ASSESSING THE ECOLOGICAL RELEVANCE OF A SPATIALLY - NESTED GEOMORPHOLOGICAL HIERARCHY FOR RIVER MANAGEMENT

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ASSESSING THE ECOLOGICAL RELEVANCE OF A SPATIALLY-NESTED GEOMORPHOLOGICAL HIERARCHY FOR RIVER MANAGEMENT

by

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Report to the Water Research Commission on the project "Linking abiotic and biotic data on South African rivers"

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EXECUTIVE SUMMARY

Introduction

Rivers are at the centre of our landscapes and lives. In South Africa, they are the source of almost all freshwater which, arguably, is the most limited of the country's resources. Despite this, they are manipulated and used in many ways not conducive to sustainable use of this resource. As the end point of drainage in catchments, they are highly vulnerable to change from land-use and other human activities. Their flow is manipulated, to provide water supplies; barriers are built across and along them for flood control; gabions, walls and canalisation are used to counteract erosion; and the river channels are used as conduits for delivering irrigation water and disposing of wastes. These practices have brought many benefits to society but they have also resulted in widespread degradation of the actual river ecosystems.

Healthy, efficiently functioning rivers provide a wealth of reliable benefits to people, from good-quality water, to resources such as fish and reeds, to recreational pleasure. Poorly functioning rivers gradually lose their valued attributes, require continual expensive remedial actions, or are costly to the nation in other ways, such as through collapsing banks, sediment-filled dams and water-quality problems. Such costs are largely unquantified at a national level but undoubtedly are very high. A reasonable objective might therefore be to maximise benefits from them for society whilst minimising disturbances to them. This is the basis of sustainable use, and requires pro-active management.

Such management of rivers requires a new approach, based on an understanding of their nature and how they function as living systems. The data upon which to develop this understanding is sparse, and generalisations will have to be made for management purposes, at least in the short term.

One generalisation often made for management purposes is that the physical and chemical (non-living; abiotic) attributes of rivers are good surrogates for their biological (living; biotic) attributes. By implication, the plants and animals (biota) that occur in one river with a given slope, altitude, aspect, geology, channel form, and water chemistry, should be present in a similar stretch of all the other rivers in the region. If the first river is undisturbed, then the degree to which the other rivers have not got similar biotas is a measure of the degree to which they are degraded. The underlying assumption is that all the rivers with the same abiotic features will have the same biota, unless they are degraded. This assumption, which is the foundation of river health biomonitoring programmes in South Africa and many other countries, is thus based on using abiotic attributes to infer ecological attributes.

Such inference is useful, not least because abiotic attributes are often more easily measured. Rivers and stretches of rivers could be grouped, and management practices and decisions streamlined, based perhaps on physical attributes gleaned from maps. We could say, for instance, that all stretches of river within the Fynbos Biome of the Western Cape that have a slope of X and are at an a altitude of Y should be ecologically similar, so as long as one has been studied, we know all we need to know to make management decisions about any of them.

But how well do such physical attributes truly reflect the ecological nature of the river systems? If they reflect them accurately, then generalising on river ecosystems based on physical data is a valid and useful management tool. If they do not, then such generalisations could represent a misleading "black-box" approach that is insensitive to the living system, and could guide management decisions that are highly detrimental to it. Clearly, abiotic surrogates should not be a long-term management option until their ecological relevance is well understood.

To aid generalisations of the physical attributes of rivers, fluvial geomorphologists have suggested an hierarchical classification system for them. The system provides a way of grouping (classifying) similar rivers or parts of rivers, based on their physical features. The hierarchy operates over a range of spatial and temporal scales. The *catchment* occupies the coarsest spatial level of the hierarchy, and changes to it occur over the longest time spans. Successively smaller-scale levels are the *zone/segment*, the *reach*, the *morphological unit*, and the *hydraulic biotope*. The hydraulic biotope occupies the smallest-scale level and changes to it occur over the shortest time spans. Each level nests in the one above and is restricted by its characteristics. As an example, fynbos plants typically found on the banks of mountain streams will not be found along a mountain-stream *zone*, if that zone does not occur within a *catchment* in the Fynbos Biome.

The objective of the project reported on here was to assess the ecological relevance of this geomorphological hierarchy. The question we set out to answer was:

Is the geomorphological character of a river a useful guide to its ecological character?

We aimed to ascertain how well the hierarchy aids ecological study of rivers; how sensitive it is to the living parts of rivers; and to what extent it could be used to generalise about rivers for management purposes. The research was carried out using Western Cape fynbos rivers, as their distinctive character and high degree of similarity should minimise "noise" in the collected data.

Project objectives

The project objectives, as agreed in the original contract between the University of Cape Town and the Water Research Commission, and amended at the first steering committee meeting, are summarised below.

1. Assess the extent to which abiotic and biotic river data are collected in ways that limit their use by others.

2. Assess the ecological relevance of the geomorphological hierarchical classification system for rivers.

3. Liaise with similar programmes in other countries, particularly in Australia and Great Britain.

Objective 1 was achieved through a preliminary exercise, designed to ascertain how well scientific data already collected could become part of a linked, geomorphological-biological approach to data collection and management. The report on this investigation is given in Appendix E1.

Objective 3 was the subject of ongoing liaison activities, which were reported upon in each progress report for the steering committee. There was close liaison with Prof. Rowntree and other geomorphologists at Rhodes University throughout the project, culminating in her writing Chapter 6 of this report. Both authors worked with the Abiotic-biotic links team in the Kruger National Park Rivers Research Programme (Appendix E2), and the first author made input to the South African, British and Australian River Health Programmes.

Objective 2 was addressed through a comprehensive research programme that is the subject of this report. Chapters 1-9 provide background information, aims and methods of the research. Chapters 10-15 detail the research results. Chapters 16-19 illustrate additional uses for the methods developed and data collected, and Chapter 20 provides a summary of conclusions and recommendations.

General approach (Chapters 3-9)

The research focused on a site in each of 28 headwater streams in the Western Cape. These were all in the mountain and foothill zones of perennial rivers, in order to standardise study sites as much as possible. Sites were designated "mountain" or "foothill" based on prior biological knowledge of which they were likely to be. All fieldwork was done during summer low flows, when flow and other physical conditions are most stable and the rivers most comparable in hydraulic terms. Eighteen of the rivers had minimal disturbance, and were used to detect underlying trends in physical-biotic links. The remaining ten had specific disturbances, and were used to assess how disturbance affected the trends.

At each of the sites, up to 12 biological samples were collected from the widest possible range of physical conditions, and these conditions were measured in detail. The sites, which ranged from 30-100 m in length, were mapped using eight categories of substrata and 14 categories of flow type, and the location of every biological sample shown (Tables E1 and E2). Aquatic invertebrates were used to provide the biological input to the study, as different species are known to seek different kinds of flow or substrata and by this selectivity should illustrate clear physical-biotic links.

The sampling programme as a whole was designed to assess the ecological relevance of all levels of the hierarchy. Details of the research for each level follow.

Assessment at the level of catchment and zone (Chapter 10)

Catchments and zones were combined in one assessment, using the 13 mountain and five foothill undisturbed sites. An initial assumption was that the invertebrate samples would group by zone: those invertebrates from all 13 mountain sites would be so similar that these rivers would group together, whilst the foothill sites would form a second group. We further assumed that, within each group, there might be sub-groups that would reflect geological or geomorphological differences at the catchment

level. In other words, we thought that the main difference in headwater river sites across the region was their position along the river (i.e. which zone they were in).

Table E1. Categories of visually distinct flow types. After Rowntree 1996; Padmore *et al.* 1996; Newson *et al.* 1998; King and Schael this project.

Flow Type	Definition
Free falling (FF)	Water falls vertically without obstruction.
Cascade (CAS)	Water tumbling down a stepped series of boulders, large cobble or bedrock.
Boil (BOIL)	Water forming bubbles, as in rapidly boiling water; usually below a waterfall or strong chute.
Chute (CH)	Water forced between two rocks, usually large cobble or boulders, flowing fast with the fall too low to be considered free falling.
Stream (STR)	Water flowing rapidly in a smooth sheet of water; similar to a chute but not forced between two bed elements.
Broken standing waves (BSW)	Standing waves present which break at the crest (white water).
Undular standing waves (USW)	Standing waves form at the surface but there is no broken water.
Fast riffle flow (FRF)	Very shallow, fast, flickering flow, still covering most of the substrata.
Rippled surface (RS)	The water surface has regular smooth disturbances which form low transverse ripples across the direction of flow.
Slow riffle flow (SRF)	Very shallow, slower, flickering flow, still covering most of the substrata.
Smooth boundary turbulent (SBT)	The water surface remains smooth; medium to slow streaming flow takes place throughout the water profile, turbulence can be seen as the upward movement of fine suspended particles.
Trickle (TR)	Small, slow, shallow flow; when occurring with small or large cobbles, flow is between bed elements with few if any submerged.
Barely perceptible flow (BPF)	Smooth surface flow; only perceptible through the movement of floating objects.
No flow (NF)	No water movement.

Table E2. Categories of substrata.

Category	Size Range (mm)
Silt (SI)	< 0.063
Sand (SA)	0.063 - 2
Small Gravel (SG)	2 – 16
Large Gravel (LG)	16 – 64
Small Cobble (SC)	64 – 128
Large Cobble (LC)	128 – 256
Boulder (B)	> 256
Bedrock (BR)	

This initial assumption was revealed as simplistic. In a similarity analysis of invertebrate communities from each site, the sites grouped principally by catchment and not by zone. Mountain and foothill sites within one catchment linked together, rather than with other mountain or foothill sites respectively elsewhere in the region. This individuality of catchments was sufficiently strong to over-ride the differences in invertebrate communities that we know take place down the length of the rivers. We have called this indication of a catchment identity, the *catchment signature*.

At present, the nature and cause of catchment signatures are not understood and, until they are, management decisions should not be based on the assumption that specific rivers can be sacrificed to developments because other similar rivers exist. At present, the only safe assumption is that rivers in different catchments are not similar. In terms of the geomorphological hierarchy, this means that it can only partially guide on river groupings at the highest ecological level within a bioregion. Geographically, it is possible to delineate each catchment on maps, but not to indicate which ones are likely to be biologically similar. This next step might be possible in the future, once catchment signatures are better understood.

Within a catchment, sites displayed a further level of individuality that over-rode the influence of zone, and so caution should be exercised regarding any assumptions of similarity between a catchment's rivers. In terms of the invertebrates, bedrock sites were quite different from the alluvial rivers in the same catchment. As the nature of the riverbed is a physical feature, its details can be incorporated into the geomorphological hierarchy. Such information cannot be gleaned from maps, however, and so cannot be part of a desktop classification but rather requires field identification.

The river zone, far from being the expected over-riding influence on invertebrate distributions within the region, appeared at the third level of differentiation of sites, after catchment and riverbed. Zones are already recognised as one level of the geomorphological hierarchy, and the delineation of zones along the river can be done, using maps in a desktop exercise. The zones should be defined using ecological data, however. This appears to be necessary, as the analyses of zones done in this project by geomorphologists, using such variables as zone class and valley form, did not reflect the biological zones revealed by this study. The relevant ecological data for delineating zones can be gleaned, for any bioregion, from ecological studies within that region.

In summary, the overall ecological natures of the studied headwater streams appear to be dictated by three main factors: the catchment; the riverbed substratum; and the longitudinal zone. The top levels of the geomorphological hierarchy partially incorporate some of these factors, but not sufficiently accurately or comprehensively to allow the hierarchy to be a surrogate for ecological aspects in research and management decisions.

Assessment at the level of hydraulic biotope (Chapter 11)

Hydraulic biotopes (HBs) sit at the lowest level of the geomorphological hierarchy, and are seen as the building blocks for its intermediate levels. They can be envisaged as the small patches of different flow and substratum conditions (tumbling white water over cobble; slow smooth water over sand, and so on) that make up the mosaic of hydraulic conditions at a river site. Once distribution of the biota at

this fine scale is understood, it should be possible to seek wider patterns of distribution at the next higher levels of the hierarchy (morphological units and reaches).

After discussions with ecologists, geomorphologists described 11 HBs, that they felt might support different invertebrate communities. In this project, only four of these HBs were shown to be ecologically relevant, with the others being encompassed within the main ones (Table E3).

Table E3. The grouping of geomorphological HBs by ecological HB.

Ecological HB	Geomorphological HB
run	run, fast glide
riffle	riffle
rapid	rapid, cascade, chute, waterfall, boil
pool	backwater, slack water, pool, slow glide

The characteristics of the four broad-ranging HBs can be summarised as follows (Table E4).

Table E4. Definition of each biologically-defined hydraulic biotope (HB) by depth (m), flow types, substrata, mean water column (0.6) velocity (m s^{-1}), and Froude number. Flow-type codes as per Table E1.

HB	Depth (m)	Flow Description	Substrata	Mean Velocity m s^{-1}	Froude Number	Comments
Rapid	shallow to deep: up to 0.70	turbulent, broken water: CAS, USW, BSW, CH, STR, FF, FRF, some fast RS	boulders and large cobbles	0.38 – 0.64	0.371 – 0.900	CAS is the dominant flow type; CH and FF are unique to this HB
Riffle	shallow: <0.30	fast, flickering flow: FRF, USW, BSW, CAS, some fast RS	cobbles and sometimes small boulders	0.27 – 0.39	0.332 – 0.425	FRF is the dominant flow type.
Run	shallow to moderately deep: up to 0.50	fast to moderately fast rippled flow: RS, SBT, some FRF	a range of substrata	0.05 – 0.19	0.070 – 0.200	RS is the dominant flow type.
Pool	shallow or deep: 0.03 - >1.00	slow, smooth flow: SBT, BPF, rarely NF	a range of substrata	0.00 – 0.10	<0.070	Bedrock and alluvial pools may have different species assemblages

In summary, the lowest level of the geomorphological hierarchy, which focuses on *the hydraulic biotopes of invertebrate communities*, distinguishes more HBs than the four that can be justified from the ecological data. Within the ecological HBs, however, individual species might inhabit slightly different hydraulic conditions. For this reason, it is suggested that another level of the hierarchy could perhaps be added, to describe the *hydraulic habitat of individual species*.

The four ecological HBs could form the basis for biomonitoring programmes in headwater streams. They are reasonably easy to distinguish on the ground, and present the four main instream conditions found in such streams. Each HB can be distinguished visually, but this should be done by judging the overall appearance of the flow as no one HB is uniquely described by one flow type (Table E4). To ensure collection of the greatest possible range of species, the full range of micro-environments within each HB should be sampled. This kind of broad-spectrum sampling of an HB is not suitable for species studies, because details of the specific micro-habitats will be lacking.

Finally, the analysis of HBs incorporated all 380 invertebrate samples, rather than a summary of them per site as used for the catchment analysis. This analysis revealed that the samples grouped by river as well as by catchment, and so *river signatures* exist as well as catchment signatures. In other words, in ways and for reasons not yet understood, every river is different.

Assessment at the level of morphological unit (Chapter 12)

Morphological Units (MUs) are the channel features one scale-size higher than HBs. Good examples are waterfalls and pools. In this study, the MUs were not particularly good predictors of the distribution of invertebrate communities. The concept of MUs remains useful, however, for preliminary assessment of a site. MUs inform on the overall nature of a studied river reach and thus provide an idea of the invertebrates likely to be present. Knowing this in advance allows sampling strategies to be planned that avoid spending unnecessary effort on areas unlikely to yield different assemblages.

In summary, the concept of MUs as a level in the hierarchy remains useful for organising thoughts and data, and for overall assessment of a study site. MUs are not particularly useful, however, as indicators of where to locate specific communities of invertebrates. In addition, use of the terms riffle, run, rapid and pool at two levels of the hierarchy (HB and MU), is confusing, and it is suggested that alternative terms be sought that are specific to one level.

Assessment at the level of reach (Chapter 13)

Reaches form the next level up from MUs in the hierarchy, with the level above them being zones. Reaches, nested within zones, are used to describe a length of river with similar channel and hydrological characteristics. A bedrock riverbed with a high volume of flow, for instance, would represent a different reach type to a cobble riverbed with a low volume of flow. Reaches can be tentatively delineated from maps, based on changes in slope, geological formations, valley form and runoff, and verified in the field by the composition of MUs.

Preliminary analysis of invertebrate data designed to assess the ecological relevance of reaches has not provided much insight. The two reaches studied were about 1 km apart, on the same river. They were geomorphologically different, but the overall densities or composition of their invertebrate communities were not significantly different. The faunal samples grouped mainly, not by site, but by whether they were in fast or slow flow. However, within the groups of fast-flow and slow-flow samples, those samples from each site (i.e reach) tended to cluster together. It seems possible that

there are differences in invertebrate communities at the reach level, but any such subtleties will only be revealed with more intensive examination of the data. The data will be further analysed in the Ph.D. thesis of the second author.

In terms of biomonitoring, reach type is a useful guide to the mosaic of MUs and HBs likely to be encountered, and thus helps development of a sampling strategy. Reaches within one zone that have similar MUs and HBs will probably yield much the same invertebrates, whilst those with different sets of MUs and HBs, could yield different species. All reach types within a zone likely to add to the list of fauna present should therefore be considered for inclusion in the sampling programme.

In summary, reach types are as important as MUs in guiding overall structure of a river study, but are too coarse to guide on the exact location of individual species or species groups. Different reach types may yield different groups of species, and sampling strategies should recognise this. This can be done through a reach analysis, which highlights similar lengths of river, and can guide on the extent to which data can be extrapolated from a study site.

Assessment of the temporal stability of HBs over a range of discharges (Chapter 14)

HBs are at the only level of the geomorphological hierarchy that incorporates a flow characteristic as well as a geomorphological one. They can thus change in short to intermediate time scales as discharge changes. A preliminary analysis of their physical stability revealed that they persisted over a range of similar low discharges, and only changed when discharge increased substantially. Essentially, there was a 14 – 24% change in wetted area once there was a 50 – 80% increase in discharge. The faunal data will be further analysed in the Ph.D. thesis of the second author, to reveal how the invertebrates reacted to these physical changes.

The impact of anthropogenic disturbance (Chapter 15)

The ten rivers with a range of disturbances were studied to assess how disturbance might affect the abiotic-biotic trends described above. Disturbance was assessed in terms of changes in the species community. Studied disturbances were not rated for severity of their impact *a priori*; instead, severity was judged based on location of each river's invertebrate community on MDS similarity plots. These plots show the relationship between sites, in terms of their invertebrate communities, by the distance apart the sites appear in two-dimensional space. Similar sites appear clustered together. Based on the findings, the following hypothesis is suggested for further testing.

The hypothesis: Increasing disturbance gradually leads to the loss of a river's catchment signature, and eventually to loss of its regional character.

Suggested explanation of the data, based on invertebrate assemblages, to support this hypothesis: The most mildly disturbed rivers yield invertebrate communities that are similar to those of the least-disturbed rivers. In other words, these rivers remain well within their catchment clusters on the MDS plot, and so their catchment signatures remain intact. As disturbance increases, rivers become less similar to others within their catchment, moving to the edge of their catchment cluster on the MDS

plot. Moderately disturbed rivers lose their catchment signature completely, moving outside their catchment grouping on the MDS plot to cluster together in the middle of the ring of catchment groups. This suggests that they have lost their individuality and become more similar, as kinds of generalised rivers of their region. Possibly, by this stage, all sensitive species have disappeared and any coarser regional signature remaining is provided by hardy, opportunistic species. Highly disturbed rivers lose even this generalised signature, being located well outside all the catchment groupings. It is not known at this stage to what extent these rivers retain any kind of regional identity. A variation on the trend may occur for rivers receiving inter-basin transfers (IBTs) of water. One of the sites we studied was 1 km *upstream* of an incoming IBT, and had taken on the catchment signature of the donating catchment.

