Development of a spatial framework

2.1 Introduction

Considerable work has been undertaken on the classification of South African rivers, each with their own set of objectives (e.g. Joubert & Hurly 1994, Brown *et al.* 1996, Eekhout *et al.* 1997, Day *et al*. 1998, Kleynhans *et al*. 1998a, b). In the context of deriving ecological reference conditions for use in a National Aquatic Ecosystem Biomonitoring Programme (NAEBP), it is important that the classification scheme divides the country in a logical and ecologically-meaningful way, so that variation among rivers in the country is best accounted for. South Africa has a varied climate (and hence hydrological type), geology (and hence water chemistry) and geomorphology (and hence channel type, substratum composition, erosion potential). Variation in these factors, both among and within rivers, together with natural biogeographic differences in the distribution of riverine biota, may potentially lead to biotic differences. Such differences need to be taken into account when implementing a national biomonitoring programme. The establishment of a spatial framework facilitates the identification of ecologically-similar river types, for which ecological reference conditions can be derived.

An ecological reference condition is the condition that is representative of a group of "least-impacted" or minimally disturbed habitats organised by selected physical, chemical and biological attributes (Reynoldson *et al*. 1997). This organisation refers to the spatial framework which would enable the characterisation of the physical, chemical and biological attributes of sites, reaches or rivers within a particular river type. In some instances this reference condition may represent the natural or intrinsic conditions of the water body whilst in others it may represent the "best available", for example in lowland rivers which have been subjected to extensive anthropogenic modification. Once the reference condition has been established for a particular river type, it forms the template against which assessments of the present ecological status or condition of sites, reaches or rivers of the same river type can be compared. In this way the degree of degradation or deviation from expected "natural" conditions can be ascertained.

A three-tiered hierarchical spatial framework was developed during a workshop of the NAEBP in January 1996 (Brown *et al.* 1996). During this workshop, the biogeographic regions of Eekhout *et al.* (1997) were modified into bioregions. Sub-regions, which were largely a reflection of the geomorphological nature or zonation of rivers, and which represent level 2 of the hierarchy, were also delineated. As the bioregions and sub-regions were derived on the basis of limited data and professional judgement, they required verification. Level 3, namely river types, which related to aspects such as river size, hydrological type, geomorphological, chemical and biological characteristics, were not identified at the workshop, but were recognised as being important. This spatial framework is discussed in more detail below and subsequent developments related to each aspect are outlined.

2.2 Level 1: Bioregions and Ecoregions

Bioregions (Brown *et al.* 1996) are a refinement of the biogeographic regions, which were based on broad historical distribution patterns of riverine macroinvertebrates, fish and riparian vegetation (Eekhout *et al.* 1997). The modifications to the biogeographic regions were made by specialists with a knowledge of macroinvertebrate, fish and/or riparian vegetation within each region. The team responsible for delineation of bioregions within the Mpumalanga region were Drs N. Kleynhans (Institute for Water Quality Studies) and J. Engelbrecht (Mpumalanga Parks Board). Subsequently, as part of the Ecological Reserve Project, a new Level 1 regional classification was proposed, namely ecoregions (Kleynhans *et al*. 1998a). Given that, for Mpumalanga, the ecoregions were a further refinement of the bioregions, it was decided to use this framework as the Level 1 classification of rivers of Mpumalanga. The bioregions and ecoregions in B and X primary drainage regions are presented in Figure 2. A second level of ecoregions has been delineated for the region using the same approach as for ecoregion level 1 (Figure 3, Kleynhans *et al*. 1998b). Details of the ecoregional approach, together with summary information of ecoregion level 1, are given below.

2.2.1 Components of the Ecoregion Classification

A top-down approach was used to classify South African rivers into ecoregions. This approach is generally one in which physical variables such as physiography, climate, geology and soils are used as criteria for classification. However, for ecoregions, potential natural vegetation (i.e. vegetation types that would of occurred were it not for the major man-made transformations) was added as an additional criterion (Kleynhans *et al*. 1998a, b). The assumption in an ecoregion approach is that instream features such as the distribution of the biota or water chemistry are intimately linked to these variables (Eekhout *et al*. 1997).

Map overlays of the various variables were prepared and used to qualitatively determine ecoregions (Kleynhans *et al.* 1998a). This process was iterative until the resulting delineations could not be improved upon based on the available information. The variables considered in ecoregion classification are given in Table 1. It is envisaged that the ecoregion boundaries may change as our knowledge of the region improves.

Using the variables and sources of information in Table 1, the following descriptions have been given for each ecoregion which occurs within the study region (taken from Kleynhans *et al*. 1998a, Figure 2).

Ecoregion 1: Limpopo Plain

- This ecoregion is characterized by plains and lowlands with a low to moderate relief, while the vegetation consists mostly of Bushveld types and Mopane veld.
- Mean Annual Precipitation (MAP) varies from 200 - 600 mm. Mean annual temperatures vary from 18 - 22 ^{o}C.

