with a karstic deranged drainage pattern in which numerous enclosed hollows have been produced by solutional weathering (e.g., Canca se leegte).

This coastal province is traversed by a number of rivers, from the Sundays River in the east to the Sout River in the west. Its limited areal extent means, however, that the segments of channel are short (Table 11). There is a general reduction of

Plate 6. The Sout River in the Southeastern Coastal Lowlands geomorphic province – cut off from the sea by Holocene dune cordons.

valley cross-sectional width from east to west (Sundays to Duiwenhoks rivers) (Table 11). The exception to this trend is the Sout River, which has an uncharacteristically flat valley slope and broader valley cross-sectional width (Table 11). All the rivers have exponential BFCs and concave profiles and sediment storage surrogate descriptors range from BF to MM (Table 11).

Southern Coastal Platform

The undulating surface of this province is essentially an erosional feature that was produced by marine planation of the southern coastal margin during the Miocene (Map 1) (Dingle *et al.*, 1983). Standing at an elevation of ~220 m amsl, it grades to the Southern Coastal Lowlands in the west and the coastline in the east. Inland of this platform pronounced steps separate broad benches cut in both the African and Post-African I cycles of erosion (Partridge & Maud, 1987). The former is often indicated by silcrete cappings on the crests of hills and ridges. Large areas of the province are underlain by rocks of the Malmesbury Group and Cape Granite Suite. Elsewhere, resistant quartzites of the Cape Supergroup have been bevelled in the course of successive marine transgressions. A few of the major rivers occupy open valleys, but most are deeply incised and cross the platform in spectacular gorges (the Goukamma, Storms and Blaauwkrantz rivers are examples) (Plate 7). The submarine channels of many of the rivers continue seaward for a considerable distance. The drowning of the present-day rivers following the rise in sea-level since the Last Glacial Maximum (17000 to 21000 yr BP) (Partridge, 2003) has resulted in many of the estuaries occupying narrow, deep valleys that are maintained by the resistance of the Table Mountain group quartzitic sandstones.

The eight main stem systems that traverse this province show many similarities. The six eastern systems (Kromme to Duiwenhoks rivers) display narrow valley cross-sectional profiles and steep to very steep valley slopes (Table 11), so that the majority of the sediment storage surrogate descriptors are NV and NS (Table 11). The longitudinal profiles are concave and characterised by exponential, linear and logarithmic BFCs (Table 11). However, the two westernmost systems, the Breede and the Sout rivers are different. These feature linear and exponential BFCs, significantly broader valley cross-sectional profiles (130% broader, significant at $\alpha = 0.05$) and flatter slopes (on average 320% flatter, but only significant at $\alpha = 0.15$), so that their sediment storage surrogate descriptors are MF and MM, respectively (Table 11).

Swartland

This province is in some respects the counterpart of the Southern Coastal Platform, and occupies a coastal platform that extends from False Bay north along the West Coast to where it impinges upon the (Atlantic) Cape Fold Mountains (Map 1). It is an area of low, rolling hills between the Atlantic Ocean and the (Atlantic) Cape Fold Mountains. The province is underlain by Cape granites and phyllites of the Malmesbury Group as well as recent Quaternary sediments (mainly drift sands). It is dominated by remnants of the African surface, and has been significantly affected by Neogene arching (uplift along the Agulhas–Vredenburg axis was, in part, responsible for the diversion of the Berg River from its previous mouth at Saldanha Bay to its current mouth at Velddrif) (Partridge & Maud, 1987). This warping is particularly evident in the longitudinal profiles followed by some of the river terraces. For example, terraces of different ages grade into each other as the Diep River traverses this arch. The effect of downwarping to the west of the hinge-line is also evidenced by the presence of submerged African surface silcretes at –50 m amsl at Noordhoek. In some cases, the original surface coincides with cappings of silcrete; where the silcrete has been removed by erosion, deeply weathered saprolite is widespread. In general,

Plate 7. Incised Goukamma River in the Southern Coastal Platform geomorphic province.

river valleys are open and channel gradients are low.

The rivers that traverse this province tend to have broad to medium valley cross-sectional profiles and flat to steep slopes (Table 11). The longitudinal profiles are concave and are characterised both by exponential and logarithmic BFCs (Table 11), while the associated sediment storage surrogate descriptors are BF and MS, respectively (Table 11).

SUMMARY AND CONCLUSION

This objective of this article has been to evolve a quantitative and semi-quantitative methodology for delineating geomorphic provinces in South Africa, Lesotho and Swaziland, and to describe each of the provinces for the purpose of freshwater conservation planning. Geomorphic provinces have been defined as similar areas containing a limited range of recurring landforms that reflect comparable erosional, climatic and tectonic histories and they impose broad constraints on lower levels of organisation (Dollar *et al.,* 2007). Thirty four geomorphic provinces and 12 sub-provinces were delineated for South Africa, Lesotho and Swaziland, utilising a combination of delineated river longitudinal profiles and expert opinion and analysis. PCA scores for the 99 main stem river longitudinal profiles and 471 macro-reaches showed a notable grouping around the origin, with some scatter along the PC1 axis. Distinct and significant groupings are, however, evident for macro-reaches of each geomorphic province. This reflects a general uniformity in the slopes, valley widths, altitudes and shape descriptors of the drainage net in each geomorphic province.

Although boundaries between the geomorphic provinces are represented by a line, the boundaries are, in many instances, gradational (e.g., the boundary between the Upper Karoo and Highveld). In some cases, however, the transitions can be defined with a reasonable degree of certainty (e.g., Cape Fold Mountains and Southern Coastal Platform, Lower Vaal and Orange Valleys and Ghaap Plateau). The boundaries can, and will no doubt, be revised as additional information becomes available. It is also likely that some provinces can be further sub-divided (e.g., Upper Karoo, Eastern Escarpment Hinterland, South Eastern Coastal Hinterland), or additional provinces defined (e.g., the area around Cedarville Flats and possibly the rain shadow area below the upper Usutu River, as well as structural benches in the western part of the Upper Karoo).

Geomorphic provinces can help in identifying representative spatial units that conserve the diversity of aquatic ecosystems that occur in South Africa, Lesotho and Swaziland, as demonstrated by Nel *et al.* (2007) and Dollar *et al.* (2010). The delineated geomorphic provinces represent a progression towards the spatial representation of aquatic ecosystem diversity, and while they are not the final word on the matter, they represent a step forward in helping to select representative spatial units for conservation.

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