In seems important to discover exactly how different kinds of disturbances transform the invertebrate communities, resulting in the gradual erosion of catchment signatures. At this stage we cannot say if there are likely to be profound management implications, but we suggest that simply understanding better how disturbance affects the signatures would be a critical step forward. To this end, further analysis of this project's data is recommended.

Usefulness of the geomorphological hierarchy

A major impression from this project was that geomorphological hierarchies are exceedingly useful tools to aid organisation of thinking, studies and data analysis. Before such hierarchies were suggested, the country's ecologists were using a spatial hierarchy of sorts, but ones like that tested here enabled a giant step forward in the way ecologists viewed rivers. As a result, the study of physical-biotic links in rivers has gradually taken its place alongside studies of chemical-biotic links, providing a much more rounded perspective on river functioning, to the benefit of both fields of study.

Geomorphological studies based on a spatial hierarchy now form part of every environmental flow assessment done in South Africa, as well as contributing to the National River Health biomonitoring programme. We feel this involvement is essential, but suggest that discussions should be held with the geomorphologists on whether it is necessary for their approaches to accommodate the findings from this project. Specifically, discussions should be held on the following:

- the nature and significance of catchment and river signatures;
- use of biologically relevant zones, rather than geomorphologically derived ones;
- reduction in the number of HBs to the four ecologically relevant ones;
- re-naming HBs and/or MUs, so that each level of the hierarchy has unique names;
- further study of which kinds of physical change might be linked to each disturbance level in the above hypothesis.

Much of this discussion could well reflect the traditional contrast between "top-down" and "bottom-up" classifications. The "top-down" approach in this case is the geomorphological one of grouping similar rivers and parts of rivers based on easily measured abiotic and landscape features. The "bottom-up" approach in this case is the use of aquatic invertebrates to indicate which rivers or parts of rivers are similar. This project was, in essence, a "bottom-up" testing of a "top-down" approach.

Inevitably, mismatches occurred, but these were not of a severe nature and there seems every reasons to assume that the "top-down" approach could incorporate the biological findings, and thereby enhance its ecological relevance. This should be the main objective of the discussions suggested above.

Additional applications of the project's techniques and data (Chapters 16-19)

An extensive database on physical-biological links was populated during this project. Additionally, mapping techniques were developed that already are being used in consultancy work. Chapters 16 to 19 serve to briefly introduce suggested further applications of the project's data and techniques.

In Chapter 16, use of the data for biogeographical and biodiversity studies is illustrated. The 380 invertebrate samples collected contained 287 species from 83 families. Different numbers of species occurred in each catchment. Although this may be due to sampling strategies, there is a possibility that real catchment differences in biodiversity are being revealed. The Eerste and Molenaars catchments, for instance, clustered together in every analysis done, and yielded 40% more species than the catchment with the next highest number. Could these rivers be located within some centre of biodiversity? Or could the results simply be reflecting our sampling strategy? Further analyses of the dataset might provide answers to these questions.

Information on the hydraulic conditions in which each species was found is also available in the database, and examples are given in Chapter 17. A preliminary investigation of the hydraulic nature of flow types is reported on in Chapter 18, and use of the mapping techniques in the environmental flow assessment for all rivers in the Lesotho Highlands Water Project is illustrated in Chapter 19.

The analyses in Chapters 16 and 17, at least, could be taken much further, but this was not possible in this project. Together with the data on catchment and river signatures, yet to be analysed, the database represents a considerable resource that could enhance understanding of the nature and functioning of the region's rivers. For this reason, further analyses of the data are recommended.

The value of species data

In invertebrate studies it is becoming increasingly common to work only to family-level identifications, because of the time and other costs entailed in species identifications. If we had done that in this project, catchment and river signatures would not have been detected. There is no intention here to detract from the use of family-level data, for such data are well established and of great use, particularly for biomonitoring purposes. A deep understanding of ecosystem functioning and biogeographical trends, however, can only be obtained when working at the level of species. Here, we record our view that, to improve the quality of advice offered by ecologists on management practices for the sustainable use of our rivers, collection of biological data on invertebrate species, their behaviour and their life-cycle requirements, must continue to have a place in research programmes.

Recommendations

This project has produced a very comprehensive data set. The data have extra value because they cover many similar rivers, within one bioregion, and were collected by a single team in a standardised way. Because of the geographical spread of the data, previously unimagined characteristics of Cape rivers have been revealed. Region-wide patterns of river type have been detected, as well as trends in how human disturbance affects these patterns. Specifically, the invertebrate data clearly show that all rivers and catchments have their own signatures.

The management implications may be profound. Without an understanding of the detected signatures, we can no longer assume that all rivers within a region are ecologically similar, or that knowledge from one can be extrapolated to the rest, or that they will respond to disturbance in a common way. There may be other, presently unknown, factors that need to be considered before assuming, for instance, that some rivers can be sacrificed to development because we have many more like them.

It is therefore recommended that further analysis of the database be undertaken. Some of this will be done in the PhD thesis of one of the authors, as detailed elsewhere in this report. The following additional aims will still need to be addressed.

- Ascertain the proximal cause of the signatures. Two possible explanations are that they are due to unique species in each catchment/river (i.e. related to historical biogeographical distributions), or that there are unique combinations of common species in each catchment/river (i.e. each river is functioning slightly differently, perhaps due to climatic or geochemical influences).
- Analyse the species and geomorphological data for all the disturbed rivers, to ascertain the influence of disturbance on catchment signatures. Rate different kinds of disturbances on a severity scale.
- Convene a workshop, with selected river scientists, to reach consensus on the management implications of catchment and river signatures. Transfer the findings to the management arena.
- Allocate SASS-type scores to all 380 invertebrate samples in the database. Using the GIS site maps, assess how reach, MU, site and sample point selection affects the SASS score. These kinds of scores are now used at national level for management of river health, and so it is important to continue assessment of their strengths and weaknesses. Transfer the findings to the management arena.
- Ascertain, as far as possible, if it is true that some of the studied catchments had far higher numbers of species and higher numbers of unique species, than others.
- Refine and upgrade the interface and query centre of the database created in this project, and complete a quality-control assessment of the data housed in it. This should a) make the database accessible as a research tool, and b) allow other researchers to add their data to the database, thereby initiating a national database of biological and physical links in rivers. The database created in this project database is compatible with BIOBASE, developed by the Freshwater Research Unit at the University of Cape Town, which links biological and chemical data for South African rivers.

Extent to which the Terms of Reference have been met

All of the objectives listed at the beginning of this Executive Summary have been achieved.

Capacity building and technology transfer within the project

Seven post-graduate theses were produced from research linked to this project: four in the Departments of Zoology and Civil Engineering at the University of Cape Town (UCT), and three in the Department of Civil Engineering at the University of Stellenbosch. Not all of the researchers were funded from the project, but all used data collected during it. In addition, one of the authors of this report (DMS) is presently writing a Ph.D. thesis, and the other author (JMK) supervised another four Ph.D or MSc. students completing river studies.

Eight undergraduate or postgraduate students at UCT were employed part-time on the project, and received scientific training from project staff.

An extensive programme of technology transfer was completed, including:

- lectures;
- presentations at conferences;
- acting in planning, organising, advisory or review roles for various scientific workshops, programmes and journals;
- a specialist review for the new Water Law;
- application of techniques and knowledge developed, both within South Africa, and in England, Australia, Lesotho, America, Taiwan, Portugal, Zimbabwe, Mozambique and for the World Bank.

Full details are given in Appendix E3.

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LINKING ABIOTIC AND BIOTIC DATA ON SOUTH AFRICAN RIVERS

The Steering Committee responsible for this project, consisted of the following persons:

Dr. SA Mitchell	Water Research Commission (Chairman)
Mr. DS vd Merwe	Water Research Commission
Dr. HC Biggs	South African National Parks
Dr. JA Day	University of Cape Town
Prof. J O'Keeffe	Institute for Water Research, Rhodes University
Prof. KM Rowntree	Rhodes University
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Prof. GR Basson	University of Stellenbosch
Prof. AHM Görgens	University of Stellenbosch
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The following invertebrate taxonomic specialists identified animals as per Table 8.1: Prof. Arthur Harrison (Professor Emeritus University of Cape Town), Dr Ferdy de Moor and Mrs. Helen Barber-James (Albany Museum), Mr. Patrick Reavell (Department of Botany, University of Zululand).

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1. INTRODUCTION

South Africa is a semi-arid country. Water is scarce and a burgeoning human population is expected to increase its water demands beyond supply within the next two decades (Basson *et al.* 1997). Rivers supply most of that water, and increasing manipulation of their flow regimes and channels, habitual use of them as waste-disposal facilities, and a range of non-point impacts on them due to man's activities, are accelerating their degradation (Davies & Day, 1998). The cost to the country of rivers functioning poorly is unknown but undoubtedly very high.

Over the last two decades there have been concerted efforts by South African water managers and scientists to bring about more sustainable use of rivers. Assessments of the flows required for river maintenance were initially done for all rivers targetted for water-resource development (King & Louw 1998; Tharme & King 1998), but are now being done for all water resources within a national plan. This moves to meet the requirements of the new Water Act of 1998, which recognises aquatic ecosystems as one of only two sectors with a right to water, the other being people, whose basic water needs are protected. Together, the water required for sustaining people and aquatic ecosystems is termed the *Reserve*, and enjoys priority of use. Biomonitoring – the use of aquatic plants and animals to indicate river health – has also been introduced, to complement the chemical monitoring of rivers already done by the Department of Water Affairs and Forestry (DWAF) (Roux 1997).

With rivers now in the spotlight in a way never contemplated even a few years ago, the imperative for aquatic scientists to work hand-in-hand with government on river management has never been greater. Advice is sought from scientists on a wide range of issues, from dam design to conservation of Red Data species and management of channels. The capacity to be able to predict how rivers will react as ecosystems to proposed water-resource developments is becoming increasingly important. Accurate predictions will facilitate more informed management decisions about the sustainable use of rivers.

For most rivers in the country, at least in the short term, such predictions and management decisions will be made without the benefit of in-depth research on the rivers of concern. This is potentially a risky endeavour, but the risk can be reduced by optimising the way in which limited data and understanding are used. One such way that this already happens, often informally, is through regional generalisation on the nature and functioning of rivers. Data and understanding from studied rivers are used to infer the character of nearby unstudied rivers.

If this kind of general regional knowledge could be organised so that all that is known about similar rivers could be grouped in a scientifically acceptable way, then its use could validly be expanded through extrapolation to all rivers within the group. In this way, the nature and functioning of any one river could be assumed to a known extent through its membership within a specific group of rivers, some of which may have been the subject of some studies. Similarly, the effects of a proposed disturbance to one river could be predicted through knowledge of a similar disturbance to a similar kind of river. Rehabilitation of a river could be guided by the known range of conditions occurring within less disturbed rivers of its group.

Such partitioning of the rivers would have other benefits. For instance, biomonitoring of river health, using the South African Scoring System (SASS) (Dallas 1995; Chutter 1998), and State of the Environment assessments, are both required to be set within a regional and local spatial framework. Any river site being assessed can then be compared with similar least-impacted ones, which could provide a reference condition of how far removed from natural the site is. Additionally, when river-specific data are sparse, environmental flow assessments often draw on regional knowledge of the character and distribution of riverine species.

There has thus evolved both a long-term scientific and short-term management-orientated need to develop approaches that allow valid extrapolation. Such techniques require a good understanding of what constitutes a "similar" river or river site, so that it can reasonably be assumed that data collected in a known area truly represent the (similar) area to which they are extrapolated.

Broad-scale grouping of similar rivers or river sites within South Africa has been done in several ways. This is addressed in more detail in Chapter 2, but essentially, rivers can be grouped at many different scales, based either on biological distributions (bottom up), environmental variables (top down), or both. At the countrywide level, catchments can be grouped by region (e.g. all the rivers within the Fynbos Biome). At the catchment level, similar longitudinal zones of many rivers within a region might be grouped (e.g. all mountain streams within the Fynbos Biome). At the zonal level, similar channel types or smaller habitat-type features might be grouped together for study or other purposes (e.g. all the pools in mountain streams within the Fynbos Biome).

For both in-depth studies and rapid management methods, it is important to understand the implications of such groupings. Much of the proclaimed variability or "noise" in biological river data may be derived from our inability to truly compare like with like. For example, are all the pools in mountain streams in the Fynbos Biome so alike in physical, chemical and biological features that one could be used to represent them all? Being able to answer this kind of question might be important, for instance, in biomonitoring, when sampling a river upstream and downstream of an effluent in order to assess the impact of the effluent. If biological samples were not taken from both areas in places which the biota perceive as being similar, the samples will probably be different irrespective of the effluent. Some of this difference might be due to natural variability, whilst a major portion will very probably be due to the mismatch of sampling areas.

So how can we improve our understanding of what constitutes a similar river or river site, in order to maximise the validity of comparison and extrapolation? A promising starting point is the tacit recognition among river ecologists of the importance of the physical features of the channel. "Pools" and "riffles" are important descriptors of species' habitats, as are the size of substratum particle sizes, the shape of the banks and the extent of floodplains. Fluvial geomorphologists have suggested an hierarchy of scales for structuring river studies, which allows all such physical features to be placed into context within the landscape. Their hierarchy is potentially of great use for ecologists, and indeed a similar, less-structured, spatial hierarchy is already used by them (Section 2.2).

If a geomorphological hierarchy proved also to be valid ecologically, then easily-recognised physical features of rivers (position in landscape, slope, substratum particle size, kind of flow) could be used as biological surrogates, in order to recognise and group ecologically similar rivers or river sites. Ecologists

could more easily and surely choose truly comparable *sampling sites* in different rivers and comparable *sampling points* within different sites. Further, sites and sampling points in anthropogenically disturbed rivers could be more surely matched with ones in undamaged ones through use of robust geomorphological features, in order to assess the degree of impact of the disturbance. Biomonitoring results would thus have one layer of "noise" removed. A greater understanding of the driving forces behind species distributions would also be gained, at scales from catchment to microhabitat, and the scientific study of patch dynamics would be facilitated over a range of scales.

The present project thus poses and is designed to answer the following question:

Is the geomorphological character of a river a useful guide to its ecological character?

This report details the research undertaken to address the above question. Chapters 2 - 4 complete the Introduction. Chapter 2 gives an explanation of geomorphological and ecological river hierarchies, and provides various perspectives of physical habitat. The Aims and Tasks of the project are then listed (Chapter 3), followed by details of the Methods used (Chapter 4).

Chapters 5 - 9 contain the Results of the research. An introduction to the Results section is given in Chapter 5. This is followed by an independent geomorphological assessment of the study sites by Prof. Kate Rowntree of Rhodes University (Chapter 6). The physical and chemical data for each site appear in Chapter 7, and the biological data, with related environmental data, in Chapter 8. The database created to contain all the above data is then described (Chapter 9).

Chapters 10 – 15 report on use of the data to test the ecological relevance of various scale levels of the geomorphological hierarchy. Starting at the largest scale in the hierarchy, Catchment and river longitudinal Zones are addressed in Chapter 10. Then, attention is turned to the smallest scale of the hierarchy, Hydraulic Biotopes (Chapter 11), in order to define these, the building blocks of the intermediate scales. Morphological Units, consisting of few to many hydraulic biotopes, are dealt with in Chapter 12, and Reaches in Chapter 13. Discharge-related changes in the proportions and distributions of Hydraulic Biotopes and of invertebrate species are described in Chapter 14. The final chapter in this Part introduces sites on selected disturbed rivers, and describes how different kinds of disturbance impact the patterns revealed in the previous chapters (Chapter 15).

Chapters 16 – 19 illustrate further applications of the project data. Biodiversity issues are discussed in Chapter 16. Taxon-specific hydraulic habitat requirements are provided in Chapter 17, the hydraulic character of flow types is explored in Chapter 18, and application of the developed habitat-mapping techniques in the Lesotho Highland Water Project is described in Chapter 19.

Finally, Chapter 20 provides Conclusions on the project and Recommendations regarding future research.

2. GEOMORPHOLOGICAL HIERARCHIES, ECOLOGICAL HIERARCHIES, PHYSICAL HABITAT AND HABITAT MAPPING

2.1 Geomorphological hierarchies

Historically, the ecological study of rivers has largely focussed on chemical and biological aspects, such as pollution levels and community distributions (Hynes 1960; Hynes 1970). Physical aspects of channels received cursory attention. More recently, study of the physical character of rivers has gained prominence in South Africa, perhaps because it was becoming clear that many rivers with relatively minor water-quality problems are nevertheless seriously degraded. In different rivers across the country, channel shape, features of the riverbed and the flow regime are all undergoing intense modification to suit short-term human requirements. The resulting structure of the channel profoundly influences the kinds of physical habitat available for riverine biotas, and thus the whole functioning of these ecosystems. Recognising this, water managers and river ecologists turned to fluvial geomorphologists for advice on the study and management of physical aspects of rivers.

Geomorphologists point out the importance of placing the river within the context of its catchment, and of viewing river systems as hierarchically organised, at scales from catchment to aggregates of substratum particles. River classifications expounding this view (Frissell *et al.* 1986; Naiman *et al.* 1992) have been suggested as useful tools for river management. Derived from these, and from relevant studies on rivers in several parts of South Africa (Cheshire 1994; James *et al.* 1996; Jewitt *et al.* 1998; and Rowntree & Wadeson 1999), a local geomorphological hierarchy has been proposed as a framework for river studies (Rowntree & Wadeson 1999). Working from Rhodes University, Rowntree & Wadeson described the hierarchy as being based on "spatially nested levels of resolution that recognise that the structure and dynamics of the river channel are determined by the surrounding catchment". They give the levels of the hierarchy as catchment, segment, zone, reach, morphological unit and hydraulic biotope (Table 2.1).

Higher levels of the hierarchy impose constraints on lower levels and, because of their different spatial and temporal scales, are characterised by different geomorphological processes. All tiers of the hierarchy, except hydraulic biotopes, are defined through geomorphological and allied characteristics, and hence are relatively stable in space and time. Hydraulic biotopes have local flow characteristics as an additional descriptor, and so are spatially and temporally more ephemeral than the higher levels of the hierarchy.

Table 2.1 Definition of geomorphological classification levels (Rowntree & Wadeson 1999).

Hierarchical unit	Description	Scale
Catchment	The catchment is the land surface which contributes water and sediment to any given stream network.	Can be applied to the whole river system, from source to mouth, or to a lower order catchment above a specified point of interest.
Segment	The segment is a length of channel along which there is no significant change in the flow discharge or sediment load.	Segment boundaries will tend to be co-incident with major tributary junctions.
Longitudinal zone	The zone is a sector of the river long profile which has a distinct valley form and valley slope. River zones fall within segments and are delineated according to *macro-reaches*.	Sectors of the river long profile.
Macro-reach	The macro reach describes the valley form characteristics, including valley shape, valley floor slope, and valley floor width.	
Reach	The reach is a length of channel characterised by a particular channel pattern and channel morphology, resulting from a uniform set of local constraints on channel form.	Scale level of hundreds of meters
Morphological unit	Morphological units are the basic structures recognised by fluvial geomorphologists as comprising the channel morphology, and may be either erosional or depositional features.	Occur at a scale order similar to that of the channel width.
Hydraulic biotope	Hydraulic biotopes are spatially distinct instream flow environments with characteristic hydraulic attributes.	Occur at a spatial scale of the order of 1 m^2 to 100 m^2 and are discharge dependent.