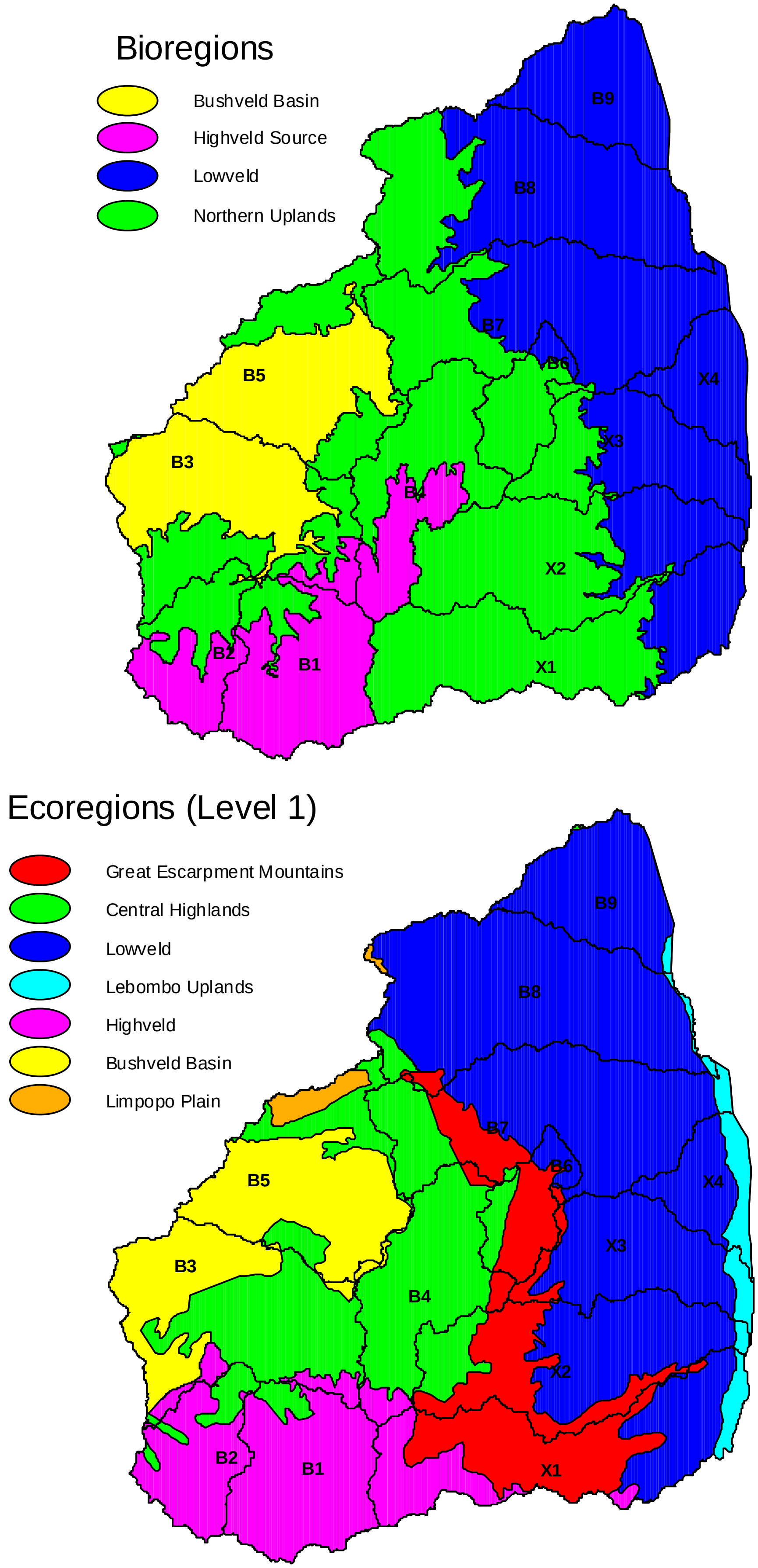

Figure 2. DWAF secondary drainage regions B1-B9 and X1-X4 in relation to two regional classifications, namely Bioregions (Brown *et al*. 1996) and Ecoregions (Level 1)

- Median annual simulated runoff per quaternary catchment varies from < 5 mm to 40 - 60 mm. The coefficient of variation (CV) for annual simulated runoff per quaternary catchment varies from 80 % to > 160 %.
- Altitude mostly ranges between 400 - 1000 m a.m.s.l. but with some parts in the east being 200 - 400 m a.m.s.l.
- Rock types include sandstone, sand, mudstone and basalt.
- Soil texture types include sand-loam, sand-clay and sand-clay-loam.

Table 1. Variables and sources of information considered in the ecoregion classification (from Kleynhans *et al*. 1998a).

Variable	Sources
Physiography	King (1942), Reader's Digest (1984), Brown *et al.* (1996), van Riet *et al.* (1997), and US Geological Survey Relief Shading Images (1998).
Climate	Midgley *et al.* (1994), Schulze *et al.* (1997).
Geology and soils	Anhaeusser and Maske (1986), Lurie (1994), Midgley *et al.* (1994), Schulze *et al.* (1997), van Riet *et al.* (1997).
Potential natural vegetation	Primarily the classification of Low and Rebelo (1996) was used. For broader reference purposes van Riet *et al.* (1997) and the vegetation biomes of Rutherford and Westfall (1994) was also used.

Ecoregion 2: Central Highlands

- Open hills, low mountains and table lands with high to moderate to low relief constitute the physiography. Lowlands with a high relief are present while plains with a moderate relief are rare. Only one area with high mountains occurs (Blouberg). Vegetation includes mainly bushveld (mountain and mixed) types. Isolated patches of indigenous forest occur (i.e. Blouberg and Soutpansberg).
- Median annual simulated runoff per quaternary catchment varies from 40 - 150 mm with some catchments in the east having a runoff of > 250 mm. The CV for annual simulated runoff varies from 40 % to 100 %.
- MAP varies from 400 - 800 mm, while mean annual temperature varies from 14 - 20 ^{o}C.
- Altitude varies from 800 - 1750 m a.m.s.l.
- Rock types include sandstone, quartzite, hornblende and biotite granite, ironstone and basalt.
- Soil texture types include sand-loam, sand-clay, sand-clay-loam, clay and sand.

Ecoregion 3: Bushveld Basin

- This region consists predominantly of plains with a low relief. In the east plains with a moderate relief and lowlands with a low relief occur. Vegetation types consist of thorn and mixed bushveld types.
- Median annual simulated runoff per quaternary catchment varies from 20 - 80 mm. The CV for annual simulated runoff per quaternary catchment varies from 60 - 140 %.
- MAP varies from 400 - 800 mm, while mean annual temperature varies from 14 - 20 ^{o}C.
- Altitude varies from 600 - 1 500 m a.m.s.l.
- Rock types include quartzite, hornblende and biotite granite, mudstone and basalt.
- Soil texture types include clay, sand-loam and sand-clay-loam.

Ecoregion 4: Great Escarpment Mountains

- This region is not continuous and extends along the Great Escarpment of South Africa. High and low mountains with high relief are common. Vegetation consists mostly of mountain grassland types with patches of isolated afromontane forest in some parts.
- Median annual simulated runoff per quaternary catchment varies from 10 to > 250 mm. The CV for annual simulated runoff per quaternary catchment varies from < 40 - 120 %.
- MAP varies from 400 to > 1200 mm, while mean annual temperature varies from < 8 - 20 ^{o}C.
- Altitude varies from 800 - > 2 500 m a.m.s.l.
- The rock types include quartzite, quartzitic sandstone, sandstone and mudstone,
- Soil texture types include sand-clay-loam, sand-loam and sand-clay.

Ecoregion 5: Lowveld

- Plains with a low to moderate relief are common in this region but open hills with high relief and low mountains with high relief are also present (mostly towards the west). Lowveld bushveld types are the most common vegetation, but in the north mopane bushveld and shrubland occur.
- Median annual simulated runoff per quaternary catchment varies from 40 - 150 mm. The CV for annual simulated runoff per quaternary catchment varies from 60 - 120 %.
- MAP varies from 400 - 800 mm, while mean annual temperature varies from 20 to > 22 ^{o}C.
- Altitude varies from 200 - 800 m a.m.s.l.
- Rock types include ironstone, sandstone, mudstone and basalt.
- Soil texture types include sand-clay-loam, sand-clay, loamy-sand and sand-loam.

Ecoregion 6: Lebombo Uplands

- Closed hills with moderate relief and low mountains with a high relief are characteristic of this region, while arid mountain bushveld is the dominant vegetation type.
- Median annual simulated runoff per quaternary catchment varies from 20 - 150 mm. The CV of annual simulated runoff per quaternary catchment varies from 60 - 140 %.

- MAP varies from 400 - 800 mm, while mean annual temperature varies from 20 to > 22 ^{o}C.
- Altitude varies from 100 - 400 m a.m.s.l.
- Rock types include mudstone and basalt.
- Soil texture types include sand-clay-loam, sand-clay and loam-sand.