Segments and zones are derived from maps showing catchment features such as rainfall, runoff, sediment production zones, and the longitudinal profile of the river. *Reaches* describe lengths of river with a similar set of controls. They are initially identified from maps, using contour lines and channel gradient (Prof. Rowntree, pers. comm.). They are then further defined in the field by their channel type, through substratum characteristics (bedrock, alluvium or mixed) and channel pattern (single, braided, anastomosing, sinuosity). Reaches that are similar in terms of these characteristics form one reach type. Reaches of two or more reach types can be repeated along the length of one zone.

Morphological units are identified in a field exercise, at the site level. Occurring on a channel-spanning scale, suites of morphological units are envisaged as occurring within a reach, with similar reach types supporting similar assemblages of morphological units. *Hydraulic biotopes* are the smallest unit in the hierarchy, and are defined by their substratum and flow characteristics. Different suites of hydraulic biotopes are envisaged as occurring in different morphological units. The assemblage of hydraulic biotopes within any one morphological unit will change with discharge.

A similar hierarchy is described by scientists working at the University of the Witwatersrand (James *et al*., 1996). Their approach starts at the lower end of the hierarchy, with geomorphological units being at the finest scale, followed by reaches, macro-reaches and zones. A later publication (Heritage *et al*., 1997) mentions channel types and functional groupings of geomorphological units. This publication also provides

an excellent discussion on scale issues. Focussing on the relationship between riparian tree communities and river features, this group did not initially address the level of small-scale (spatial and temporal) instream habitat, as had been done by the group introducing hydraulic biotopes. However, later additions to their approach, to accommodate fish studies, provided a "top-down" component for dealing with instream habitat. The coarse to finer scale levels were, respectively, channel type, geomorphological unit and cover/substratum categories. In contrast to the hydraulic-biotope approach, no explicit use of instantaneous flow conditions was used.

The two approaches have triggered considerable interest among South African river ecologists. The two geomorphological approaches share many characteristics with each other and with the ecological scale-related perspective of rivers. This latter perspective is described in the next section.

2.2 Ecological hierarchies

Ecologists have long sought to impose order on their studies of rivers, at scales from regions to instream habitat.

2.2.1 Ecological regions

In South Africa, *regions* of the country with similar rivers have been delineated, either directly, using the biota to define similarity, or indirectly, using environmental variables. Harrison (1959), for instance, recognised 12 hydrobiological regions within South Africa, based on water chemistry and distributions of the aquatic biota. Noble & Hemens (1978) recognised seven regions, based on much the same features, together with geological and zonation aspects of the rivers. In 1994, the Department of Water Affairs and Forestry funded a Spatial Framework Workshop, designed to further define areas within the country with different kinds of rivers (Brown *et al.* 1996). Derived from this and parallel research, Eekhout *et al.* (1997) recognised ten bioregions for rivers, based on the oldest available records (i.e. to the extent possible, those recording pre-disturbance conditions) of the distributions of fish, riparian vegetation and aquatic invertebrates. Although the details may differ, there was good general agreement between these analyses on which parts of the country are biologically different in terms of rivers.

Adopting the alternative approach, Kleynhans *et al.* (1998) used map overlays of mostly environmental variables with some biological input to subjectively determine ecoregions. Information on physiography, climate, geology and soils, and potential natural vegetation was used to delineate 18 ecoregions in a first broad assessment. This approach recognised much the same broad areas as the earlier mentioned biological approaches.

2.2.2 Longitudinal biological zones

Within regions of similar rivers, *biological zones* along the rivers have long been recognised as the next level of spatial organisation. Illies (1961) was prominent among those introducing the concept at an international level, and Noble & Hemens (1978) expanded on this concept when suggesting a characteristic set of biological zones for South African rivers. Rivers in different parts of the country exhibited different combinations of the zones. South-western Cape clear acid rivers, for example, contain all five zones

(mountain source and cliff waterfall, mountain stream, foothill sandbed, low and midland river and estuary), generally all well developed. In comparison, the short southern Cape rivers have only the mountain source, mountain stream and estuarine zones, whilst the southern Karoo rivers have no mountain source or mountain stream zones.

Harrison & Elsworth (1958), Oliff (1960), Chutter (1970), King (1981), King & Tharme (1994), and many others have described such zonation along South African rivers. The biological differences between zones have been linked to a range of physical and chemical features characteristic of the zones. Water temperature and chemistry are often markedly different between zones, although there is usually a gradual downstream transition rather than an abrupt change. The same is true for physical features, with the main characteristics that differ between zones often being geomorphological in nature. Slope, substratum particle size and shape of the channel within its valley have all been recognised as important physical descriptors of the available living space for riverine biota.

Eckhout *et al.* (1997) saw their regional groupings (bioregions) as potentially subdividing into subregions, each of which contained the same zone of many rivers. For instance, Sub-region One of the Capensis bioregion could contain all the mountain streams within this Western Cape bioregion.

2.2.3 Instream habitat at the mesohabitat level

Within zones, ecologists partition the instream component of rivers further using physical habitat. This reflects an implicit understanding that the major determinant of biotic distributions, not only at the level of zones but also at finer scales, is the physical environment. Chemical variables also determine distributions at larger scales (i.e. zone), but do not appear to have such a clear influence at finer scales (i.e. morphological unit). This is because most chemical or physico-chemical variables have different values along the length of a river, but much the same value within any one site. There are some within-site differences, such as increased levels of dissolved oxygen in riffles or higher phosphate levels in pool sediments, but these are usually reflections of local differences in channel morphology. This suggests that the physical structure of the site is the primary determinant of the environmental conditions experienced by instream biota.

There are several well-used terms to describe such physical habitat at what might be described the mesohabitat level (10^0 –10^1 m). Older terms, such as "ripple" and "stickle" may have been taken from fishermen's language and are rarely used by river ecologists now, whilst others from the same probable origin, such as "run", "pool" and "backwater" are in common use. These, and terms such as "riffle", "cascade", "rapid", "backwater", "chute" and "waterfall" are routinely used by river ecologists. Chutter (1970) introduced "stones-in-current" and "stones-out-of-current", which added an explicit substratum element to the descriptions of where riverine biota lived. The characteristics of all of these kinds of areas are implied through use of these familiar terms, and not well described.

Wadeson (1995) provided a detailed review of the terms used by ecologists and an excellent comparison of how geomorphologists and ecologists named the same channel-flow features. Both groups, for instance, were in agreement as to what constitutes a riffle, but ecologists used the terms pool, run, glide, flats and backwaters for a geomorphological pool. Wadeson suggested that this difference in perception of a pool

may be because geomorphologists recognise distinct physical features (the zone of deposition (bar; riffle) and the zone of scour (pool)), whilst ecologists also take into account the way water is flowing through the site. Wadeson concluded that both disciplines are somewhat "woolly" in their descriptions of these channel features, with much reliance on others' intuitive understanding of what was meant by a term.

2.3 Comparing geomorphological and ecological hierarchies

There is great similarity in scale between the geomorphological and ecological hierarchies described above, again reflecting the strong influence of physical attributes of rivers on their ecological characters. Bioregions or ecoregions are largely reflections of topographical and geological features of the landscape and so will have much in common with geomorphological regions. Biological zonation along rivers probably largely reflects geomorphological zonation (Table 2.2) as the latter dictates the availability and nature of wetted habitat for species, as well as such other physical features as levels of oxygenation and turbidity. Only at the finest scales of the hierarchy do geomorphologists need to produce new levels. The term hydraulic biotope has been suggested to describe the physical environment of assemblages of species. A further hierarchical level – perhaps termed hydraulic habitat – could describe the physical environment of individual species within the assemblage.

Table 2.2 **Broadly comparable levels, in terms of scale, of the geomorphological hierarchy of Rowntree & Wadeson (1999) and ecological hierarchies (King and Tharme 1994; Armitage *et al.* 1995; Eekhout *et al.* 1997).** The final level of the hierarchy is a new suggestion.

Geomorphology	Ecology
Catchment groups	Bioregion, ecoregion
Segment, zone	Biological zone, sub-region
Reach	Macrohabitat
Morphological unit	Mesohabitat
Hydraulic biotope	Assemblage-specific biotope
? Hydraulic habitat	Species-specific habitat

There is a compelling attraction in the concept of organising biological data and understanding, using such a scale-based hierarchy. But similarities in the hierarchies undoubtedly extend beyond those of scale. Although ecologists were already using a scale-based hierarchy, adding the geomorphological perspective somehow strengthens and structures biological thinking so that new ideas develop and new fields of study become possible. The ecological significance of different kinds of channel shape becomes more apparent, and the impacts of anthropogenic disturbance are more easily and accurately described. The reasons for wishing for these new understandings have already been mentioned (Chapter 1). The need remains to test the extent to which the geomorphological hierarchy can act as a surrogate to the ecological one (Section 2.4). Ecologically, the lowest level of the hierarchy is the instream physical habitat. This is now reviewed in more detail.

2.4 Physical and hydraulic habitat

In the last two decades there has been increasing collaboration between ecologists and geomorphologists, reflecting a growing international demand for more specific descriptions of physical instream habitat. Much of the earlier development centred around descriptions at what might be called the microhabitat scale ($10^{-1} - 10^{0}$ m), but larger scales were also recognised as important.

For example, within the Instream Flow Incremental Methodology (IFIM) (Bovee 1982), *macrohabitat* is described by those variables that have much the same value over some considerable length of river (i.e. several to many kilometres), such as discharge, morphological character, temperature and water chemistry. The character of the macrohabitat reflects changing macro-conditions, and thus biological zonation patterns, along the length of the river. *Microhabitat* is described by those variables that vary within a study site, such as substratum type, hydraulic characteristics and refuge value. The character of the microhabitat thus reflects the mosaic of micro-conditions, and so biological distribution patterns, at any one place on a river.

Others have simply used the terms habitat and biotope. If *habitat* is seen as the biotic and abiotic environment of a species (Macan 1963), then *biotope* has become recognised as the biotic and abiotic environment of a community or species assemblage. Tharme & King (1998), for instance, recognise the biotope as describing the biological, chemical and physical attributes of the environment of a biotic community. Following from that, Rowntree & Wadeson (1999) and Newson *et al.* (1998) recognise the hydraulic biotope as excluding the biological, chemical and thermal influences, and concentrating on the flow-related aspects of living space. Wadeson (1995) describes hydraulic biotopes as spatially distinct instream flow environments characterised by specific hydraulic attributes that provide the abiotic environment in which species assemblages or communities live. This approach recognises that the boundaries of the hydraulic biotope are defined not by the biota but simply by physical aspects, and so there is no direct confirmation of their ecological relevance.

Newson *et al.* (1998) view Wadeson's approach as a "top-down" one, whereby biotic use of an area is inferred from a knowledge of its physical conditions. A potentially complementary, "bottom-up" approach (Harper *et al.* 1997) uses knowledge of the biotic distributions to identify *functional habitats*, which then act in the opposite way to Wadeson's hydraulic biotopes by inferring patterns of instream conditions. The *mesohabitats* of Armitage *et al.* (1995) appear to be a combination of these, consisting of "visually distinct" areas of different substrata and instream vegetation, each supporting a distinctive assemblage of invertebrate species. Harper *et al.* also recognise *potential habitat* as that which is actually available, as opposed to functional habitat, which is that used by a species. Newson *et al.* (1998) point out that we are beginning to understand the links between physically-derived hydraulic habitats and biologically-derived functional habitats, but it is not yet possible to connect each of the former to the latter.

2.4.1 Describing physical habitat with cross-sections

Whatever the terms used, description of local hydraulic conditions within a river, that is, the physical environment available for habitation, has traditionally been done through data gleaned from surveyed cross-sections of the river. The best known application is through the IFIM (Bovee 1982), whereby sites are

selected along the river that are deemed representative of longer river reaches. Cross-sections are then placed within each site to describe typical and critical physical habitat for selected target species, whilst additional ones are placed at selected hydraulic features, in order to meet the input requirements for the hydraulic-habitat model PHABSIM (Physical HABitat SIMulation, Bovee 1982). Each point surveyed along the cross-sections becomes the centre of a "cell" that extends half-way along the cross-section to each adjacent surveyed point, and some chosen distance upstream and downstream toward each adjacent cross-section. The study site thus consists of a grid of "cells", for each of which the hydraulic conditions can be simulated separately, to show how each changes over a range of discharges. These changing conditions can be linked to collected data on the physical conditions in which the selected species are most often found, measuring the same variables as used within PHABSIM, to reveal how changes in discharge affect their habitats.

One of the problems many ecologists encountered with this approach is that once field-collected data on physical conditions are entered into the model, intuitive understanding of the data and the river is obscured. The model's output is precise and simple, but not necessarily sympathetic to the ecologist's "feel" for the river ecosystem. Nevertheless, most authors continue to report a cross-section approach to describing hydraulic habitat (e.g. Nestler *et al.* 1996), as this is undoubtedly an informative and cost-effective approach. Information is inevitably lost at this scale, however. For instance, Padmore (1997) reports that cross-section data typically under-represent marginal deadwaters and chutes, and fail to describe areas of slower flow among faster ones. Such shortcomings of cross-section data may be countered to some extent by the use of cross-section derived digital depth maps (GIS) to model changing hydraulic and sediment conditions. These provide greater spatial detail of flow-related changes at the studied site (Semmekrot *et al.* 1996), and also allow limited appreciation of the wider context of the river within its landscape. However, Semmekrot *et al.*'s cross-sections were 50 m apart, and so much finer detail would have remained uncaptured.

This is of concern because there has been increasing recognition of the importance of habitat patchiness, or physical heterogeneity, in freshwater ecosystems, and dissatisfaction with the inability to adequately describe this with cross-sectional data. The cells within the IFIM approach are described by broad extrapolation from relatively few surveyed points and do not reflect the complex mosaic of conditions present in rivers that are thought to be so important for maintaining efficient ecosystem functioning. For instance, Hildrew *et al.* (1994) point out that fine-scale, short-term biotic interactions, as well as fine-scale abiotic factors, influence longer term and spatially extensive patterns in benthic communities. Further, they state that understanding the spatio-temporal heterogeneity of physical features is the key to understanding the biological links between scales. They conclude that the two most important roles of this physical heterogeneity are to provide refugia and thus to buffer the effects of physical and chemical disturbance, and to modify the outcome of local species interactions. It follows that in order to understand the implications of management decisions on rivers, it is imperative to develop a better understanding of the physical-biological links in river ecosystems at these small scales.

2.4.2 Describing physical habitat by habitat mapping

A new field of science, called variously: hydraulic stream ecology, ecohydraulics, habitat hydraulics (Newson *et al.* 1998), or similar, has evolved to study the links between physical (mainly hydraulic)

conditions in rivers and biotic distributions, as well as to develop predictive capacity of how riverine biotas respond to changes in these physical conditions. Habitat mapping is one extremely useful way of studying those links.

The concept of habitat mapping is not new. Most ecologists unconsciously perform such a mapping exercise, at least in their minds, whenever they work at a study site. Focussing on describing the shape, physical characteristics and local hydraulics of river sites at a scale relevant to biological studies, mapping allows the ecologists to retain a hands-on feel for the river and collected data. There is, however, a need to develop mapping techniques both to take advantage of modern tools used in the terrestrial environment (Meixler *et al.* 1996) and to structure more clearly how physical habitat, particularly its patchiness, is described.

In South Africa, one development relevant to habitat mapping was a recent collaborative research effort between South African and English river scientists. This included a joint workshop on the hydraulics of physical biotopes, held in Citrusdal in 1995 (Rowntree 1996). One output from that workshop was the first tentative linkage of visually assessed flow types (Table 2.3) with visually assessed substratum size categories (Table 2.4), to produce on paper a matrix of hydraulic conditions then named "physical biotopes". The term hydraulic biotope evolved from this, to specify more clearly the hydraulic focus of the identified areas. This term then became recognised as the lowest level of Rowntree & Wadeson's (1999) geomorphological hierarchy, thereby triggering the research reported on here.

Table 2.3 Categories of visually distinct flow types. After Rowntree 1996; Padmore *et al.* 1996; Newson *et al.* 1998; King and Schael this project.

Flow Type	Definition
Free falling (FF)	Water falls vertically without obstruction
Cascade (CAS)	Water tumbling down a stepped series of boulders, large cobble or bedrock
Boil (BOIL)	Water forming bubbles, as in rapidly boiling water; usually below a waterfall or strong chute
Chute (CH)	Water forced between two rocks, usually large cobble or boulders; flowing fast with the fall too low to be considered free falling.
Stream (STR)	Water flowing rapidly in a smooth sheet of water; similar to a chute but not forced between two bed elements
Broken standing waves (BSW)	Standing waves present which break at the crest (white water)
Undular standing waves (USW)	Standing waves form at the surface but there is no broken water
Fast riffle flow (FRF)	Very shallow, fast, flickering flow, still covering most of the substrata
Rippled surface (RS)	The water surface has regular smooth disturbances which form low transverse ripples across the direction of flow
Slow riffle flow (SRF)	Very shallow, slower, flickering flow, still covering most of the substrata
Smooth boundary turbulent (SBT)	The water surface remains smooth; medium to slow streaming flow takes place throughout the water profile; turbulence can be seen as the upward movement of fine suspended particles
Trickle (TR)	Small, slow, shallow flow; when occurring with small or large cobbles, flow is between bed elements with few if any submerged
Barely perceptible flow (BPF)	Smooth surface flow; only perceptible through the movement of floating objects
No flow (NF)	No water movement

Table 2.4 Categories of substrata.

Category	Size Range (mm)	Guide Line	ϕ
Silt (SI)	< 0.063	Fines and mud	6.5
Sand (SA)	0.063 - 2	Coarse grit	2.0
Small Gravel (SG)	2 – 16	finger nail	-2.0
Large Gravel (LG)	16 – 64	middle joint of finger	-4.5
		length of small finger	
Small Cobble (SC)	64 – 128	wrist to halfway along finger	-6.5
Large Cobble (LC)	128 – 256	inside elbow to wrist	-7.5
Boulder (B)	> 256	armpit to wrists	-9.0
		ground to waist	
		length of tall person	
		> length of tall person	
Bedrock (BR)		slabs of rock	-9.5

Since then and in close collaboration, the English and South African geomorphologists have followed their lines of investigation on hydraulic biotopes and other aspects of the two hierarchies (Newson *et al.* (1998); Rowntree & Wadeson 1999), and the ecologists theirs. The geomorphological perspective is at the mesohabitat scale, and with an understanding *at that scale* of the ecological relevance of their units (Grundy 1997). This scale may be appropriate for most fish studies.

An ecological perspective of all scale levels is reflected in this project. Biotic distributions were used, at each level of the hierarchy, to define what is perceived to be different *lebensraum* (living space). The extent to which the geomorphological hierarchy reflects these differences was then assessed. Initially, the highest level of the hierarchy was addressed, by using the distribution of aquatic invertebrates in many rivers to define ecologically similar rivers and river zones. Then, the lowest level, or hydraulic biotopes, was addressed, using the concept of describing them by their substratum and flow characteristics. To do this, the reach-level scale at which these characteristics are mapped by geomorphologists was reduced in order to map substratum and flow at the microhabitat scale. Following this, faunal samples collected at the site revealed which combinations of flow type and substratum (or groups of combinations) actually supported different species assemblages. These combinations were identified as different hydraulic biotopes. With this smallest-scale level of the hierarchy better understood, the interim levels were addressed as follows.