Ecoregion 7: Highveld

- Plains generally characterize this region with low and moderate relief but also significant areas of lowlands with low and high relief, open hills with low relief and closed hills with moderate relief. Vegetation consists of a combination of grassland types with moist types present towards the east and drier types towards the west and south.
- Median annual simulated runoff per quaternary catchment varies from 10 - 250 mm. The CV for annual simulated runoff per quaternary catchment varies from 40 - 160 %.
- MAP varies from 400 - 1200 mm, while mean annual temperature varies from 14 to 18 ^{o}C.
- Altitude varies from 1250 - 1750 m a.m.s.l.
- Rock types include sandstone, quartzite, mudstone, basalt and biotite granite.

The level 1 and 2 ecoregions which occur within Mpumalanga province compared to those in DWAF drainage regions B and X are given in Table 1. The decimal digits refer to the Ecoregion Level 2 classifications (Figure 3).

Table 2. Ecoregion Level 1 and 2 regions showing differences between Mpumalanga Province and DWAF drainage regions B and X. The decimal digits refer to the Ecoregion Level 2 classification.

	Mpumalanga Province	**Regions B and X**
Ecoregion Level 1	**Ecoregion Level 2**	**Ecoregion Level 2**
1. Limpopo Plain		1.03, 1.04
2. Central Highlands	2.08, 2.09, 2.10, 2.11, 2.12	2.01, 2.08, 2.09, 2.10, 2.11, 2.12, 2.13, 2.14
3. Bushveld Basin	3.02, 3.03	3.02, 3.03
4. Great Escarpment Mountains	4.01, 4.02, 4.03, 4.04	4.01, 4.02, 4.03, 4.04
5. Lowveld	5.01, 5.02, 5.05, 5.06, 5.07	5.01, 5.02, 5.03, 5.04, 5.05, 5.06, 5.07
6. Lebombo Uplands	6.01, 6.02	6.01, 6.02
7. Highveld	7.01, 7.02, 7.03, 7.04, 7.05	7.01, 7.02, 7.03, 7.04, 7.05

Level 2 ecoregions were derived in a similar manner as to level 1 ecoregions but an attempt was made to consider more detailed information in the determination of the level 2 ecoregion boundaries (Kleynhans *et al*. 1998b). This level does not form a part of the three tier spatial hierarchical framework described in this report, but rather, may contribute to the level 3 river type groupings.

DWAF secondary drainage regions B and X are presented in relation to ecoregion level 2 (Figure 3, Kleynhans *et al*. 1998b), broad terrain patterns (Figure 4, Van Riet *et al*. 1997), broad terrain morphological divisions (Figure 5, Van Riet *et al*. 1997), terrain morphology (Figure 6, Van Riet *et al*. 1997), natural potential vegetation (Figure 7, Low and Rebelo 1996) and lithostratigraphic units (Figure 8, Vegter 1995). The terrain morphology is hierarchical with broad terrain patterns depicting the upper level of the hierarchy, broad terrain morphological divisions depicting the middle level and terrain morphology the lowest or most detailed level of the morphological classification.

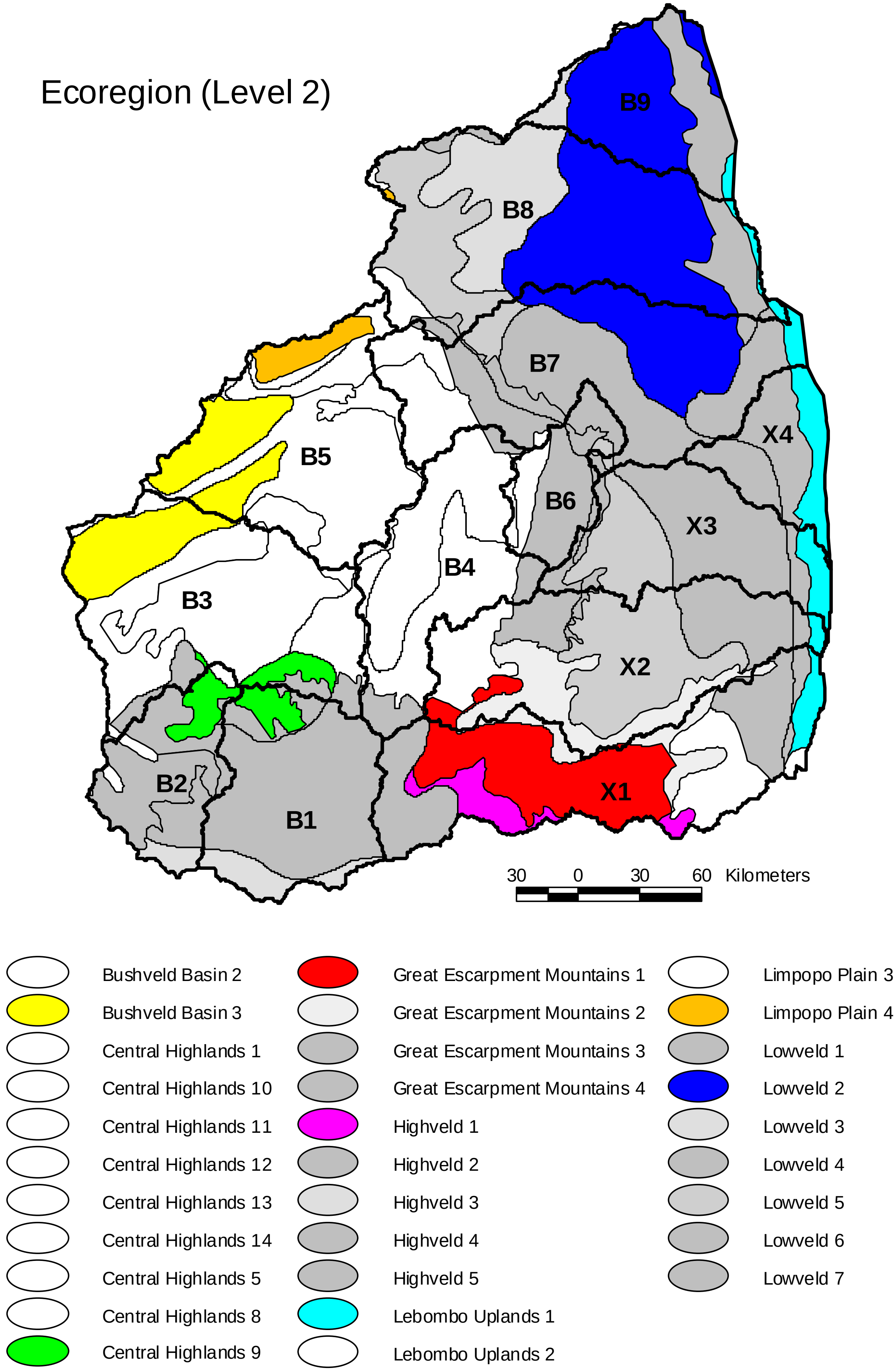

Figure 3. DWAF secondary drainage regions B1-B9 and X1-X4 in relation to Ecoregion Level 2s.

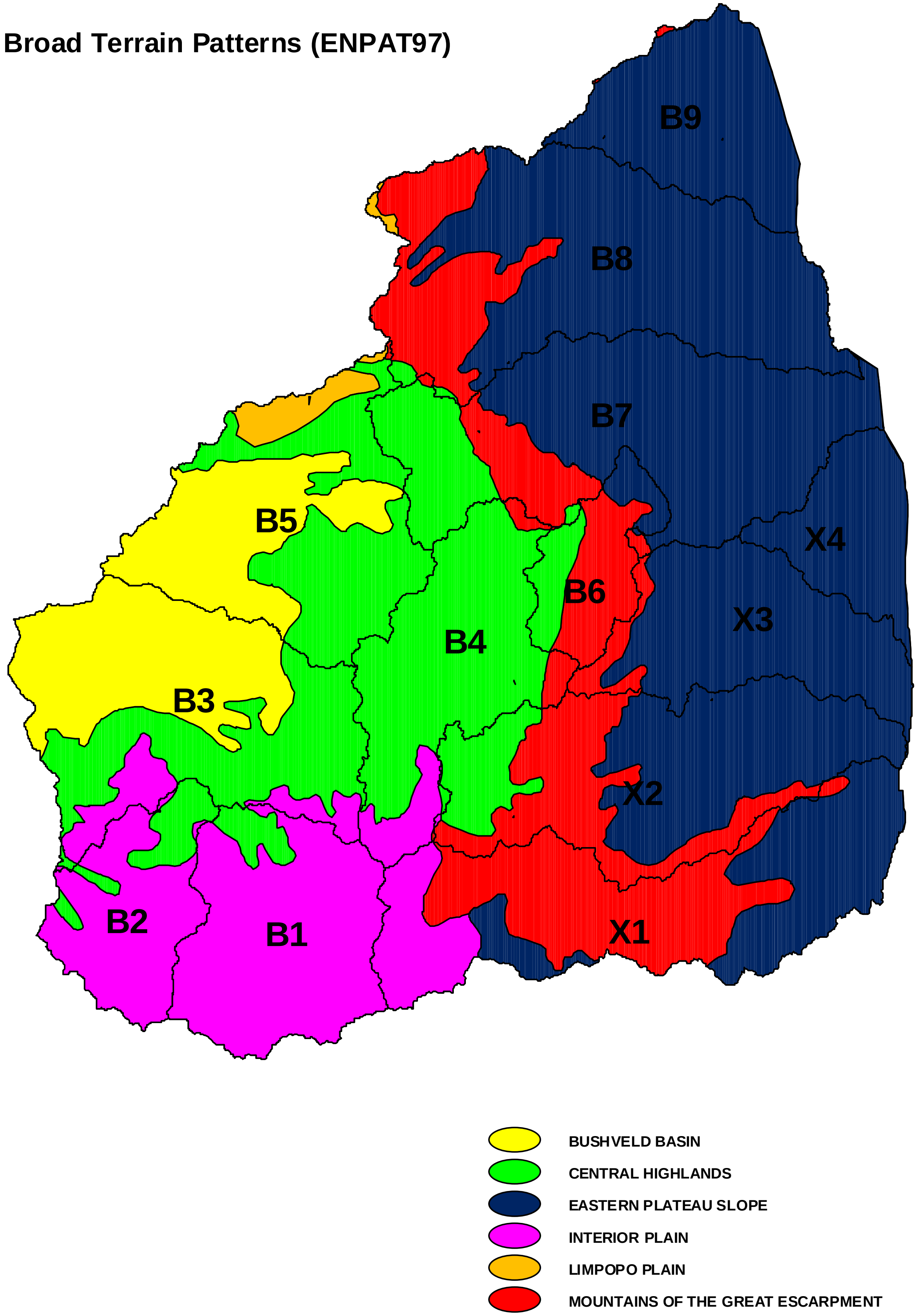

Figure 4. DWAF secondary drainage regions B1-B9 and X1-X4 in relation to broad terrain patterns (modified from van Riet *et al*. 1997)