- The distribution of hydraulic biotopes - and thus their species - in different morphological units was compared.
- The distribution of morphological units - and thus their hydraulic biotopes and species - within different reach types was compared.
- The effect on these distributions of changes in discharge was investigated.
- The effect of specific disturbances on the basic patterns of distributions was investigated.

2.5 Summary

There is a good match between the geomorphological and ecological hierarchies of scale recognised by river scientists. It seems possible that using this similarity, ecological studies of rivers could be guided by the geomorphological character of the rivers. If the ecological relevance of the geomorphological hierarchy could be defined, then the former could justifiably be used as a surrogate for the latter in many kinds of ecological studies. It would provide a relatively easy way of identifying similar river sites or sampling points, and could also play a vital role in organising the collection and interpretation of biological data.

For this concept to develop, it is vital to increase understanding of the ecological relevance of:

- the geomorphological hierarchy of scales, recognising that each level from substratum particle to catchment is nested in higher levels, and that each level is constrained by the dictates of higher levels;
- the within-site complex mosaic of physical conditions, recognising that biological interactions and refugia operate at this scale.

3. AIMS AND TASKS

3.1 Overview

The overall aim of the research completed in this project was to assess the ecological relevance of Rowntree & Wadeson's (1999) geomorphological hierarchy, and the potential use of this hierarchy as a guiding structure for ecological studies.

Some ground rules applied to the project as a whole. The research would address the instream, or aquatic, component of river ecosystems. It would be confined to mountain and foothill zones of perennial Western Cape rivers. This would allow a maximum number of rivers to be visited during the fieldwork, and would focus research on the least-disturbed parts of rivers in order to minimise "noise" in the data sets. Aquatic invertebrates would be used to provide the biological input to the study. At each river site chosen, a habitat map of flow types and substrata would be drawn of the complete site, and invertebrate samples taken with accompanying physical and chemical data.

All fieldwork would be done at summer low flow, when flow and other physical conditions in the rivers are most stable, and thus the rivers most validly comparable. A range of complementary catchment, physical and chemical data would be collected at each site, for diagnostic purposes (Section 4.2). The sensitivity of the ranges of what was revealed as "natural" for all components (physical and biological) would be assessed by comparison with similar sampling and mapping in selected rivers with known disturbances.

Individual aims within the project are given in Sections 3.2 – 3.7. Each is explained, together with the tasks done to achieve the aim.

3.2 Testing the highest (first, second and third) levels of the geomorphological hierarchy: catchments, segments and zones.

The aim was to record the species assemblage of aquatic invertebrates in a range of Western Cape, biologically defined, mountain and foothill river zones. These species lists would be used to assess the extent to which biologically similar rivers and river zones are reflected by geomorphologically similar catchments and zones. Because the same data would be used to test other levels of the hierarchy, the invertebrates would be collected from a range of flow types and substrata, guided by detailed site maps.

An initial assumption in the study was that the sites would primarily group abiotically across catchments into mountain and foothill sites. A secondary objective of this part of the study was therefore to describe the proportions of different flow types and substrata per site, and to compare these with the site's position within the catchment. Mountain zones, for instance, might have a greater proportion of boulders than do foothill zones, and both, in an undisturbed condition, would probably have very low proportions of sand. It was suggested that the proportions could lie within specific ranges, which could be used to aid identification of a "Physical Reference Condition" for such river zones.

Based on historical data from Western Cape rivers (e.g. Harrison & Elsworth 1958; King 1981) it was further assumed that the species assemblages from each site would also group across catchments into mountain and foothill zones. It was therefore suggested that these assemblages could be used to derive a "Biological Reference Condition" for such zones.

Tasks completed:

Eighteen single sites on least-disturbed rivers were mapped and sampled once during the 1996/97 summer low-flow period. At each river, twelve invertebrate samples were taken from as wide a variety of flow-substratum combinations as possible, in order to maximise the number of species collected. No replicate samples were taken. The collecting point for each sample was marked on the habitat maps.

3.3 Testing the lowest (sixth) level of the geomorphological hierarchy: hydraulic biotopes.

The aim was to record which combinations of substrata and flow types supported the same species assemblage of invertebrates. These flow-substratum combinations (or groups of combinations) would be recognised as biologically-derived hydraulic biotopes. The results would be used to assess the extent to which geomorphologically defined hydraulic biotopes matched the biologically-derived ones.

Note that whereas in the geomorphological hierarchy, hydraulic biotopes are identified simply on specific combinations of flow and substrata, here the physical habitat would be disaggregated down to its two basic hydraulic characteristics (flow and substratum) and the biota used to define which combinations of these are perceived as different.

Tasks completed:

Fifty-two invertebrate samples were collected in groups of three replicates from a number of different substratum-flow combinations. They were taken from a range of morphological units at one site on one occasion. Additionally, data on the species from different flow-substratum combinations were available from all of the previous 18 study sites (Section 3.3).

3.4 Testing the fifth (second lowest) level of the geomorphological hierarchy: morphological units.

The aim was to record the distribution of morphological units in each of the studied sites, and how this differs between sites and is linked to position within the catchment. Following this, the 12 invertebrate samples from each Western Cape site (Section 3.2), and the 52 invertebrate samples from the intensive-study site (Section 3.3) would be used to assess the extent to which faunal distributions and species proportions are explained by their presence in different geomorphologically described morphological units. Different sites could have different proportions of morphological units, which could influence the hydraulic biotopes and thus species present.

Tasks completed:

Morphological units were mapped at all study sites by Prof. K. Rowntree (Rhodes University) and the project team. The faunal samples used were those collected for the first two aims (Sections 3.2 and 3.3).

3.5 Testing the fourth (third lowest) level of the geomorphological hierarchy: reaches.

The aim was to record distributions of substrata, flow types, morphological units and invertebrates in two adjacent geomorphologically-derived reach types in one zone in one river. Invertebrate samples taken from specific flow and substrata combinations from each of the two sites would be used to assess the extent to which faunal distributions are explained by their presence in different reach types.

Adjacent sites within different reach types could have different combinations or proportions of morphological units. As a result, the sites could differ in the proportions of their hydraulic biotopes, and this could influence the distributions and abundances of invertebrate species. If the sites are within the same biological zone, their overall faunal assemblages could be similar. However, because the sites are in different reach types, there could be differences in the proportions and distributions of species.

Tasks completed:
Single sites in two adjacent reach types in one "least disturbed" river were mapped and sampled (linked to Section 3.7).

3.6 Assessing how anthropogenic disturbances may alter the distributions of physical habitat and species

The aim was to collect the same kinds of abiotic and biotic data from a number of rivers with specific disturbances. These could range from bulldozing of the river bed, to emptying of nutrient-rich effluents into the river. It was suggested that anthropogenic disturbances to a river would alter the distribution and proportions of hydraulic biotopes, species assemblages, and possibly even morphological units away from natural recorded ranges. Physical disturbance would possibly result in persistence of the original species assemblage of invertebrates, but in some depauperate form, with few new species. Chemical disturbance, on the other hand, would possibly leave the basic morphological structure intact, but change the overall chemical environment. It could, however, also change physical microhabitat conditions by, for instance, covering rocky bed elements with algae. Thus, in several ways and depending on its severity, chemical disturbance could change the faunal assemblage, with a significant loss of original species and addition of new pollution-tolerant species.

Some other disturbances, such as upstream dams and infestation by alien trees, could affect the river ecosystem in many ways. Flow and temperature regimes could change in several ways, banks could become destabilised and affect sediment transport and the morphological configuration of the channel, and so on. Within this project it would not be possible to investigate a wide array of disturbances. Rather, the aim was to ascertain if the effects on the rivers of single different disturbances could be distinguished.

Tasks completed:
Eight rivers with specific disturbances were mapped and sampled once in the 1997/98 summer low-flow season. The same approach was used as described in Section 3.2.

3.7 Assessing the temporal stability of hydraulic biotopes

The aim was to record changes in the distributions of flow types and invertebrates with discharge, and use these data to assess the temporal stability of hydraulic biotopes and their biotas.

Changes in discharge should result in changes in the distribution and abundance of substratum-flow combinations. It was thought that up to a point, these changes would not be reflected in changes in the distribution of invertebrate species. However, discharge should eventually increase (or decrease) to a point where invertebrate distribution patterns are significantly affected.

Tasks completed:

Two adjacent reach types in one biological zone were mapped and sampled at four different discharges.

4. METHODS

4.1 Overview

The overall plan was to map physical habitats, collect invertebrate samples and supporting physical and chemical data, from approximately 20 least-disturbed rivers in the first summer, and from about five disturbed rivers in the second summer. Choice of river sites was to be guided by an early segment analysis and reach analysis by Prof. Kate Rowntree's team. Unfortunately, the two projects could not start in the same year, and so river sites for this project had to be chosen independent of these preliminary geomorphological analyses.

An alternative approach was adopted whereby sites were chosen using topographical maps of many catchments within the Western Cape, and local specialist knowledge, to tentatively identify least-disturbed headwater streams, and potential sites within those headwaters. In an *a priori* assessment, each site was allocated to either a mountain or a foothill zone, as per the biologically-defined slope and altitude limits of each zone (Brown *et al.* 1996). To do this, the overall slope of each site was calculated from 1:50 000 topographical maps, using the two 20 m contour lines bracketing each site. Physical, chemical and biological data collected at each site (Chapters 5-9) were then used in several different permutations, as detailed below (Section 4.6), to test the ecological relevance of the geomorphological hierarchy (Chapters 10-14).

4.2 Site information

Before the site visit, a site information sheet was partially completed from maps and other information:

- identity number of the relevant1:50 000 topographic map;
- name of the main river in the catchment;
- name of the river on which the site is situated;
- latitude and longitude of the site;
- property on which the site is situated;
- owner of the property, contact telephone number and address, and arrangements for access;
- distance of the site from the source of the river;
- altitude contours bracketing the site and approximate altitude of the site;
- stream order, using the system of Strahler (1952);
- presence of upstream inpoundments.

At the site, information on the site information sheet was checked for accuracy and any missing details completed. The field data sheet was also filled in:

- site access route and final access details;
- geomorphological information, modified from the site data sheet of Rowntree & Wadeson (1999):
  - details of upstream catchment condition, upstream disturbance and land-use;
  - details of disturbance within the reach containing the site;

    - geomorphological classification of this reach;
    - geomorphological features of the channel, such as sinuosity, single or multiple thread, mobility or entrenchment of the channel, presence of a floodplain;
    - information on bed condition, in terms of packing of substrata and aggradation;
    - information on erosion and shape of each bank;
- estimate of the proportion of alien and native riparian tree species in the reach;
- frequency and distribution of trees, shrubs, grasses, reeds and herbs along the left and right banks of both the active and macro-channels recorded;
- width of active channel.

Ecological notes of relevant features were recorded for diagnostic purposes, as follows:

- air temperature, taken in the shade on arrival at the site;
- estimate of percent cloud cover;
- estimate of canopy cover from riparian trees: percent open;
- estimate of macrophyte cover within the water and at water's edge;
- estimate of algal cover, within the water;
- estimate of moss cover, within the water and at water's edge;
- estimate of the percent of wetted bed covered by CPOM (coarse particulate organic matter > 1mm particle size);
- estimate of the percent of wetted bed covered by FPOM (fine particulate organic matter < 1mm particle size);
- local site slope, using an Abney level.

A photographic record was made at each site. From four to about 20 photographs were taken per site, of upstream and downstream views of the site, selected biotopes and any features of special interest. The slide collection has been catalogued (Appendix 4.1).

4.3 Physical conditions

4.3.1 Mapping

Sites were mapped over a length of 7-10 times their width, in order to encompass all likely physical habitats in that stretch of river (Bovee 1982). Mapping was done in the field of the distributions of different size substrata, different flow types, and later, by Prof. Rowntree, of different morphological units.

A grid of tapes delineated each site. One 100 m tape was laid along the river in a straight line, to delineate the length of the site; the tape was re-laid further on if the site was more than 100 m long. If possible, this tape was laid out along one bank, but if the channel was sinuous, the tape might at some points lay across open water or even the opposite bank. The guiding principle was that the tape should be straight. At intervals of 5 m or 10 m, depending on site length, 50 m tapes were than laid across the long tape from bank

to bank. To facilitate the mapping exercise, the long tape and cross tape always crossed at a whole meter mark.

Guided by the tapes, the dimensions and sinuosity of the site were laid out on graph paper, choosing a scale that allowed the width of the river to fit into the width of the page. As the same scale was used for both axes, the complete study site usually stretched over three to five sheets of paper laid end to end. Distribution of the different sized substrata (Table 2.4) was then mapped onto the sheets, with an ordinary lead pencil used to depict dry areas and a blue pencil to demarcate wet areas. In this way, the dimensions of the wetted channel showed clearly. Other useful markers, such as notable trees or wood debris, were also marked on the map in green and brown. The two edges of the macro-channel were mapped, thereby showing the extreme edge of the flood channel, as were the tree lines, which are believed to indicate the water level reached by floods with a return period of about 2 – 5 years.

A sheet of tracing paper was then stapled over each substratum map, and the wetted edge drawn in, using a red pencil. The distribution of different flow types (Table 2.3) was delineated within the wetted area.

The complete mapping exercise took about a half to one day per site, depending on site length and bed complexity, with two people setting up tape measures and one person mapping. Before leaving the river, each sheet was labelled with the river, site name and code, and its number in the series of maps for that site.

Based on Rowntree and Wadeson's (1999) descriptions, preliminary estimates of the types and numbers of morphological units were made at the time of the original site visits. These were re-assessed by Prof. Rowntree on later visits to all sites for the purpose of mapping morphological units.

4.3.2 Channel cross sections and local slope

As the cross-section shape of the channels, and the position of water in the channel, provide important extra diagnostic information required by the geomorphologists, this information was recorded for each site. Time constraints did not permit formal surveying of the channel at each site using a theodolite or similar equipment. Instead, a tape was strung from edge to edge of the macrochannel, tightened, and used to guide the positioning of measuring points at half-meter intervals. At each point, the cross-channel chainage was recorded, along with the vertical elevation (using a marked pole), the substratum composition, the presence of riparian trees or other vegetation, leaf litter and instream or overhead vegetal cover, and the water's edge.

4.3.3 Discharge

Along the same cross-section, measurements were taken for the calculation of discharge. At 20 or more points along the cross-section, the following were recorded:

- water depth;
- mean water column velocity at 0.6 depth, using a Marsh-McBirney FLO-MATE Model 2000 portable electromagnetic flow meter with top-setting wading rod. Discharge was calculated by the velocity-area method as described in King & Tharme (1994).

4.3.4 Local hydraulics

For each invertebrate sample collected, the following data on local hydraulics were collected at one to five points within the sample area:

- the flow type;
- the dominant substratum type;
- the sub-dominant substratum type;
- the degree of embeddedness of coarse substratum particles in fines, on a scale of 1 to 5:
  - 1 no embeddedness;
  - 2 low;
  - 3 moderate;
  - 4 high;
  - 5 coarse particles barely showing;
- the water depth;
- the velocity of the current; this was always recorded at near-bed and 0.6 total depth, but additionally in deep water (> approximately 50 cm), at 0.2 and 0.8 total depths, and mean velocity calculated as described by King & Tharme (1994).

In the laboratory, hydraulic indices such as Froude numbers (Gordon *et al.* 1992) were computed from the sample-linked hydraulic data.

4.3.5 Bed heterogeneity

A device was created for measuring physical heterogeneity of the surface of the river bed. This was modelled on those used by King & Tharme (1994) and Wadeson (1995). Fifty metal rods, approximately 50 cm long, were positioned in parallel within a clamp, so that each was individually clamped. The clamp was held horizontally over the sampled area, and then the rods released so that they dropped onto the underlying river bed. They were then re-clamped, lifted to the bank and the line described by the bottom edges of the rods traced onto a long sheet of paper. This line described the surface heterogeneity of the riverbed at the sampled point.

The profiler was used during the intensive survey of 52 samples (Section 3.3) and the reach and discharge investigations (Sections 3.5 and 3.7), as its application was too time-consuming for the general study. Two profiles were measured for each invertebrate sampling point: one perpendicular to the banks and one parallel to the banks. Initially, the sampling equipment for the invertebrates was placed in the area to be sampled. Then, the bed-profiler was placed over the area and the rods dropped to take the measurements. The sample net caught any animals dislodged by the bed-profiler, and collection of the invertebrate sample was completed immediately after the bed-profiler was removed. Each trace of the bed profile drawn from the rods was labelled in the field, and the lengths of each rod measured on the trace in the laboratory.

Interpretation of the results is dealt with in Chapter 13.

4.4 Water chemistry

The focus of the project was on physical-biological links, and a comprehensive programme of chemical analyses was not undertaken. However, the values of physico-chemical variables that could be measured on site with instruments were recorded as follows, at one place within each site from areas where water was moving:

- pH, using a *Crison* portable pH meter;
- conductivity, using a *Crison* 524 portable conductivity meter;
- colour, using a portable Hach colour meter;
- water temperature, using a *Refco* WM 150 digital thermometer.

4.5 Biological samples and allied environmental data

Invertebrate samples taken for most of the study were qualitative rather than quantitative, because of the very small area covered by some flow-substratum combinations (such as chutes between two boulders). Animal abundances were thus not comparable between samples, although proportions of different taxa were. This meant that the absolute densities of invertebrates per unit area of river bed could not be compared between sampling points and sampling sites, but the overall composition of assemblages could. The approximate areas from which these samples were taken are known, however, as each sampling point is delineated on its substratum-flow maps. In the study of reaches (Section 4.6.3) and discharge (Section 4.6.6), quantitative samples were taken which were directly comparable in terms of animal numbers.

Custom-made handnets were used for the qualitative collections, varying in size so that all kinds of flow-substrate combinations could be sampled, all with mesh size of 250 µm. The substratum within each sampling point was either kicked or scrubbed or a combination of both for approximately 1-2 minutes. For quantitative sampling, a 50 x 50 x 50 cm box sampler was used with a 250-µm mesh on the downstream collecting side and on the two adjacent sides. A 500-µm mesh was used on the upstream side, to allow fast flow into the sampler that would carry the animals disturbed from the bed downstream into the collecting net. The substratum within the box-sampler was scrubbed with a brush, and the bed thoroughly disturbed, to dislodge all animals.

Invertebrates from the qualitative faunal samples were initially analysed live in the field, by emptying each sample into a flat enamel tray and identifying the animals to at least family level. The samples were then fixed in 4% formalin in the field, for later preservation in the laboratory in 70% ethanol. In the laboratory, the entire sample was placed into a flat tray and gravel, wood and leaf debris were searched for animals and removed. An initial "macro-sort" for animals was then done for one hour. In this activity, as many animals as possible were picked out and placed in a series of vials. After one hour, an hour-long "micro-sort" by stereo microscope was completed of the remaining sample. If the sample contained few animals, then it was sorted in its entirety. If the sample was too large to sort in one hour, a sub-sample was sorted, the size of which was suitable for the imposed time limit. Sub-sampled animals were placed in different vials to those sorted in the "macro-sort", so that the final proportions of different taxa could be calculated.

Quantitative samples for the reach and discharge studies were processed slightly differently. They were fixed and preserved in the same way, but when sorting, the organic debris was kept for measurement of the amounts of coarse and fine particulate matter (CPOM and FPOM respectively). To do this, samples were carefully washed through 950-µm and 80-µm mesh sieves, the larger fraction being used for the macro-sort and the finer fraction for the micro-sort. The same time limits as above were used for each fraction. For sub-sampling, a specially designed box with 12 equal sized squares was used. The sample was poured into the box, which had sides that were higher than the internal divisions. The box was then covered and shaken up and down gently to allow the animals to mix and settle evenly in the grid of squares. An appropriate number of squares was then randomly selected as the sub-sample. The residual debris from the macro-sort and micro-sort were dried, weighed and burned in the muffle furnace. The ashes were re-weighed to determine the proportions of organic matter, such as leaves and flowers, and inorganic matter (sand and mud) within each sample.