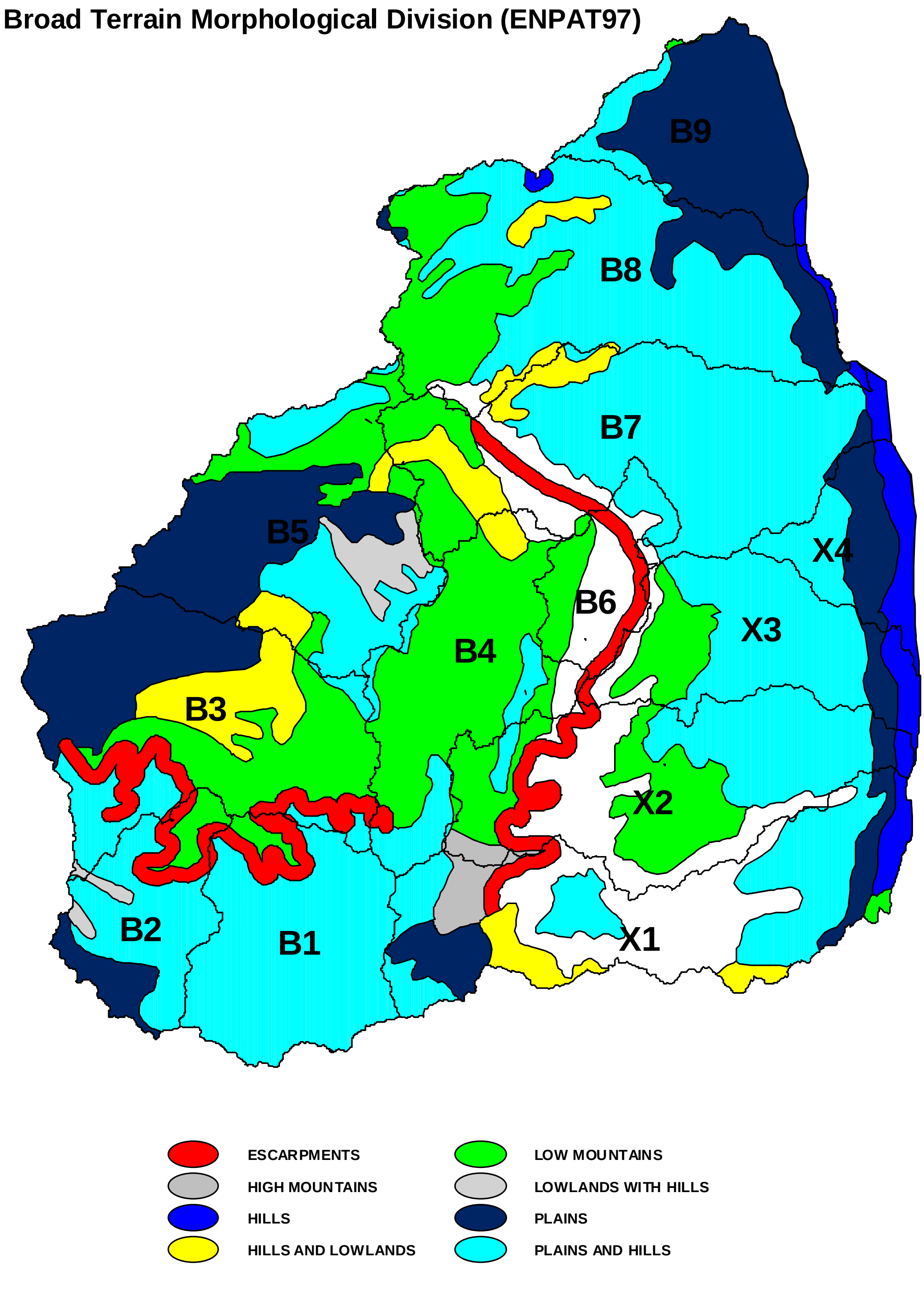

Figure 5. DWAF secondary drainage regions B1-B9 and X1-X4 in relation to broad terrain morphological divisions (modified from van Riet *et al*. 1997)

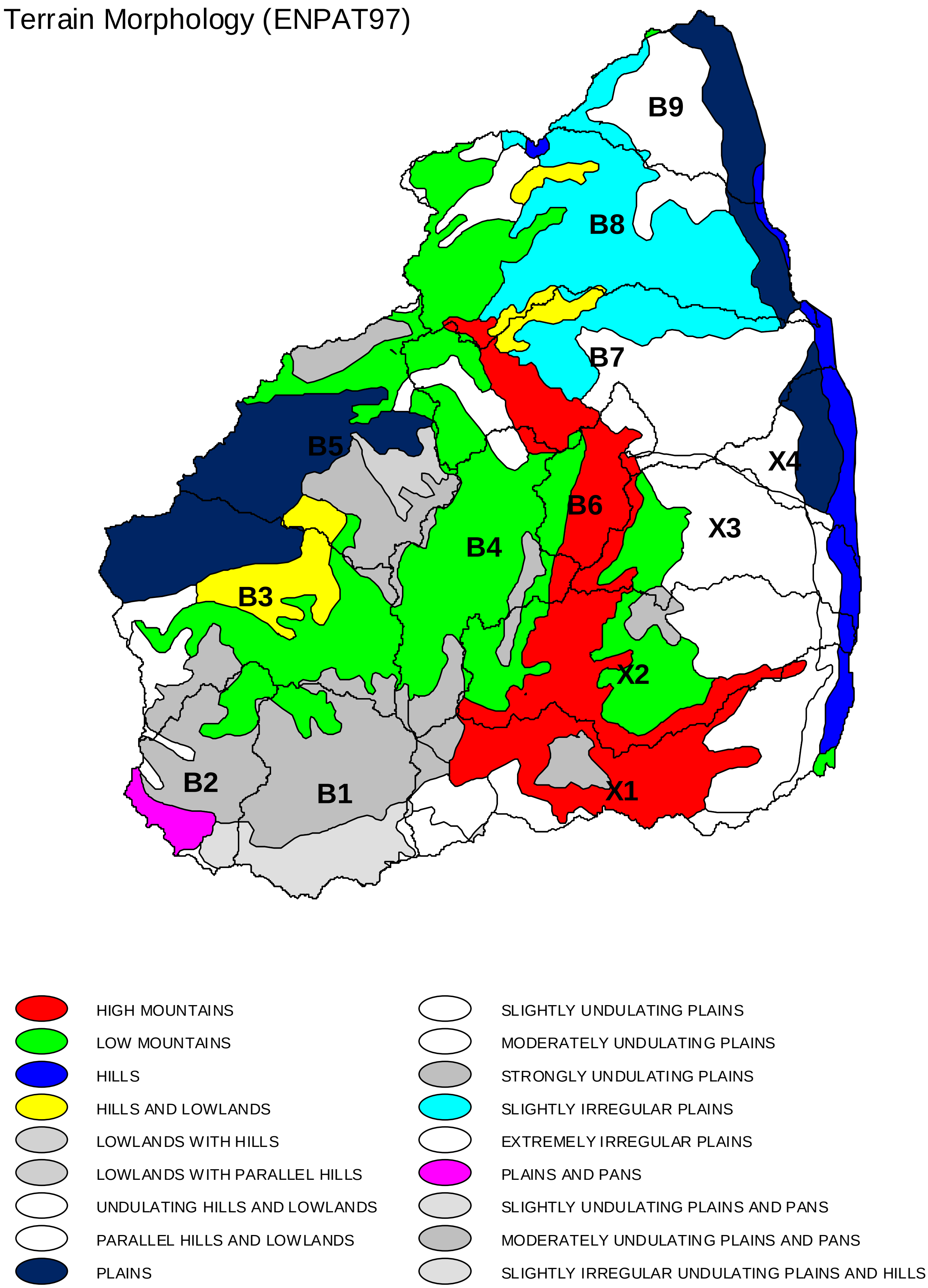

Figure 6. DWAF secondary drainage regions B1-B9 and X1-X4 in relation to terrain morphology (modified from van Riet *et al*. 1997)

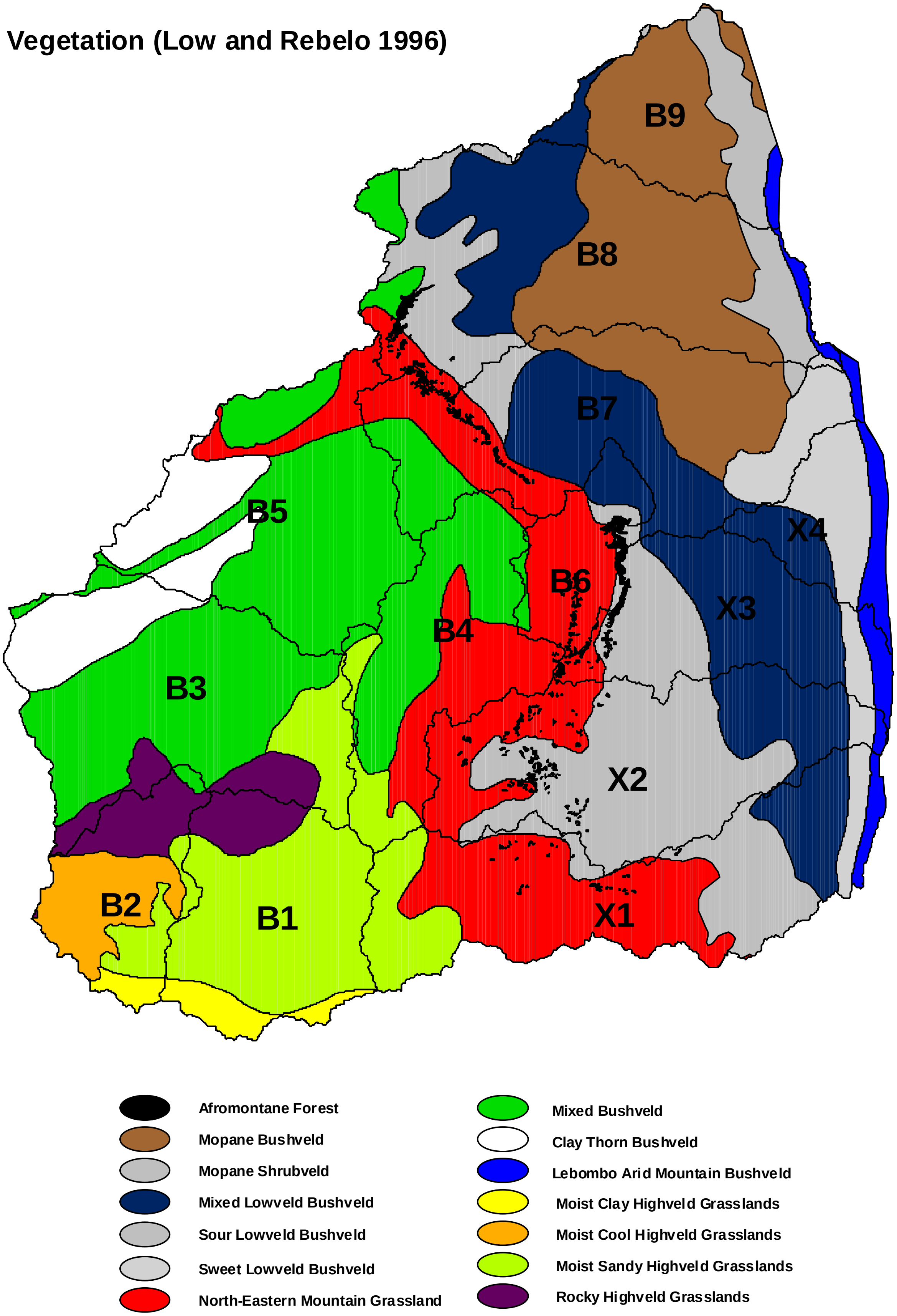

Figure 7. DWAF secondary drainage regions B1-B9 and X1-X4 in relation to potential natural vegetation (modified from Low and Rebelo 1996). Details of the vegetation are given in Appendix 1.

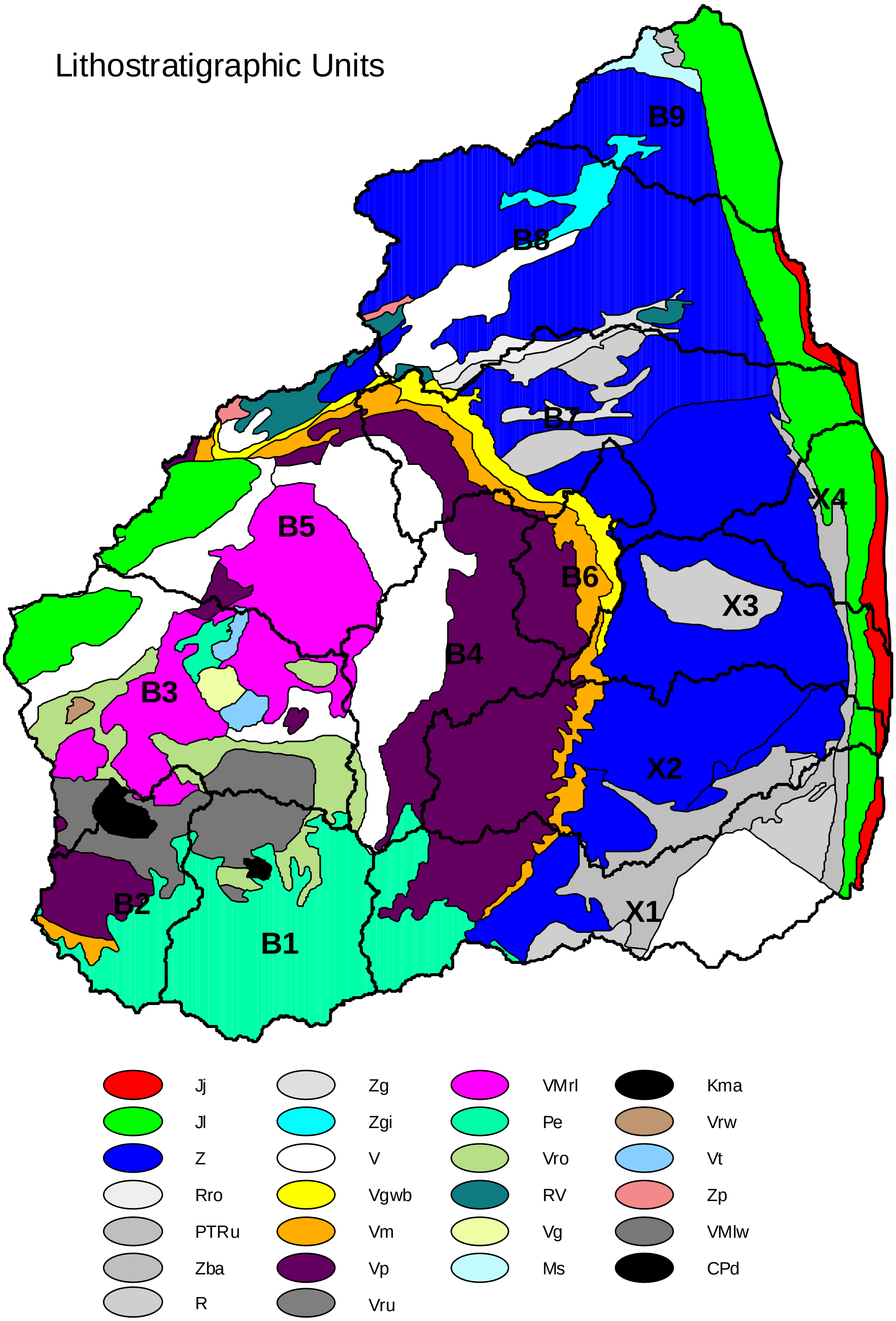

Figure 8. DWAF secondary drainage regions in relation to lithostratigraphic units (modified from Vegter 1995). Definitions and details of the lithostratigraphic units are given in Appendix 2.

2.3 Level 2. Geomorphological zones or subregions

A sub-regional classification, which reflects broad geomorphological characteristics and distribution patterns of components of the biota, was developed at the spatial framework workshop (Brown *et al.* 1996). The main rivers and selected tributaries of regions B and X were divided into sub-regions, such as Source Zone, High Gradient Mountain Stream, Mountain Stream, Foothill-cobble bed, Foothill-gravel bed (previously termed Transitional) and Lowland Floodplain based on the proposed geomorphological divisions of Rowntree and Wadeson (1999, Table 3). Three other geomorphological zones, namely Upland Flood Plain, Rejuvenated Cascade (or gorge) and Rejuvenated Foothill were also identified, where possible, based on examination of channel gradient in relation to surrounding topography on cartographic maps. In some cases, however, zonation will only be verified at the ground-truthing stage.