In the laboratory, the invertebrates were identified to the lowest possible taxonomic level using a variety of taxonomic keys. Where confident identification using available keys could not be made to genus/species level, a morphological type, or "morph type", designation was given and a drawing for future reference was created. The use of morph types allowed consistency of identification within and between samples. Initial morph types were often given more definite genus/species designations as more information became available, or a check against another reference specimen was done. Prior arrangement had been made to have identifications confirmed by specialists. Alternatively, in some cases, arrangements had been made for specialists to identify all the specimens in their speciality group and then write co-authored papers with project staff on the physical habitats of the identified taxa. This latter arrangement was only partially successful, as in one case, specimens were lost in transit, and in other cases the specialists could not allocate the necessary time to the task (Table 8.1).

All specimens identified by project staff are preserved in 70% ethanol in taxon-specific vials for long-term storage. The vials have unique codings, which relate to a datasheet for a specific sampling point in a specific river. The vials are regularly curated until they can be handed over to the Albany Museum.

4.6 Data analyses

For each aim listed in Chapter 3, a different set of analyses was undertaken as outlined in Sections 4.6.2 - 4.6.6. Before this, the mapped information for each site was prepared for analysis as outlined in Section 4.6.1.

4.6.1 Analysis of mapped information, using GIS

The maps of the distributions of flow types, substrata and morphological units were digitised, using ArcInfo to create an individual coverage for each type of data. Related site information, such as the location of invertebrate sampling points, was also entered. ArcView was then used to manipulate the digitised covers, to provide graphic representation of the maps. The proportions, by area, of each category of flow type (Table 2.3), substratum (Table 2.4) and morphological unit were produced, as well as the proportions of different flow-substratum combinations, the proportions of different flow types per morphological unit, and so on. Analysis tables were created in ArcView and subsequently exported to a spreadsheet package for

further manipulation into percentages and proportions. Further ArcInfo manipulation was done by Prof. Rowntree's group at Rhodes University to create a new cover of flow/substratum combinations, and then calculate the three-way combination of flow/substratum proportions within individual morphological units.

The resulting data sets from the faunal samples, the physical measurements, and the GIS coverages, were used for a series of tests on the ecological significance of the geomorphological hierarchy, as detailed below.

4.6.2 Testing the ecological significance of geomorphological catchments, segments and zones

An analysis of all studied rivers (*Chapter 6*) provided a map-based overview of similar stretches of river in terms of rainfall, runoff, sediment production and transport, and vegetation and land-use.

The biological data were then used as follows.

- The 12 invertebrate samples from each undisturbed site were used to produce a "biological fingerprint" of that site.
- The extent to which the sites, in terms of these fingerprints, reflect the geomorphological analyses, was assessed.
- Conclusions were drawn about the extent to which a map-based analysis can be used to locate biologically similar river stretches.
- The role of water chemistry in the non-grouping of sites from similar segments was assessed to the extent possible.

4.6.3 Testing the ecological significance of geomorphological reaches

The samples and maps from the two adjacent reach types were assessed in terms of the distribution of morphological units, hydraulic biotopes (Section 4.6.5) and invertebrate species assemblages. Conclusions were drawn about the biological validity of a map-based reach analysis, through describing how different reach types in the same biological zone of a river influenced invertebrate distributions. This could have implications in, for instance, the selection of biomonitoring sites.

4.6.4 Testing the ecological significance of morphological units

GIS data sets were used to ascertain the differences in distributions and proportions of hydraulic biotopes and invertebrate species assemblages between morphological units. Similarities between rivers, and trends linked to position on the long profile, were sought. Conclusions were drawn about the way in which different morphological units in the same site influence the suite of hydraulic biotopes present and thus invertebrate distributions. This could have implications in, for instance, the selection of sample points within a biomonitoring site.

4.6.5 Testing the ecological significance of geomorphologically-derived hydraulic biotopes (1)

All the faunal samples were analysed to ascertain which combinations of flow and substrata were different in terms of invertebrate assemblages. Conclusions were drawn about whether or not hydraulic biotopes, as

reflected in the substrata and flow-type definitions, are biologically relevant, or if some coarser or finer scale should be sought.

4.6.6 Testing the ecological significance of gemorphologically-derived hydraulic biotopes (2)

Hydraulic biotopes are, spatially and temporally, the most unstable component of the geomorphological hierarchy. To investigate the effect of changing discharge on hydraulic biotopes, the sets of samples taken from the two adjacent reach types over a range of discharges were analysed to ascertain how hydraulic conditions change with discharge, and how this is linked to invertebrate distributions. Tentative conclusions were drawn about the extent to which hydraulic biotopes are biologically relevant over a range of discharges.

5. INTRODUCTION TO THE RESULTS SECTION

5.1 Purpose and choice of study sites

It was planned to visit between 20 and 30 river sites during the course of the study. Most of the sites, visited in the first summer of field work, would be relatively undisturbed. These would be used to describe the natural range of physical conditions and the character and distribution of the invertebrate biota of Western Cape headwater streams. The remainder, visited in the second summer, would be sites with specific single disturbances, to be used to assess how much and in what way these disturbances altered the physical conditions and biotic characteristics compared to the least-disturbed sites.

Not all the rivers were known to the project staff, and many were chosen after consultations with other local river scientists (Figure 5.1). Site visits revealed that some of the "natural" sites were disturbed. After these inspections, a final *a priori* decision was made as to which sites were to be treated as least-disturbed and which disturbed (Table 5.1). In total, 18 least-disturbed sites were recognised, and ten disturbed sites.

5.2 Catchment conditions

General records of catchment conditions were completed for each site. Much of this information was not needed directly for the project, but is routinely collected for any river study and often provides good diagnostic information with which to explain results. Some of the information was collected specifically to contribute to regional geomorphological records being compiled by Prof. Rowntree. An example of the catchment data is given in Table 5.2, with the full data set in the database.

Routine data collected were those dealing with catchment location, upstream and surrounding catchment condition and land use and relevant map numbers. Geomorphological data collected were those related to channel shape and features, bed and bank condition, reach classification and reach disturbance.

5.3 Site conditions

General records related to the study sites were also completed (Table 5.3), as well as data on some relatively stable aspects of the sites. General data recorded included the site code and, from 1:50 000 topographical maps, the location of the river along the long profile. Project-related data recorded included altitude and map gradient, from the same topographic maps, and site gradient measured on site with an Abney level.

Climatic conditions at the time of the site visit and ecological notes on site condition are dealt with in Chapter 7.

Figure 5.1 Location of 29 study sites in the Western Cape. For river names see Table 5.1.

Table 5.1. **River sites mapped and sampled between November 1996 and February 1998**. The sites are numbered starting with the most northerly and moving south. The biological zone was determined from 1:50 000 maps prior to visiting each site, using the altitude and gradient guidelines of Brown *et al.* (1996). The contribution to particular analysis goals is listed under "Purpose". The Eerste River was sampled at two sites and at several different times; only dates where invertebrates were sampled are listed below.

River #	River Name	Zone	Date	Latitude	Longitude	Purpose
1	Jan Dissels	Foothill	6-Mar-97	32 13 38	18 59 24	Reference Condition
2	Rondegat	Foothill	5-Mar-97	32 22 08	19 03 06	Reference Condition
3	Noordhoek	Foothill	4-Feb-98	32 40 13	19 04 09	Disturbance: bulldozing
4	Middeldeur	Foothill	5-Feb-98	32 41 06	19 16 48	Disturbance: agriculture
5	Grootrivier	Foothill	4-Mar-97	32 36 39	19 24 35	Disturbance: agriculture/ road
6	Steenbok	Mountain	26-Feb-97	33 32 57	19 08 37	Reference Condition
7	Wolwekloof	Mountain	12-Mar-97	33 33 45	19 07 45	Reference Condition
8	Wit	Foothill	25-Feb-97	33 39 05	19 06 29	Reference Condition
9	Molenaars	Foothill	22-Jan-97	33 43 50	19 07 00	Reference Condition
10	Elands	Mountain	13-Feb-97	33 44 02	19 06 58	Reference Condition
11	Elandspad	Mountain	24-Jan-97	33 45 39	19 10 09	Reference Condition
12	Holsloot	Foothill	30-Jan-98	33 50 09	19 15 11	Disturbance: Dam
13	Du Toits	Mountain	18-Mar-97	33 56 13	19 10 10	Reference Condition
14	Bakkerskloof	Mountain	20-Feb-97	33 49 13	19 02 48	Reference Condition
15	Zachariashoek	Mountain	21-Feb-97	33 49 39	19 02 13	Reference Condition
16	Wemmershoek	Foothill	22-Jan-98	33 51 11	19 02 29	Disturbance: Dam
17	Berg	Foothill	19-Feb-97	33 58 24	19 04 38	Reference Condition
18	Eerste 1	Mountain	15-Jan-97	33 59 37	18 58 37	Reference Condition
			1-3 Apr-97			Testing Hydraulic Biotopes
			18-19 Sep-97			First reach and site:
			10-11 Oct-97 29-30 Oct-97 28-29 Nov-97			Reach Comparison and Variable Discharge Study
19	Langrivier	Mountain	17-Jan-97	33 59 16	18 58 02	Reference Condition
20	Swartboskloof	Mountain	13-Jan-97	33 59 18	18 57 25	Reference Condition
21	Eerste 2	Mountain	15-17 Sep-97	33 59 20	18 58 00	Second reach and site:
			8-9 Oct-97 28-29 Oct-97 30-Nov-97			Reach Comparison and Variable Discharge Study
22	Lourens	Foothill	20-Jan-98	34 04 00	18 54 01	Disturbance: agriculture
23	Palmiet	Mountain	12-Feb-98	34 06 20	19 03 17	Disturbance: dam/ weir
24	Dwars	Mountain	3-Feb-97	34 17 09	18 56 11	Reference Condition
25	Davidskraal	Foothill	29-Jan-97	34 20 50	18 55 17	Disturbance: weir/ dam/ retaining walls
26	Window	Mountain	20-Nov-96	33 59 06	18 26 09	Disturbance: botanical garden
27	Newlands	Mountain	13-Dec-96	34 58 03	18 26 40	Reference Condition
28	Cecilia Ravine	Mountain	8-Jan-98	33 59 48	18 25 11	Disturbance: alien trees
29	Disa	Mountain	10-Dec-96 15-Jan-98	34 00 25	18 23 31	Reference Condition (first set of samples spoiled)

Table 5.2 **An example of the catchment information collected and recorded on the Field and Site data sheets.** Field data were determined in the field by project staff at the time of initial mapping and sampling, and re-assessed in follow-up visits with Prof. K. Rowntree.

Routine Data Collection		Observation
CATCHMENT		Eerste
RIVER		Langrivier
SITE CODE		E19#
1:50 000 MAP		Stellenbosch 3318DD
UPSTREAM CATCHMENT		
	Condition:	widespread natural veld and forest; forest predominantly riparian
	Land Use:	the following were present but had a low degree of impact: roads, bridges and weirs
	Upstream impoundment:	No
	Alien vegetation:	None
	Other:	Moderate level of large woody debris
PROPERTY/ACCESS		SAFCOL and Cape Nature Conservation, controlled access at gate.

Geomorphological Data Collection		Observation
CHANNEL FEATURES		
	Valley floor:	Absent
	Lateral mobility:	Moderately confined
	Channel pattern:	Single thread, low sinuosity
REACH CLASSIFICATION		
	Channel type:	Alluvial
	Reach type:	Step- pool
	Morphological Units (#):	Step (8), pool (5), riffle (2), rapid (1), plane - bed (1)
REACH DISTURBANCE		None
BED CONDITION		No packing
BANK		
	Erosion:	active and macro-channel, left and right banks as a whole are 100 – 90% stable with little to no active basal erosion and no subaerial erosion. Between the 35 – 40 m points in the study site there is some basal erosion making that portion of the bank 90 – 70% stable.
	Shape:	Overall shape on both the left and right banks is convex. Between the 35 – 40 m points the left bank is vertical (Morphological Units step and pool).

Table 5.3 **River sites mapped and sampled between November 1996 and February 1998, listing site codes, and associated site data.** Site codes are derived as follows: First letter = catchment: Olifants (O); Berg (B); Eerste (E); Molenaars (M); Breede (R); Table Mountain (T); Palmiet (P); Davidskraal (D); Lourens (L). Next two numbers are the river number. Last symbol denotes mountain zone (#) or foothill zone ($). Site gradient data were not collected at two sites (-).

River #	River Name	Site Code	Stream Order	Source Distance (km)	Altitude (m asl)	Catchment Area (km^2)	Map Gradient	Site Gradient	Channel Width (m)	Mapped Site (m)	Discharge ($m^3 s^{-1}$)
1	Jan Dissels	O01$	5	22.5	190		0.005	0.037	13.0	56	0.266
2	Rondegat	O02$	4	10.0	470		0.026	0.030	6.0	84	0.122
3	Noordhoek	O03$	5	14.0	230		0.020	0.018	16.0	84	0.151
4	Middeldeur	O04$	5	21.5	660		0.011	0.026	11.0	84	0.302
5	Grootrivier	O05$	5	35.0	500		0.002	0.009	10.0	84	0.283
6	Steenbok	R06#	3	5.0	290		0.060	0.061	4.0	42	0.009
7	Wolwekloof	R07#	3	2.5	350	9	0.100	0.039	10.0	84	0.020
8	Wit	R08$	4	5.5	700		0.013	0.015	10.0	84	0.011
9	Molenaars	M09$	5	6.3	430	84	0.010	0.016	35.0	100	0.587
10	Elands	M10#	4	16.0	460	61	0.020	0.035	20.0	56	0.185
11	Elandspad	M11#	3	6.0	860		0.020	0.072	6.0	42	0.043
12	Holsloot	R12#	3	10.0	440		0.020	0.021	10.0	42	0.326
13	Du Toits	R13#	3	7.5	400	21	0.020	0.017	9.0	84	0.162
14	Bakkerskloof	B14#	2	2.8	320		0.100	0.090	6.0	42	0.002
15	Zachariashoek	B15#	3	2.3	310		0.100	0.087	4.0	42	0.003
16	Wemmershoek	B16$	3	5.3	190		0.010	0.011	16.0	84	0.142
17	Berg	B17$	6	8.8	260	38	0.002	0.026	20.0	84	0.069
18	Eerste 1	E18#	3	2.3	380	10	0.030	0.058	12.0	50	0.134
19	Langrivier	E19#	3	3.3	350		0.080	-	8.0	40	0.071
20	Swartboskloof	E20#	3	2.3	340		0.080	-	7.5	50	0.109
22	Lourens	L22#	3	13.5	110		0.020	0.017	9.0	84	0.247
23	Palmiet	P23#	3	10.0	400		0.022	0.045	3.0	42	0.356
24	Dwars	P24#	4	5.3	80		0.040	0.032	10.0	80	0.052
25	Davidskraal	D25$	2	3.5	70		0.010	0.030	8.0	42	0.027
26	Window	T26#	2	1.8	120		0.087	0.123	4.0	40	0.012
27	Newlands	T27#	2	2.0	180		0.060	0.151	8.5	40	0.012
28	Cecilia Ravine	T28#	2	1.0	270		0.220	0.169	2.0	28	0.002
29	Disa	T29#	2	3.3	100		0.080	0.060	3.0	30	0.006

6. GEOMORPHOLOGICAL CLASSIFICATION OF STUDY SITES

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6.1 Introduction

Geomorphological processes that sculpture the channel determine the physical structure of a river ecosystem. They determine the channel type - whether it is bedrock or alluvium – the channel shape and the stability of the bed and banks, that is, the channel geomorphology. The channel geomorphology in turn determines the substratum conditions for the stream fauna and flora and the hydraulic conditions for any given discharge. Geomorphology therefore provides an appropriate basis of classification for describing the physical habitat of aquatic ecosystems. The classification system reported on in this chapter has been developed through application in a number of South African water management projects, including the estimation of the Ecological Reserve, biomonitoring under the River Health Programme, and Environmental Impact Assessments (Rowntree pers. comm.).

The river cannot be considered in isolation from its catchment. The catchment provides the surface area that supplies runoff and sediment to the channel, which in turn provides the network through which these are transported. A number of hierarchical classification systems have been developed which provide a framework within which the catchment-channel linkages can be considered (Frissel *et al.* 1986; Rosgen 1994; Rowntree & Wadeson 1999). The system presented here is based on that developed for South African rivers by Rowntree & Wadeson (1999) (Table 2.1). As noted by them, use of the term classification at the catchment and segment scale may be a misnomer. This is because each catchment is unique, defying classification. Rather, classification at this level involves a description, using a common framework against which other catchments or segments can be compared. Classification in the true sense is more appropriate at the zone level and lower.

This chapter consists of:

- a brief overview of relevant classification methods and the kinds of data they use;
- a desk-top classification of the catchment, segment and zone in which the project study sites are situated;
- a follow-up field classification of site groupings, using site characteristics.

These geomorphological groupings of sites are later compared in Chapter 10 with the biologically grouped sites.

6.2 Classification: background information for each hierarchical level

The kinds of background data and knowledge used in classification at each scale level are described in this section and their application in Section 6.3.

6.2.1 The catchment

The catchment is the land surface that contributes water and sediment to any given stream network. A catchment audit is more meaningful than classification at this scale. Such an audit differentiates areas in

terms of their potential to produce runoff or sediment. The method used depends on the size of the area of concern, the time available for the study, and the available data. That described in this chapter is suggested by geomorphologists as being appropriate for site selection to estimate the Ecological Reserve, or for a regional biomonitoring programme. The method entails the derivation of a sediment concentration index (SCI) for each site, estimated from the runoff and sediment-production potential of each catchment in which a study site is located.

Runoff potential

In South Africa the most widely available hydrological (runoff) data are those derived from the monthly Pitman model, as used in the WR90 data base for all quaternary catchments in South Africa (Midgley *et al.* 1994). The WR90 GIS data base details the mean annual runoff (MAR) both as a depth and a volume for each quaternary catchment and provides the best available estimate of the spatial distribution of runoff within South Africa. A shortcoming, however, is that these figures are annual data, which do not give a direct measure of flood runoff, the most relevant flow component from a geomorphological perspective.

Runoff data in WR90 relate to the virgin or unmodified condition. A catchment audit should also take account of the location and extent of developments that could be impacting runoff, especially those likely to be impacting flood flows. Of particular relevance would be large instream dams, urban areas that are large relative to the catchment area and any land-use that tends to decrease infiltration capacities (e.g stock grazing, cultivation).

Sediment production

Data on estimated sediment yields by quaternary catchment are available in the WR90 database. These yields are calculated from regional estimates derived from dam surveys, adjusted for specific catchment features that moderate erosion rates, such as slope gradient and soil erodibility. The reliability of these estimates is low due to the paucity of measured sediment yield data on which they are based. Furthermore, land use and land cover are not taken into account; it is advisable, therefore, to make a separate qualitative assessment of the main sediment sources, based on topography, geology, soils, vegetation and land use. Drier areas with a low vegetation cover and densely populated rural areas tend to have elevated erosion rates. Also important is the delivery ratio for each catchment, a measure of the effectiveness of hillslope sediment transport pathways. In steep catchments with a dense network of first-order streams most of the sediment eroded from the hillslopes will be delivered to the river channel. In gently sloping catchments, however, or catchments with a low density of first order streams, much of the eroded sediment will be stored on the hillslopes. In any catchment, gully networks connected to the river channel provide efficient sediment-delivery pathways.

Sediment yield relates to the total volume of sediment lost from a catchment. Also important is the calibre of the material, be it cobble, gravel, sand, silt or clay. The finest material, silt and clay, normally makes up the larger proportion of sediment lost from the catchment and is an important criterion for water quality. However, as it is carried through the system as wash load, this fine sediment has only a small impact on channel geomorphology. Materials of sand size and larger, which make up the bed-material load, are of much greater significance to channel form.

Estimates of bed-material load are particularly difficult. Knighton (1987) states that the bed-material load is generally less than 15% of the total load, but this varies widely, depending on the catchment geology and the nature of slope erosion processes. Catchment geology can be used to derive a first approximation of the relative contribution from wash load and bed-material load. For example, the Table Mountain sandstones and Witterberg Quartzites produce mainly coarse material of sand size and larger, whereas the mudstones of the Karoo Group are associated with highly erodible soils that contribute to a high wash load. Steep slopes well connected to the channel are potential source areas for coarse sediment derived from mass movement processes such as rock fall, debris flows and landslides.

Channel process and form are related to total discharge, which is a function firstly of the catchment area contributing runoff to any point along the river channel and, secondly, of the capacity of that discharge to transport the available sediment. The ratio of the catchment sediment yield to the volume of catchment runoff to gives an indication of the concentration of sediment carried by the flow. High concentrations indicate that the channels would tend towards being transport limited whilst low concentrations indicate that the channels are supply limited, with the flow having excess capacity to transport sediment. A sediment concentration index (SCI) is calculated as:

$$SCI = \sqrt{\frac{\text{quaternary catchment sediment yield (tonnes per annum)}}{\text{quaternary catchment runoff volume (million m}^3\text{ per annum)}}}$$

The square root function is applied to make the resulting numbers more manageable. Maps of the SCI index by quaternary catchment can be derived from the WR90 database, using data on the MAR and cumulative sediment yield.

6.2.2 The segment

A segment is a length of channel along which there is no significant change in discharge or sediment load. Segments are defined along the length of the channel of interest (usually the main channel in the catchment) based on the catchment audit. Segment boundaries may be co-incident with major tributary junctions, especially where these signify a change in stream order. The quaternary catchment SCI can be used to identify transport limited and supply limited sections of channel.

6.2.3 The longitudinal zone

Zonal classifications have been widely used in the past to explain variations in biotic distributions down the long profile of South African rivers (Harrison & Ellsworth 1958; Oliff 1960; Harrison 1965; Hawkes 1975; Noble & Hemens 1978). Concepts on zonation were overshadowed in the 1980s by new ones that viewed the river as a continuum rather than as distinct fragments. Vannote *et al.* (1980), for instance, argued that river ecosystems respond to the flow of energy and matter through the system rather than to site-specific variables. Undeniably, no point along a river can be isolated from the channel and catchment upstream which determines its inputs. Classification, however, requires the sub-division of systems into their component parts. Longitudinal river zones provide a basis for within-river classification that can be used not only to identify geomorphologically similar streams, but also to retain the concept of longitudinal downstream changes.

A characteristic long profile of a river occurs in a geomorphologically graded long profile, that is, one in which the slope gradient is adjusted to transport the available sediment load. Occurring within a uniform geology, the profile initially represents steep headwater streams flowing within confined, steep sided valleys, and progresses downstream to gentler gradients and more open valleys. Because discharge increases downstream, the channel also tends to increase in width and depth. The main source area for sediment is usually the high-gradient upper catchment, whilst the middle and lower reaches act as a storage system for sediment in transport. Sediment calibre changes from large boulder and cobble in the steep headwaters, to gravel, sand and silt or clay in the lower reaches. Many long profiles have a characteristically sharp transition between the upland or mountain streams and the lowland streams, represented by the piedmont or foothill zone, an area of high storage of coarser sediment. Thus, in a graded system there is a natural progression from mountain stream through foothill stream to lowland river. Mountain streams are characterised by steep gradients over bedrock and boulders and little storage of potentially mobile sediment. Valley sides are steep and contribute sediment directly to the channel. Foothill streams are characterised by moderate gradients over relatively coarse, but more mobile material (small boulder and cobbles), with significant storage of coarse sediments in the form of lateral bars and narrow flood plains within relatively confined valleys. Lowland rivers typically have significantly reduced gradients and flow within an alluvial floodplain that represents a long-term store of finer sediments. The plan form of the channel becomes increasingly sinuous in lowland rivers and true meandering often develops. The material on the bed tends to be of a finer calibre of gravel size or finer and pool-riffle sequences, or simply continuous pools and runs, are common channel forms.

The theoretical sequence of river zones described above is often disrupted to give a more complex downstream zonation. Factors that affect this include downstream differences in the geological nature of the land and concomitant impacts on stream sediments through differences in both the resistance to erosion and the calibre of weathering products. A strong climatic gradient between upland and lowland areas, or widespread rainshadow effects, may alter the nature of downstream increases in discharge. Also, patterns of slope erosion may be more related to changes in land use and land cover than to topography, resulting in increased sediment loadings in downstream localities. Probably the single most important factor disrupting zonation patterns is that of tectonic uplift (or, alternatively, downwarping), which results in rejuvenation of the drainage system. In South Africa, widespread uplift in the Miocene and Plicocene has left a legacy in the middle and lower parts of many of the country's rivers of steepened long profiles and deep gorges. This influence is more pronounced along the eastern seaboard of the Eastern Cape and KwaZulu-Natal, but subdued in the Western Cape.

Wadeson & Rowntree (2000) defined the zone as a section of river which is distinguished primarily by its position on the long profile and which is dominated by macro-reaches having a characteristic valley form and valley-floor slope. The macro-reach characteristics can be derived from topographic maps and are used as diagnostic of the zone class.

The macro-reach

The boundaries of macro-reaches are firstly determined by segment boundaries (Section 6.2.2) and, secondly, by variations in valley form within a segment. Macro-reaches are further classified in terms of the valley floor.

Valley form is classified according to a system modified from Rosgen (1994). This takes into account the gradient of valley side slopes, their connectivity to the channel, the degree of channel confinement and the sediment-storage potential of the valley floor.

The most common cross-section valley forms found in South Africa are V1, V2, V3, V4, V6, V8 and V10 (Figure 6.1).

V1 and V2 valley forms have an entrenched nature. The river course thus occupies the full valley floor, with little opportunity for sediment storage. V1 valley forms have steep valley-side slopes (>20°) adjacent to the channel. Such slopes are prone to mass movements such as land slides and rock falls that contribute coarse debris directly to the channel. V2 valley forms have moderately steep lower valley-side slopes, often formed in colluvium. As transport of hillslope material is dependent on fluvial processes such as slope wash, the potential for transporting coarse material into the river is less than for V1 forms. Where colluvial slopes are dissected by erosion gulleys, however, input of coarse sediments is likely to be high.

V3 valley forms are essentially depositional in nature, in that alluvial fans and debris cones occupy the valley floors. V4 valley forms have steep valley side slopes and significant valley floors wherein sediment storage may take place in the form of well developed lateral bars or a narrow flood plain. This valley form is typical of gorges in rejuvenated areas, as well as in foothill zones where the valley floor is starting to widen out.

V6 valley forms are fault-bounded valleys, characteristically confined on one side, but with a channel that is freer to migrate on the other side. Colluvial hill slopes predominate, giving rise to a low sediment supply (Rosgen 1994). The V8 and V10 valley forms represent true unconfined alluvial systems with well-developed floodplains within which the rivers are free to meander. The existence of river terraces (former floodplains) distinguishes the V8 form from the V10. In both forms the channel may be incised into the modern floodplain, so that overbank flooding occurs only infrequently. In such cases it may be difficult to distinguish between infrequently inundated flood plains and river terraces.

Channel pattern and channel morphology are closely related to channel gradient and associated bed material. The gradient of the valley floor is therefore a good predictor of channel characteristics within a macro-reach. Valley-floor gradient can be used to classify macro-reaches into ten zone classes that have been found to be good predictors of channel morphology (Rowntree pers. comm.). The zone classification (Table 6.1) is a modification of that produced by Rowntree *et al.* (1996), which was based on their studies of South African rivers. Gradient ranges for the zones in Table 6.1 have been modified to comply with the stream types suggested by Rosgen (1994) (In Rosgen's system, stream types were labelled A+ to G. A+ is equivalent to our A, A to our B, B to our C, but thereafter there is no direct concurrence. Our zone classes should not, therefore, be confused with Rosgen's stream types.).

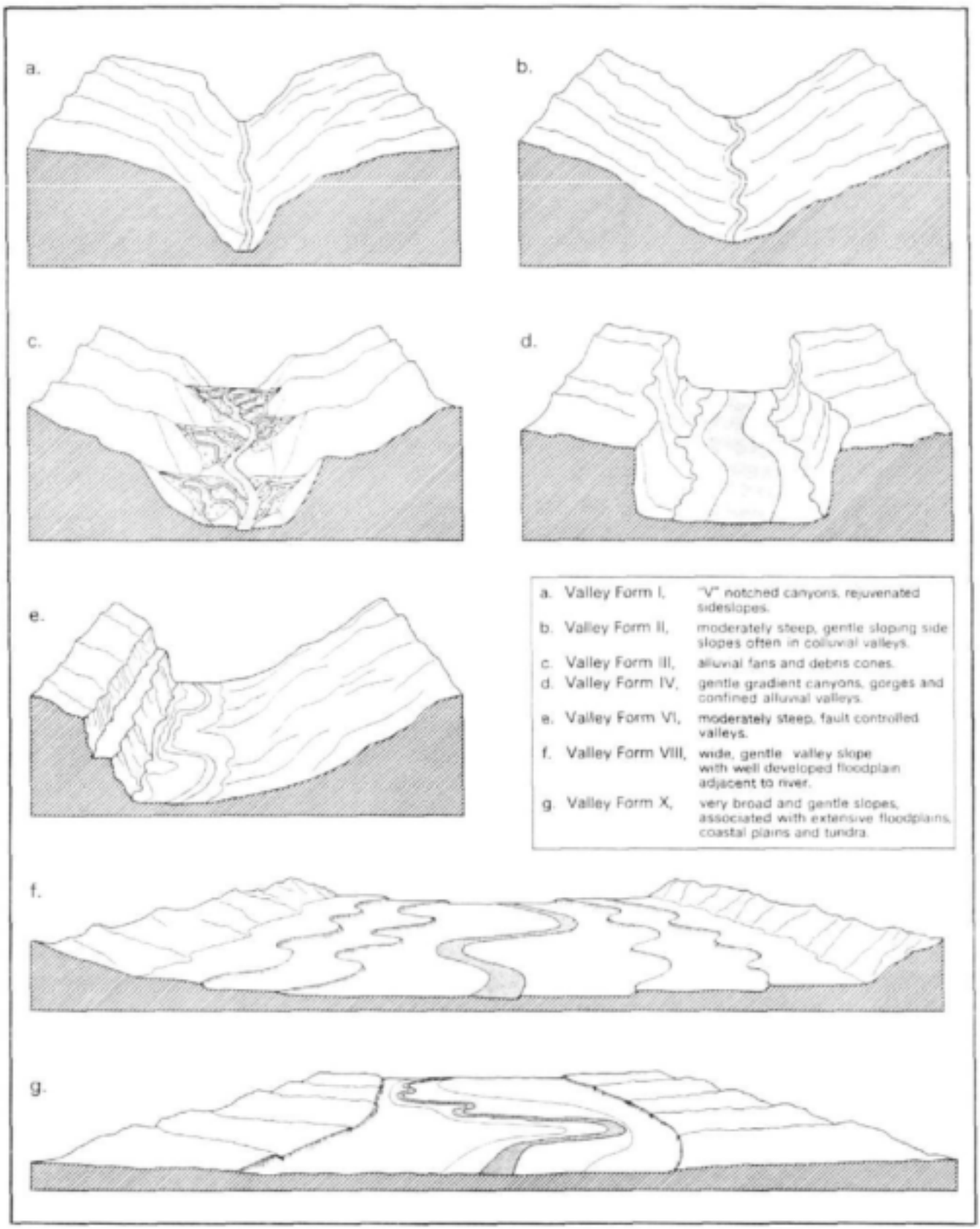


Figure 6.1 The most common cross-section valley forms found in South Africa.

The first seven zone classes, labelled S, A to F, are those associated with a 'normal' river profile as described above. The remaining three zone classes (BCr, DEr and Fr) are associated with steepened rejuvenated profiles in lower rivers. Class BCr indicates rejuvenated macro-reaches with gradients equivalent to classes B and C, class DEr to classes D and E. The stream order and therefore discharge of classes BCr and DEr are significantly higher than their upstream counterparts. Class Fr has a gradient equivalent to class F, but is found in upland areas associated with uplifted plateau areas above escarpment zones. It therefore has a lower stream order and discharge relative to its lowland counterpart.

Table 6.1 Geomorphological zonation of South African river channels (after Rowntree & Wadeson 1999), and with acknowledgement to Harrison & Ellsworth 1958; Oliff 1960; and Rosgen 1994). For reach types, see Table 6.2.

Longitudinal Zone	Macro-reach Characteristics			Characteristic Channel Features
	Valley Form	Zone Class	Gradient Class	
A. Zonation associated with 'normal' profile				
Source zone	V10	S	not specified	Low gradient, upland plateau or upland basin able to store water. Spongy or peat hydromorphic soils.
Mountain headwater stream	V1, V2, V3	A	>0.1	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	V1, V2, V3	B	0.04 - 0.09	Steep gradient stream dominated by bedrock and boulders, locally cobble or coarse gravels in pools. Reach types include cascades, bedrock fall, step-pool. Approximate equal distribution of 'vertical' and 'horizontal' flow components.
Mountain stream (transitional)	V2, V3, V4, V6	C	0.02 - 0.039	Moderately steep stream dominated by bedrock or boulder. Reach types include plane-bed, pool-rapid or pool-riffle. Confined or semi-confined valley floor with limited floodplain development.
Upper Foothills	V2, V4, V6	D	0.005 – 0.019	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.
Lower Foothills	V8, V10	E	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 river	V4, V8, V10	F	0.0001 – 0.001	Low gradient alluvial fine bed channel, typically regime reach type. May be 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	V1, V4	BCr	>0.02	Moderate to steep gradient, 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	V2, V3, V4, V6	DEr	0.001 – 0.02	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 limited flood-plain may be present between the active and macro-channel.
Upland flood plain	V8, V10	Fr	<0.005	An upland low gradient channel, often associated with uplifted plateau areas, as occur beneath the eastern escarpment.

6.2.4 The reach

6.2.4 The reach

The reach is a length of channel characterised by a particular channel pattern and morphology, resulting from a uniform set of local constraints on channel form. Reach boundaries can be identified on 1:50 000 topographical maps using channel pattern, sinuosity and width as indicators. In the field, reaches are further classified in terms of channel type and channel morphology.

Channel pattern refers to the degree of channel division and channel sinuosity as depicted on a 1:50 000 map. Channels can be either single thread or multi-thread, with the latter often identifiable on the maps by clear islands in a widened channel. In some systems, two or more channels may be separated by a distinct floodplain. Channel sinuosity is a measure of the degree of channel meandering relative to valley meandering. It can be quantified as the ratio of channel length to valley floor length. Values greater than 1.5 indicate a true meandering channel. A first indication of channel width can be obtained from the nature of channel depiction on the map: as a single blue line or as a wider shaded area.

Channel type is determined in the field. It is a key indicator of channel form and the nature of its response to disturbance. There are two main types of river channel: **alluvial channels** and **bedrock-controlled channels.** The bed and banks of an alluvial channel are composed of the river's bed-material load. Bedrock-controlled channels are dominated by bedrock exposures in the channel bed, with banks that may be composed of bedrock or alluvium. Many rivers in South Africa represent a mixture of these two forms, with alternating bedrock controlled and alluvial sections. These channels have been classified as **mixed channels**. A fourth channel type is the **fixed-boulder channel,** in which the bed material is composed of large material that the flow is not normally competent to transport. This material may have been derived directly from the adjacent hill slopes or riverbanks through mass movement processes, or exhumed from a palaeo valley-fill underlying the river course. The boulders effectively function as bedrock because they must be broken down by weathering before they can be transported downstream. Thus they act as stable obstructions to stream flow rather than their distribution being the result of flow.

Reaches may be classified into reach types based on channel morphology (Table 6.2). Different reach types are associated with alluvial, bedrock and mixed channel types. The reach type is assessed at a site, but it should be confirmed for the length of the reach from a video or aerial photograph, or from a reconnaissance of the reach upstream and downstream of the site, if possible. The reach type is based on the typical assemblage of morphological units present.

Table 6.2 Reach type classification, modified from Rowntree and Wadeson (1999).

Reach Type	Description
ALLUVIAL CHANNELS & FIXED BOULDER	
Step-Pool	Characterised by large clasts that are organised into discrete channel spanning accumulations that form a series of steps separating pools containing finer material.
Plane-bed	Characterised by plane-bed morphologies in cobble or small boulder channels lacking well-defined bedforms.
Pool-Rapid	Channels are characterised by long pools backed up behind fixed boulder deposits forming rapids.
Pool-Riffle	Characterised by an undulating bed that defines a sequence of bars (riffles) and pools.
Regime	Occur in either sand or gravel. The channel exhibits a succession of bedforms with increasing flow velocity. The channel is characterised by low relative roughness. Flat bed morphology, sand waves, mid channel bars or braid bars may all be characteristic.
BEDROCK CHANNELS	
Bedrock Fall	A steep channel where water flows directly on bedrock with falls and plunge pools.
Cascade	High gradient streams dominated by waterfalls, cataracts, plunge pools and bedrock pools. May include bedrock core step-pool features.
Bedrock Rib	Formed in steeply dipping bedrock; short alluvial areas separate rock ribs which span the channel, significant pools, rapids or falls absent.
Planar Bedrock	Predominantly bedrock channel with a relatively smooth bed. Significant pools, rapids or falls absent.
MIXED CHANNELS	
Step-Pool	As for alluvial step-pool, but steps are formed in association with bedrock exposures where boulders or large cobble are lodged.
Pool-Rapid	Channels are characterised by long alluvial pools behind channel spanning bedrock intrusions forming rapids. Boulder rapids may also mask underlying bedrock.

6.2.5 The morphological unit

Morphological units are the basic structures recognised by fluvial geomorphologists as comprising the channel and may be either erosional or depositional features (Table 6.3). Three groups of morphological units have been recognised as making up the active channel: pools, hydraulic controls and bars. Pools are scour (erosional) features with relatively low width-depth ratios and for which macro-scale flow hydraulics are controlled by a downstream morphological unit, the hydraulic control. The hydraulic controls represent a local steepening in the reach long profile so that the macro-scale hydraulics are not controlled by downstream morphological units. Hydraulic controls have a relatively high width-depth ratio compared to pools. They may be aggradation features (formed by deposition of sediment), such as cobble riffles or boulder rapids, or erosionally resistant features such as bedrock rapids. Bars, the third group of morphological units, are aggradation features that may occur in a number of locations such as along channel margins, within pools or even within the hydraulic controls. They are often formed of relatively mobile material such as sand or gravel and represent the short term storage of sediment that is in transit through the channel.

Table 6.3 Classification of morphological units, modified from Rowntree and Wadeson (1999).