The primary determinant of these geomorphological zones is channel gradient (see report on geomorphological zonation, Rowntree and Du Plessis 1998), where particular ranges in gradient characterise each geomorphological zone. These ranges are based on commonly found associations and may be modified in the light of further experience (K. Rowntree, Rhodes University, pers. comm). Details of the methodological aspects related to this component of the research are available in Rowntree and Du Plessis (1998). The assumption is that these geomorphological zones reflect distribution patterns of components of the biota and a project, currently underway in the Freshwater Research Unit, University of Cape Town, aims to establish the link between these geomorphological zones and observed biotic zonation J. King, Freshwater Research Unit, University of Cape Town, pers. Comm.).

Rivers in DWAF secondary catchments B1 to B7, X2 and X3 were digitised from 1:250 000 maps and the main rivers and tributaries divided into geomorphological zones. Details of the rivers coverage is given below and in Figure 9.

- B1: Olifants, Klein Olifants, Steenkoolspruit
- B2: Bronkhorstspruit, Wilge
- B3: Olifants, Elands, Moses, Selons
- B4: Dorps, Spekboom, Steelpoort
- B5: Olifants, Chunies, Ngwaritsi
- B6: Blyde, Ohrigstad
- B7: Olifants, Ga-Selati, Klaserie, Timbavati
- X2: Crocodile, Elands, Kaap (Noord-Kaap), Mbyamiti, Nelspruit, Nsikasi
- X3: Sabie, Marite, Sand

Table 3. Geomorphological zonation of river channels (after Rowntree *et al.* 1996, Rowntree and Wadeson 1999, and Rowntree *et al.* 1998, with acknowledgement to Harrison and Elsworth 1958, Olif 1960 and Chutter 1967)

Geomorphological Zone	Characteristic Gradient	Diagnostic Channel Characteristics
A. Zonation associated with a 'normal' profile		
Source zone	not specified	Low gradient, upland plateau or upland basin able to store water. Spongy or peaty hydromorphic soils.
Mountain Headwater Stream	0.1 - 0.7	A very steep gradient stream dominated by vertical flow over bedrock with waterfalls and plunge pools. Normally first or second order. Reach types include bedrock fall and cascades.
Mountain Stream	0.01 - 0.1	Steep gradient stream dominated by bedrock and boulders, locally cobble or coarse gravels in pools. Reach types include cascades, bedrock fall, step-pool, plane bed, pool-rapid or pool riffle. Approximate equal distribution of 'vertical' and 'horizontal' flow components.
Foothills (cobble bed)	0.005 - 0.01	Moderately steep, cobble-bed or mixed bedrock-cobble bed channel, with plane bed, pool-riffle or pool-rapid reach types. Length of pools and riffles/rapids similar. Narrow floodplain of sand, gravel or cobble often present.
Foothills (gravel bed)	0.001 - 0.005	Lower gradient mixed bed alluvial channel with sand and gravel dominating the bed, locally may be bedrock controlled. Reach types typically include pool- riffle or pool-rapid, sand bars common in pools. Pools of significantly greater extent than rapids or riffles. Floodplain often present.
Lowland Floodplain or Lowland sand bed	0.0001- 0.001	Low gradient alluvial sand bed channel, typically regime reach type. Often confined, but fully developed meandering pattern within a distinct floodplain develops in unconfined reaches where there is an increased silt content in bed or banks.
B. Additional zones associated with a rejuvenated profile		
Rejuvenated Bedrock fall / Cascades	0.01 - 0.5	Moderate to steep gradient, often confined channel (gorge) resulting from uplift in the middle to lower reaches of the long profile, limited lateral development of alluvial features, reach types include bedrock fall, cascades and pool-rapid.

Rejuvenated Foothills	0.001 - 0.01	Steepened section within middle reaches of the river caused by uplift, often within or downstream of gorge; characteristics similar to foothills (gravel/cobble bed rivers with pool-riffle/ pool-rapid morphology) but of a higher order. A compound channel is often present with an active channel contained within a macro channel activated only during infrequent flood events. A floodplain may be present between the active and macro-channel.
Upland Flood Plain	0.0001-0.001	An upland low gradient channel, often associated with uplifted plateau areas as occur beneath the eastern escarpment.