Morphological Unit	Description
ALLUVIAL	
Plane-bed	Topographically uniform-sloped bed formed in coarse alluvium, lacking well defined scour or depositional features.
Pool	Topographically low point in an alluvial channel caused by scour; often characterised by relatively finer bed material.
Backwater	Morphologically detached side channel which is connected at lower end to the main flow.
Riffle	A transverse bar formed of gravel or cobble, commonly separating pools upstream and downstream.
Rapid	Steep transverse bar formed from boulders.
Step	Step-like features formed by large clasts (cobble and boulder) organised into discrete channel spanning accumulations; steep gradient.
Lateral Bar	Accumulation of sediment attached to the channel margins, often successively on opposite sides of channel so as to induce a sinuous thalweg channel.
Point Bar	A bar formed on the inside of meander bends in association with pools. Lateral growth into the channel is associated with erosion on the opposite bank and migration of meander loops across the floodplain.
Mid-channel Bar	Single bars formed within the middle of the channel; strong flow on either side.
Braid Bar	Multiple mid-channel bars forming a complex system of diverging and converging thalweg channels.
Lee Bar	Accumulation of sediment in the lee of a flow obstruction.
Channel Junction Bar	Forms immediately downstream of a tributary junction due to the input of coarse material into a lower gradient channel.
Sand Waves or Lingoid Bars	A large mobile feature formed in sand bed rivers which has a steep front edge spanning the channel and which extends for some distance upstream. Surface composed of smaller mobile dunes.
Rip Channel	High flow distributary channel on the inside of point bars or lateral bars; may form a backwater at low flows.
Bench	Narrow terrace-like feature formed at edge of active channel abutting on to macro-channel bank.
Islands	Mid-channel bars which have become stabilised due to vegetation growth and which are submerged at high flows due to flooding.
BEDROCK	
Bedrock Pool	Area of deeper flow forming behind resistant strata lying across the channel.
Plunge Pool	Erosional feature below a waterfall.
Bedrock Backwater	Morphologically detached side channel which is connected at lower end to the main flow.
Waterfall	Abrupt discontinuity in channel slope; water falls vertically; never drowned out at high flows. Height of fall significantly greater than channel depth.
Cataract	Step like succession of small waterfalls drowned out at bankfull flows, height of fall less than channel depth.
Rapid	Local steepening of the channel long profile over bedrock, local roughness elements drowned out at intermediate to high flows.
Bedrock Pavement	Horizontal or near horizontal area of exposed bedrock.
Bedrock Core Bar	Accumulation of finer sediments on top of bedrock.

6.2.6 The hydraulic biotope

The lowest level of the hierarchy consists of hydraulic biotopes, which are nested within the morphological units. Hydraulic biotopes are defined as spatially distinct instream flow environments, with characteristic hydraulic attributes. Classification of hydraulic biotopes is based on two criteria:

- the visual characteristics of flow, which in turn give expression to the complex hydraulic interactions occurring between the body of water and the bed of the stream,
- the underlying substratum.

The scale of hydraulic biotopes varies from the order of 0.5 m^2 to that approximating to the morphological unit itself.

A morphological unit will be composed of one or more hydraulic biotopes, depending on the complexity of the morphological unit. As discharge changes, the assemblage of hydraulic biotopes also changes, both in type and proportion of each type.

Morphological units that form hydraulic controls often contain a diverse assemblage of hydraulic biotopes, whereas pool morphological units tend to have fewer hydraulic biotopes as they are more homogenous. For all morphological units, the available evidence points to the greatest diversity being associated with intermediate discharges, that is, those between the 50^{th} and 70^{th} percentiles on the flow duration curve of daily flows (Rowntree and Wadeson 1996).

The spatial pattern of hydraulic biotopes within a morphological unit can be determined from observing, mapping or photographing the surface flow characteristics (flow type). The substratum can then be classified for each mapped unit. In the project reported on in this report, flow type and substratum were mapped separately, in order to use the biota to define which combinations of substrata and flow types constituted definably different hydraulic biotopes (Chapter 11).

6.3 Desk-top classification of the project study sites

There has been a paucity of research designed to test relationships between the river channel and biotic distributions at various levels of the hierarchy. In this chapter, the sites are grouped by catchment and zone characteristics, to establish if geomorphological classification at these scales provides a useful indication of the biological nature of the sites. The results are compared to biological classification of sites at the same scales in Chapter 10. Abiotic-biotic links at lower levels of the hierarchy are explored in Chapters 11-13. The classification system used here was based on the premise that the river channel provides the physical framework for the river ecosystem and that channel form will thus be a major determinant of the species present at any point along the river.

6.3.1 Catchment audit

The catchment audit consisted of a desk-top analysis of catchment characteristics, to group and classify the 29 study sites.

The WR90 GIS data base was used to map regional-scale catchment attributes including:

- mean annual precipitation;
- mean annual runoff (quaternary catchment),
- mean annual sediment yield (quaternary catchment);
- sediment concentration index;
- geology and soils.

The site locations were plotted on these regional maps and viewed on the computer so that the characteristics of the catchment upstream of each site could be described (Table 6.4 and Figure 6.2). With the exception of the Grootrivier site, the catchment above each site was contained within one quaternary catchment. Thus, a conventional segment analysis became irrelevant. This approach gave rise to problems in the case of small headwater streams that were contained within a larger catchment that included large areas of significantly lower rainfall and therefore lower catchment runoff. This applied particularly to the Table Mountain sites and to the Steenbok site in the Breede catchment, where the mean annual runoff (MAR) given for the sites were judged to be too low by local scientists. For instance, although the mean annual rainfall over the catchment upstream of the Steenbok site is similar to that of the neighbouring Wolwekloof site, the assigned MAR (Table 6.4) is only about one-third that of Wolwekloof.

There are a number of clear similarities between the sites. Nearly all sites are on a lithology dominated by sandstones (the Table Mountain group)(Figure 6.2a). This is reflected in the predominantly sandy soils. Relatively coarse material (sands) and a low wash load will, therefore, dominate sediment input to the channels. The catchments of two sites, Molenaars (site 9) and Langrivier (site 19), have significant areas of igneous rocks, including granite, that produce abundant coarse sediments. The Lourens catchment is an exception, being comprised of igneous rocks in the higher areas and porous sediments of the Malmesbury group lower down.

There is a significant difference in mean annual runoff between catchments (Figure 6.2b). Values below 100 mm per annum are characteristic of the Doring catchment (Middeldeur and Grootrivier) and catchments on the leeward slopes of Table Mountain (Window Stream and Newlands) (but as noted above, the runoff values for the Table Mountain subcatchments are undoubtedly underestimates). High runoff values, exceeding 700 mm, are found for quaternary catchments of the Breede (Wolvekloof, Witrivier, the Molenaars (Molenaars, Elands and Elandspad), the Berg (Berg, Bakkerskloof, Wemmershoek and Zachariashoek), the Eerste, and the upper Palmiet.

The sediment yield for all catchments is low (Figure 6.2.c), ranging from 8 tonnes per square kilometre per annum to 24 tonnes per square kilometre per annum, and will be comprised largely of bed material load. On a national scale, high values would lie between 300 and 1000 tonnes per square kilometre per annum.

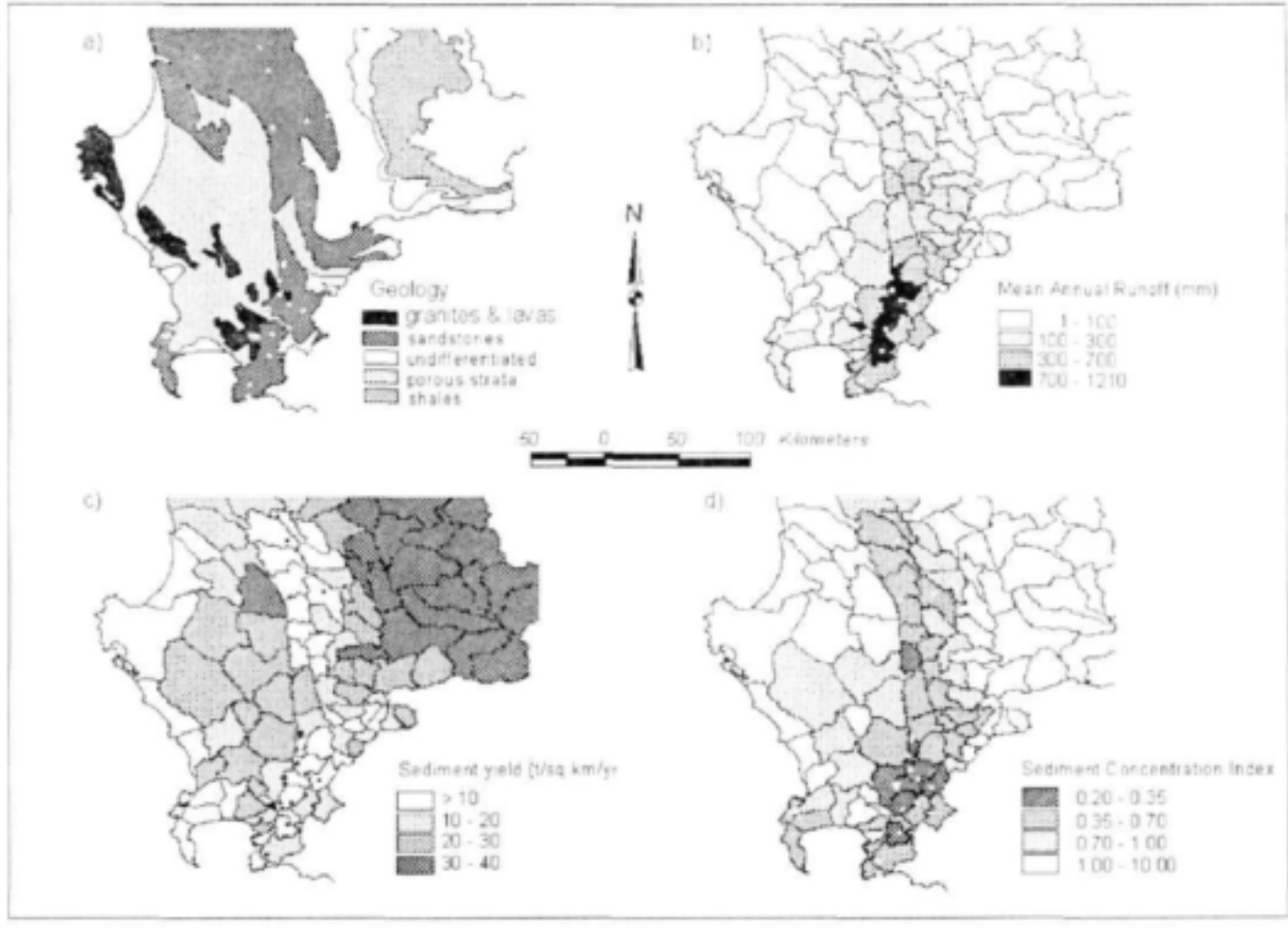


Figure 6.2 **Catchment characteristics of study sites: a) Geology, b) Sediment yield; c) Mean Annual Runoff; d) Sediment transport capacity.**

Table 6.4 **Data used for the catchment audit of study sites.** Catchment size classes are designated as being small (S), medium (M) and large (L). * = disturbed river.

			Catchment Attributes						
No.	Catchment	River	Size Class	MAP (mm)	MAR (mm)	Sed. Yield (t. $km^{-1}.yr^{-1}$)	SCI	Geology	Soils
1	Olifants	Jan Dissels	M	400 ->500	207	8	0.49	sandstone	loamy sand to sandy loam
2	Olifants, Doring	Rondegat	M	400 ->500	136	14	0.45	sandstone	loamy sand to sandy loam
3*	Olifants	Noordhoek	M	400 ->500	209	14	0.53	sandstone	loamy sand to sandy loam
4*	Olifants, Doring	Middeldeur	L	400	94	6	0.46	sandstone	loamy sand to sandy loam
5*	Olifants, Doring	Groot	L	400	80	17	0.95	sandstone	loamy sand to sandy loam
6	Breede	Steenbok	S	1000 -1500	349	19	0.47	sandstone	loamy sand to sandy loam
7	Breede	Wolvekloof	S	1000 -1500	1064	8	0.30	sandstone	loamy sand to sandy loam
8	Breede	Wit	M	>1500	1064	8	0.30	sandstone	loamy sand to sandy loam
9	Molenaars	Molenaars	L	>1500	859	8	0.21	sandstone & igneous	loamy sand to sandy loam
10	Molenaars	Elands	L	>1500	859	8	0.21	sandstone	loamy sand to sandy loam
11	Molenaars	Elandspad	M	>1500	859	8	0.21	sandstone	loamy sand to sandy loam
12*	Breede	Holsloot	M	1000 ->1500	573	8	0.27	sandstone	loamy sand to sandy loam
13	Breede	DuToits	M	1000	563	19	0.40	sandstone	loamy sand to sandy loam
14	Berg	Bakkerskloof	S	800	726	8	0.30	sandstone	Sand to loamy sand
15	Berg	Zacharishoek	S	800	726	8	0.30	sandstone	loamy sand to sandy loam
16*	Berg	Wemmershoek	M	800 -1500	726	8	0.30	sandstone	loamy sand to sandy loam
17	Berg	Berg	M	>1500	1014	6	0.21	sandstone	Sand to loamy sand
18	Eerste	Eerste1	M	>1500	868	10	0.42	sandstone	loamy sand to sandy loam
19	Eerste	Langrivier	M	>1500	868	10	0.42	igneous	loamy sand to sandy loam
20	Eerste	Swartboskloof	M	>1500	868	10	0.42	sandstone	loamy sand to sandy loam
21	Eerste	Eerste2	M	>1500	868	10	0.42	sandstone	loamy sand to sandy loam
22*	Lourens	Lourens	M	800 ->1500	459	24	0.64	porous sediments & igneous	loamy sand to sandy loam
23*	Palmiet	Palmiet	M	1000 ->1500	726	10	0.31	sandstone	loamy sand to sandy loam
24	Palmiet	Dwars	M	1000	435	22	0.39	sandstone	sand
25*	Davidskraal	Davidskraal	M	1000	403	8	0.40	sandstone	loamy sand to sandy loam
26	Liesbeek	Window	S	800 -1000	91.7	14	0.78	sandstone	Sand to loamy sand
27	Liesbeek	Newlands	S	800 -1000	91.7	14	0.78	sandstone	Sand to loamy sand
28*	Sand	Cecilia	S	>1000	165	8	0.51	sandstone	Sand to loamy sand
29	Disa	Disa	S	800 -1000	296	8	0.50	sandstone	Sand to loamy sand

The sediment concentration index is also variable (Figure 6.2d), largely reflecting the distribution of runoff. Sites in the upper Breede, Berg and Eerste are high rainfall areas with high runoff values and have very low SCIs (0.20-0.35). The remaining sites have low SCIs (0.35-0.70), with the exception of Grootrivier, Window and Newlands, which have moderate SCIs (0.70-1.00). The calculated values for Window and Newlands are probably misleading, as these two are in upper, high-rainfall reaches of a larger catchment with an average moderate to low MAR (Table 6.5).

Table 6.5 **Grouping of catchments by size and Sediment Concentration Index (SCI).** Sites divided by catchment size and each river number, river name and SCI given.

	Catchment Size								
SCI	Small			Medium			Large		
Very low	6	Steenbok	0.3	11	Elandspad	0.2	10	Elands	0.2
	7	Wolvekloof	0.3	8	Wit	0.3	9	Molenaars	0.2
	14	Bakkerskloof	0.3	12	Holsloot	0.3			
	15	Zachariashoek	0.3	16	Wemmershoek	0.3			
				17	Berg	0.3			
				23	Palmiet	0.3			
				18	Eerste1	0.4			
				19	Langrivier	0.4			
				20	Swartboskloof	0.4			
				21	Eerste2	0.4			
				25	Davidskraal	0.4			
				3	Noordhoek	0.5			
Low	28	Cecilia	0.5	13	DuToits	0.4	4	Middeldeur	0.5
	29	Disa	0.5	24	Dwars	0.4			
				1	Jan Dissels	0.5			
				2	Rondegat	0.5			
				22	Lourens	0.6			
Moderate	26	Window*	0.8				5	Groot	1.0
	27	Newlands*	0.8						

* Site on low order tributary in upper reaches of system; low confidence in SCI

Given the similarities in geology and soil type, the main factors that are likely to distinguish sites at the catchment level are the size of the system and the SCI. Table 6.5 groups the sites according to catchment size and the SCI. There are eight main groups indicated, though Window and Newlands maybe misclassified as noted above.

6.3.2 Zone classification

In this section, the river zone in which each study site occurs is classified using a rigorous geomorphological zoning exercise. Delineation of zones is based on a classification of macro-reaches, as described below.

The location of each site was identified on the appropriate 1:50 000 map. Valley form was used to delineate the macro-reach within which each site was located. Macro-reaches did not extend beyond clear segment breaks marked by major tributary junctions. The valley-floor gradient for the macro-reach was estimated as the height difference between the upstream and downstream boundaries of the macro-reach,

divided by the length of the macro-reach measured along the centre of the valley floor (Table 6.6). The altitude of the lower contour of each site was also noted.

Table 6.6 River zonation: macro-reach analysis. An "-" denotes missing value.

			Desktop analysis: Valley form classification				Field Survey	
No.	Catchment	River	Valley Type	Valley Gradient	Zone	Altitude	Channel Gradient	Zone
1	Olifants	Jan Dissels	V4	0.012	D	180	0.037	C
2	Olifants, Doring	Rondegat	V2	0.032	C	450	0.030	C
3	Olifants	Noordhoek	V4	0.015	D	220	0.018	D
4	Olifants, Doring	Middeldeur	V4	0.013	D	660	0.026	C
5	Olifants, Doring	Groot	V8	0.005	D/E	480	0.009	D
6	Breede	Steenbok	V2	0.035	C	280	0.061	B
7	Breede	Wolvekloof	V1	0.060	B	340	0.039	C
8	Breede	Wit	V2	0.018	D	680	0.015	D
9	Molenaars	Molenaars	V4	0.006	D	420	0.016	D
10	Molenaars	Elands	V1	0.013	D	440	0.035	C
11	Molenaars	Elandspad	V2	0.029	C	840	0.072	B
12	Breede	Holsloot	V4	0.014	D	420	0.021	C
13	Breede	DuToits	V1	0.090	B	380	0.017	D
14	Berg	Bakkerskloof	V1	0.230	A	300	0.090	B
15	Berg	Zachariashoek	V1	0.174	A	300	0.087	B
16	Berg	Wemmershoek	V8	0.010	D	180	0.011	D
17	Berg	Berg	V4	0.023	C	260	0.026	C
18	Eerste	Eerste1	V1	0.055	B	380	0.058	B
19	Eerste	Langrivier	V1	0.139	A	340	-	-
20	Eerste	Swartboskloof	V2	0.139	A	340	-	-
21	Eerste	Eerste2	V4	0.024	C	320	0.260	C
22	Lourens	Lourens	V8	0.018	D	100	0.017	D
23	Palmiet	Palmiet	V1	0.062	B	420	0.045	B
24	Palmiet	Dwars	V2	0.032	C	80	0.032	C
25	Davidskraal	Davidskraal	V1	0.064	B	60	0.030	C
26	Liesbeek	Window				120	0.123	A
27	Liesbeek	Newlands	V2	0.200	A	180	0.150	A
28	Sand	Cecilia	V1	0.523	A	260	0.169	A
29	Disa	Disa	V1	0.080	B	100	0.060	B

The macro reaches within which the sites were located represented four geomorphological zones: mountain headwater, mountain stream, transitional mountain stream and upper foothills. There is generally a strong association between zone class (represented by A to D) and valley form (Table 6.7). Mountain headwater streams and mountain streams (A and B zone class) are associated with confined valleys: V1 valley forms have a strong potential for direct debris inputs to the channel whereas V2 valley forms derive coarse sediment from upstream. The transitional mountain streams (C zone class) are associated either with the confined but more gently sloping V2 streams, or V4 streams which have steep side walls but some valley-

floor storage potential. Streams in V4 valleys are expected to exhibit a narrow flood plain. The upper foothill sites (D zone class) tend to be found associated either with V4 valley types or V8 valley types. In V8 valley types, the potential for valley-floor storage has increased considerably. The channel is incised into a higher alluvial terrace with or without a modern flood plain. Two sites, 8 and 10, are in more confined valley forms than expected for their zone class (Table 6.8). The groups given in this table can be used as the basis for comparison with the biological groupings (Chapter 10).