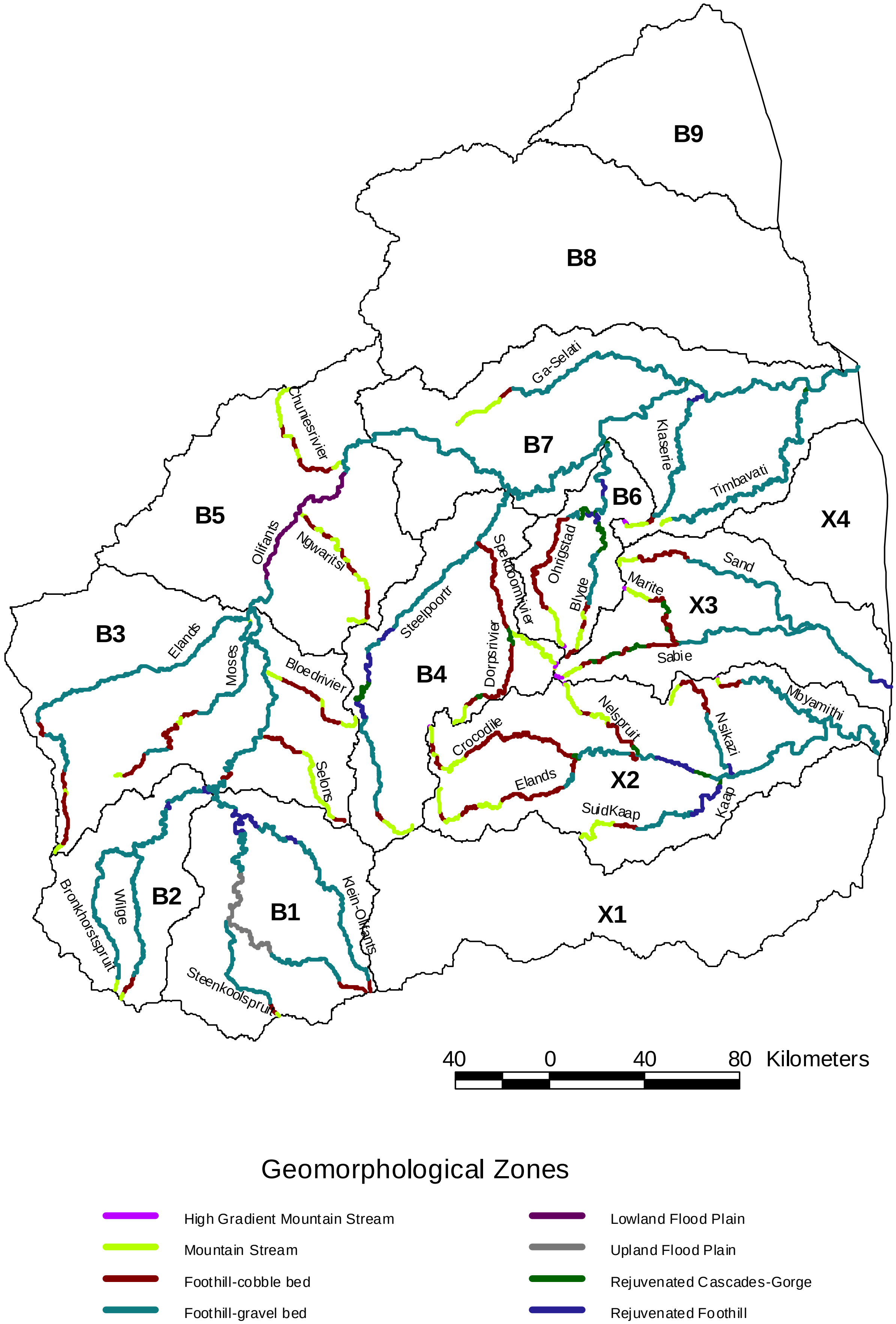

Figure 9. Geomorphological zones for the main rivers and tributaries in DWAF secondary catchments B and X.

The length of each geomorphological zone occurring in each Ecoregion Level 1 was expanded to give an indication of the proportion of each zone within each ecoregion (Figure 10). Given that only the main rivers and tributaries were divided into zones, this information only serves as a preliminary guide as to the proportional representation of each zone. Only the six most common ecoregions have been included in the analysis as the seventh, namely the Limpopo Plains, is only represented by a single river, and is therefore not likely to be reflective of general conditions within this ecoregion.

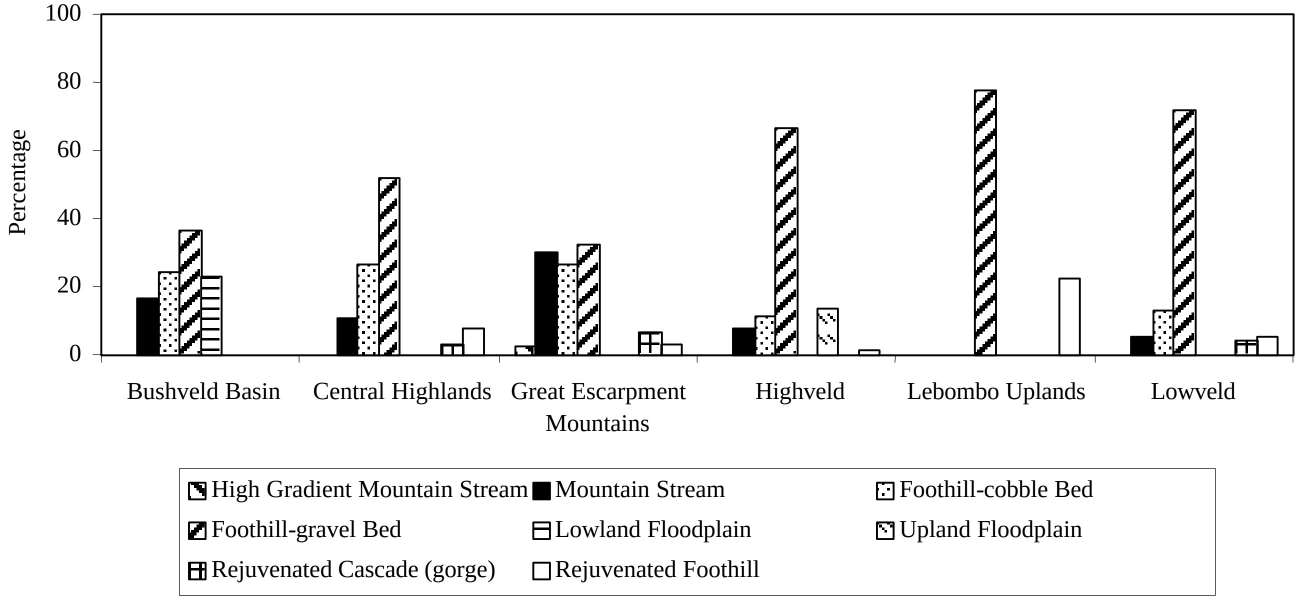

Figure 10. The proportional representation (as a percentage) of each geomorphological zone in the six common ecoregion in DWAF secondary catchments B and X.

Based on the zonation of the main rivers and tributaries in Figure 9, the Foothill-gravel Bed zone is the most common in all ecoregions, particularly so in the Highveld and Lowveld (Figure 10). The Lowland Floodplain zone is not represented in the Lowveld ecoregion. The Upland Floodplain zone occurs in the Highveld ecoregion. The Lebombo Uplands is only represented by the lower reaches of the Olifants, Crocodile and Sabie rivers and this analysis is therefore unlikely to be an accurate reflection of the relative importance of the two zones represented, namely the Rejuvenated Foothill and the Foothill-gravel bed zones. The Bushveld Basin has a relatively even spread of Mountain Stream, Foothill-cobble bed, Foothill-gravel bed and Lowland Floodplain zones, whilst in the Central Highlands, the Foothill-gravel bed zone is the most common, followed by Foothill-cobble bed. The Great Escarpment Mountain ecoregion has similar proportions of Mountain Stream, Foothill-cobble bed and Foothill-gravel bed zones.

The geomorphological zones within each of the main rivers and tributaries are presented, together with the rivers coverage, for each DWAF secondary catchment (Figures 11 to 75). Rivers in catchments B8, B9, X1 and X4 are given at 1:500 000 scale and no geomorphological zones were identified. Rivers in catchments B1 to B7 and X2 and X3 are given at 1:250 000 scale and the geomorphological zones of the main river and tributaries are included.

A summary table of all named rivers at 1:250 000 scale for secondary catchments B1 to B7 and X2 and X3, and 1:500 000 scale for secondary catchments B8, B9, X1 and X4, has been compiled (Table 4). Details related to each river's "parent" river, ecoregion level 1, vegetation type, geological or lithostratigraphic type and hydrological type (based on maps) are presented.

2.4 Level 3: River type

Level 3 of the hierarchy aims to account for variation among rivers within a sub-region or geomorphological zone. Factors such as river size, hydrological type (ephemeral, seasonal or perennial), geomorphological characteristics (channel type, substratum composition) and other chemical and biological factors are considered. It was initially intended to utilise local knowledge of river scientists in the region to identify likely river types, and a questionnaire was circulated to this end. However, poor response from local experts and insufficient information from available literature, prevented the identification of river types.

Whilst it is possible to group rivers on the basis of hydrological type using maps, this information needs to be verified in the field. In addition, river size, geomorphological and biological characteristics can only be assessed in the field and it seems, therefore, that this level of the hierarchy is best undertaken during ground-truthing or verification fieldwork. Components incorporated in level 1 ecoregions and presented graphically in this report such as terrain morphology, potential natural vegetation, geology or lithostratigraphy may also prove useful contributors to the identification of river types. Finalised river typing will, however, need to be done later at the field verification stage.