Table 6.7 Association between valley floor gradient and valley form for each river (represented by river number as per Table 6.6).

	Valley Form				
Gradient Class	V1	V2	V4	V8	No.
A	14, 15, 19, 28	20, 26, 27			**7**
B	7, 13, 18, 23, 25, 29				**6**
C		2, 6, 11, 24	21, 17		**6**
D	10	8	1, 3, 4, 9, 12	5, 16, 22	**10**
No.	11	8	7	3	

Table 6.8 Grouping of sites by catchment audit and zone. Mod. = moderate sediment concentration index (SCI).

	Catchment Audit by Zone Class								
Size	Small			Medium			Large		
SCI	High	Mod. High	Mod.	High	Mod. High	Mod.	High	Mod. High	Mod.
Mountain Headwater Stream									
V1A	14, 15	28		19					
V2A			27	20					
unclassified			26						
Mountain Stream									
V1B	7	29		18, 23	13, 25				
Mountain Stream (transitional)									
V2C	6			11	2, 24				
V4C				17, 21					
Upper Foothills									
V2D				8					
V4D				3, 12	1				
V8D				16	22				
Rejuvenated Foothills									
V1D							10		
V4D							9	4	
V8D									5

6.4 Field classification of the project study sites

The objective of the research reported in this chapter was to ascertain how well a desktop geomorphological grouping of the sites would reflect a biological grouping. Although the field classification of channel form was not necessary for this desktop exercise, it is useful at this point to use the geomorphological data that were collected on site to compare the occurrence of observed reach types in different river zones.

During the ecological mapping visits to sites, the author of this chapter classified their reach type and channel morphology, using the forms given in Appendix 6.1 to produce the classification given in Appendix 6.2. The site gradients measured using an abney level during these visits are listed in Table 6.6. Comparing the field-measured gradients with the map-derived macro-reach gradients, 13 of 25 sites remained in the same zone class. Ten of these were in zone classes C and D, two in class B and one in class A. Three of the zone class C rivers moved to B, whilst three class D rivers moved to C; for these sites, the map analysis underestimated the field gradient. Two zone class B rivers moved to class C and one to class D, the map analysis over estimating the field gradient. Two class A rivers moved to class B. The biggest change was for site 13 (Du Toits) which went from class B to a class D.

There are a number of possible reasons for the discrepancy between macro-reach gradients taken from the map and the site gradient measured in the field. First, the macro-reach gradient relates to the valley floor whereas the site gradient relates to the river channel. Meandering will always tend to reduce the gradient. Given the low sinuosity of all the sites this should not have been a major factor. Second, the macro-reach gradient is the average over a significant valley length whereas the field gradient is site specific and should be more representative of the site itself. Site gradients could be steeper or gentler than the macro-reach gradient. Thirdly, errors are inherent in both map-derived gradients and field-measured gradients. The accuracy of the map gradient depends on both the accuracy of the contours on the map and the measurement accuracy. Both become more difficult in steep terrain (zone class A). In the field, the resolution of the abney level is not sufficiently high to distinguish between gradients characteristic of D and C zone classes.

Given these various reasons for differences it is encouraging that the macro-reach zone class predicted the site gradient to within one class or better for all but one site. The exception (Site 13) was significantly less steep than predicted, and the site does not appear to be representative of average conditions in the macro-reach.

Table 6.9 gives the main groupings of sites from this on-site classification. The sites are allocated to a zone class and valley type, as per the desk-top analysis and the reach type for each site is described. Generally, zone classes have a good predictive potential in terms of reach types. Class A rivers (mountain headwaters) include bedrock cascades in bedrock channels, step-pool in fixed boulder or mixed channel types. An anomaly is the cobble plane-bed for site 13, which can be explained by the lower site gradient. There was no obvious difference between sites in V1 or V2 macro-reaches. The class B rivers (mountain streams) had a similar morphology to the A rivers. The pool-riffle morphology of site 25 (Davidskraal) is an anomaly, probably due to disturbance to the channel caused by an upstream dam and downstream weirs. The class C rivers (transitional) are characterised by pool-rapid reaches or plane-bed in bedrock, fixed boulder and

mixed rivers and by pool-riffle reaches in the alluvial river. Pool-rapid is also the dominant reach type in the class D bedrock, fixed boulder and mixed channels, whilst pool-riffle reaches are characteristic of class D alluvial rivers. Bulldozing at Sites 3 (Noordhoek) and 16 (Wemmershoek) flattened the bed to give either a cobble plane-bed or a sandy flat bed respectively. One exception to the general pattern is the classification of the Middledeur site (4) as a bedrock cascade. Although rock steps do occur in the site, rapids, bedrock pools and bedrock runs are also present. It perhaps should have been classified as a pool-rapid reach.

The above analysis of reach types indicates that zone class A and B rivers tend to have similar reach morphologies, as do zone classes C and D. Differences between A and B and between C and D will be reflected in the detailed morphological structure and the size of the channel, which will tend to increase from A to D. As the river gets larger and the gradient gentler, pools tend to elongate and come to be spatially dominant. Valley form does not have an obvious effect on reach morphology. It is notable that in these rivers bedrock and boulder dominate the bed material, even in the alluvial channels. This probably in part reflects the predominance of V1 and V4 valley types even in the lower zone classes.

6.5 Conclusion

The study sites were classified at the catchment, zone and reach scales. A conventional segment analysis was deemed inappropriate for this study, given that many sites were in mountain streams contained within one quaternary catchment. A desktop survey of catchments (Table 6.5) produced eight groups of sites based on catchment size and sediment transport capacity index. It also revealed that the sites were in four longitudinal zones: mountain headwater streams, mountain stream, transitional mountain streams and upper foothill streams, or zone classes A to D respectively. There was a good association between valley form and zone class, with A and B zone classes tending to have V1 and V2 valley forms. Zone class C consisted of V2 and V4 valley forms and zone class D mostly of V4 and V8.

A comparison between zone class and the field data showed that the desk-top analysis of zone classes and valley forms produced an acceptable grouping of sites in terms of their reach morphology (Table 6.9). Although all channel types were found in all the river zones, there was a tendency for bedrock and fixed-boulder types to dominate the mountain stream zones, whilst alluvial channels were more common in the foothill reaches. Mixed channels were most common in the transitional mountain stream zone. The alluvial sites were also those most subjected to direct physical disturbance.

Table 6.9 **Reach type at sites, arranged by zone class, valley form and channel type.** River zone (zone class and valley form) as classified in Table 6.6. River number as per Table 6.6 given in parenthesis after reach type designation.

	Channel Type			
River Zone	**Bedrock**	**Fixed Boulder**	**Mixed**	**Alluvial**
A V1	bedrock cascade (14)	boulder & cobble step-pool (19); boulder step-pool (28)	bedrock & boulder step-pool (15)	cobble plane-bed (13)
A V2		boulder step-pool (20); boulder & cobble step-pool + plane-bed (27)		
B V1	bedrock cascade (23)	boulder step-pool + plane-bed (18)	cobble step-pool (7)	gavel pool-riffle (25)
C V2	bedrock pool-rapid (11)		boulder plane-bed (2); bedrock & cobble plane-bed (6); bedrock & cobble pool-rapid (24)	
C V4		boulder pool-rapid (21)		cobble pool-riffle (17)
D V1		boulder pool-rapid (10)		
D V2			bedrock & boulder plane-bed + pool-rapid (8)	
D V4	bedrock cascade (4); bedrock & boulder pool-rapid (1)			mixed pool-riffle (12); mixed + boulder plane-bed (3); boulder pool-riffle (9)
D V8				boulder pool-riffle (22); mixed + boulder pool-riffle (5); sand + cobble flat bed (16)

7. ABIOTIC AND ALLIED ECOLOGICAL SITE INFORMATION

7.1 Overview

The 29 river sites were visited on the dates indicated in Table 5.1. Routine records were made of several water-quality, climatic and ecologically-relevant variables at each site (Section 7.2). The geomorphological character of the channel was measured, as were relevant hydrological and hydraulic variables (Section 7.3). The site was then mapped (Section 7.3.3), prior to the collection of invertebrate samples.

7.2 Chemical, weather and ecological variables

Twelve site variables (Table 7.1) were routinely measured or estimated during the site visits. They can provide valuable diagnostic data for interpretation of trends in biological distributions. Conductivity, pH, colour, and water temperature can be measured quickly with instruments, and provide a first characterisation of water quality. Nothing more detailed was attempted in this study, because of the accent on physical characterisation of the river. Air temperature and cloud cover are less often used diagnostically, but are usually recorded because they may reflect weather or other conditions that could help explain anomalies in samples. The amount of canopy cover over the stream is indicative of the extent to which the water is shaded, as well as the potential for allochthonous inputs of riparian food sources. The extents of macrophytic, algal and moss cover within the stream indicate the degree of vegetation-based hydraulic cover, habitat, refuge and possible primary food sources available to the aquatic fauna. Fine and coarse particulate organic matter (FPOM and CPOM), usually dominated by decaying leaves but also including any other organic debris, are a major food source for different kinds of detritivores.

As a group (Table 7.1), the river waters were acidic (pH range: 4.1-6.4) and quite pure (conductivities: 16.1-76.8 µS cm^{-1}, plus two on Table Mountain >100 µS cm^{-1}). The colour of the water ranged from unstained to dark brown (Hach units: 0 - >100), but with only the weakest of correlations between pH and colour (Figure 7.1). The darker waters tended to have a low pH value of about 4, but so did several less-stained waters.

Mid-summer water temperature was mostly in the range 17-24 °C, although some heavily-wooded sites close to river sources were cooler (14-16 °C), as was a disturbed site directly downstream of a bottom-release dam (Holsloot: 12.3 °C). Acknowledging that temperatures were not necessarily taken at the same time of day from site to site, there was still some pattern to the difference between air and water temperatures at the sites. Sites with dense canopy cover tended to have similar air and water temperatures (<6° C difference), whilst those with open canopies had water that was up to 13° C cooler than the air (Figure 7.2). Most open-canopied sites were either in foothill zones, and thus at a greater distance from the source than the heavily-canopied mountain-zone sites, or were sites with bedrock. One might have expected that the water in both foothill and bedrock sites would be close to air temperature due to the distance travelled under the hot summer sun or over warm bedrock, but only in three cases was this apparent. These were two open-canopied foothill sites (Rondegat and Noordhoek), in the extreme northern (i.e. hotter) end of the study area, and one site closer to Cape Town (Berg), which was one of the widest channels studied. All had boulder-cobble beds.

Table 7.1 **Water chemistry and observations recorded for the 28 rivers of the main study.** pH readings denoted by an * should be treated with caution as the pH meter was not functioning properly, + means that the observation exceeded the available scale. The amount of particulate matter observed at each site was visually separated into two types: particles < 1 mm, or fine particulate organic matter (FPOM), and particles > 1 mm, or coarse particulate organic matter (CPOM).

No.	River	pH	Conductivity ($\mu S\ cm^{-1}$)	Colour (HACH)	Air Temp. (°C)	Water Temp. (°C)	Cloud Cover (%)	Canopy Cover (% open)	Macrophyte Cover (%)	Algal Cover (%)	Moss Cover (%)	FPOM (%)	CPOM (%)
1	Jan Dissels	5.4	31.6	5	26.5	19.5	0	70	60	0	10	10	1
2	Rondegat	5.4	22.8	15	17.6	18.0	5	85	<1	0	<1	5	<1
3	Noordhoek	4.9	28.8	0	20.4	21.8	0	100	<1	10	1	50	<1
4	Middeldeur	4.8	34.2	25	30.8	21.2	0	80	60	80	5	70	<1
5	Grootrivier	5.9	62.4	25	23.5	24.1	20	10	2	<1	0	10	5
6	Steenbok	5.1	31.9	5	23.3	22.5	1	50	<1	0	<1	5	<1
7	Wolwekloof	4.9	29.1	15	17.0	15.3	0	95	<1	<1	<1	1	<1
8	Wit	5.1	18.5		31.0	22.7	5	100	<1	<1	<1	<1	0
9	Molenaars	4.5*	19.5	25	27.1	20.6	1	99	0	<1	0	2	<1
10	Elands	5.0*	20.2	10	21.9	17.5	0	95	10	<1	<1	<1	<1
11	Elandspad	3.6*	16.1	55	30.0	17.4	0	90	85	0	5	5	<1
12	Holsloot	5.3	16.7	40	23.2	12.3	5	80	10	90	0	1	1
13	Du Toits River	5.7	30.4	15	21.8	19.0	5	95	0	<1	<1	5	1
14	Bakkerskloof	*	32.7	30	21.2	19.8	0	95	3	1	<1	1	<1
15	Zachariashoek	*	45.6	5	25.5	19.5	0	90	<1	<1	<1	8	2
16	Wemmershoek	4.7*	47.8	0	26.0	20.0	95	80	10	10	5	50	10
17	Berg	4.6*	21.6	10	22.9	22.7	5	85	<1	<1	1	7	5
18	Eerste 1	4.8	29.1	10	22.8	17.9	5	60	1	0	<1	5	<5
19	Langrivier	4.8	28.5	10	16.6	14.2	0	10	0	<1	1	10	20
20	Swartboskloof	4.6	25.8	0	22.7	17.5	0	20	1	0	<1	5	<1
22	Lourens	6.4*	54.6	20	27.0	19.8	0	90	0	<1	0	15	1
23	Palmiet	4.0	39.3	50	23.5	18.9	100	50	30	0	40	<1	<1
24	Dwarsriver	3.6*	48.9	100+	28.2	20.2	1	65	95	0	<1	3	1
25	Davidskraal	3.7*	76.8	100+	20.5	19.8	100	10	0	0	2	20	10
26	Window	4.5	69.4	80	23.1	17.0	0	0	0	0	<1	<1	<5
27	Newlands	5.0	67.4	25	21.0	16.5	0	10	0	0	<1	<5	<1
28	Cecilia Ravine	3.9*	168.2	20	18.0	16.0	100	10	0	0	15	95	80
29	Disa (1st trip)	4.1	106.2	100	19.7	16.2	0	20	10	5	70	1	<1
29	Disa (2nd trip)	4.3*	126.9	70	20.3	15.4	0	5	10	5	70	50	20

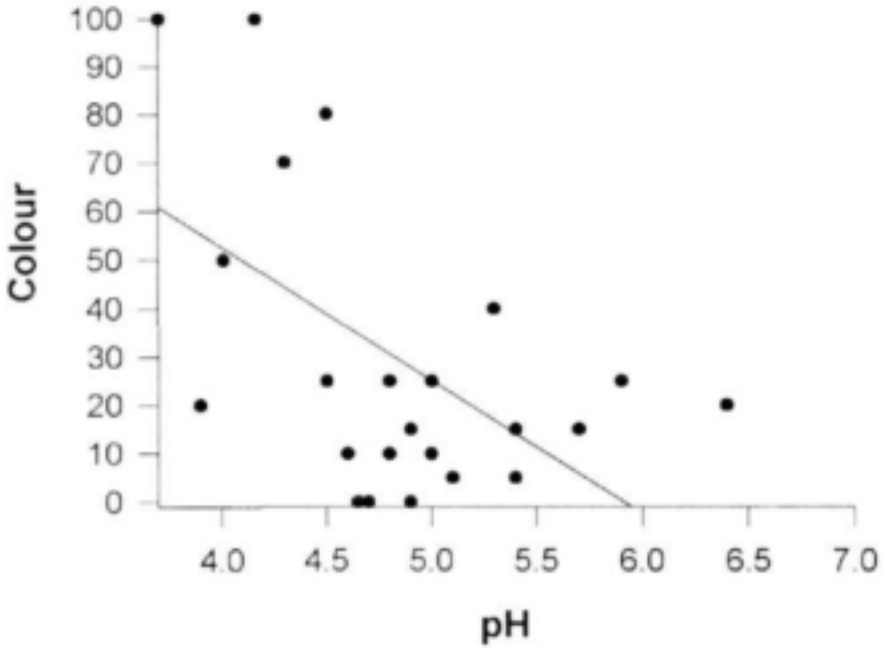


Figure 7.1 Plot of pH against colour for 18 least-disturbed study sites.

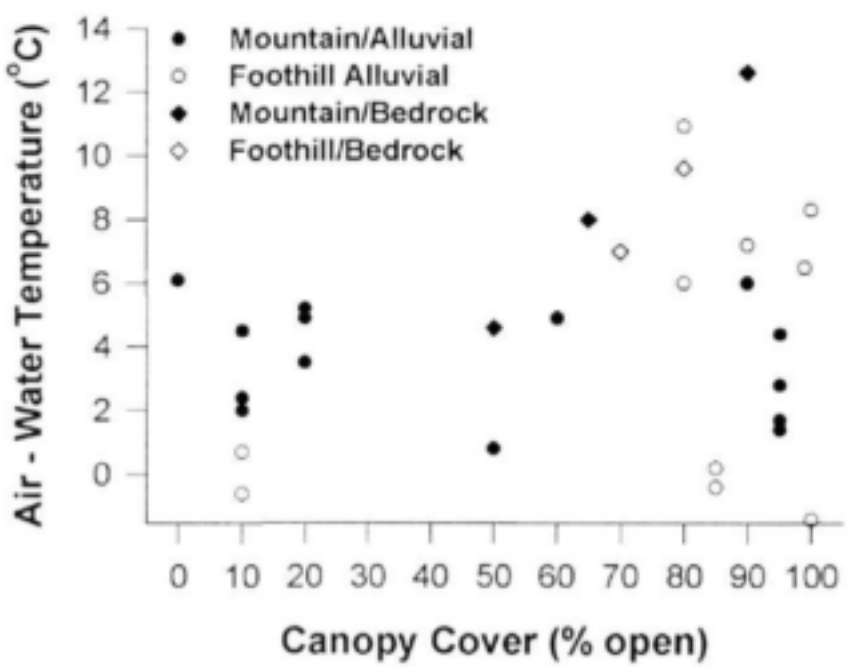


Figure 7.2 Plot of the difference between air temperature and water temperature against percent canopy cover for 18 least disturbed study sites.

The highest occurrence of macrophytes was at the sites with predominately bedrock riverbeds (Elandspad, Dwarsrivier, Jan Dissels), where *Scirpus fluitans* was a common feature. Other sites with a high proportion of macrophyte cover (Middeldeur, Palmiet) had large stands of Palmiet *Prionium serratum*, and some *S. fluitans*. Algal cover was low at all but two disturbed sites. One of these, Holsloot, was <1 km downstream of a large earth dam with a hypolimnetic release. The water was at winter level of temperature (12.3° C) and the riverbed had a 90% cover of algae. The other disturbed site with algae was Middeldeur. This northern site, according to the farmer owner (J. Hanekom), has shown increasing algal growth over the last decade. Nutrients leaching from upstream farming areas in this high mountain catchment are the most probable cause of the growth, which now covers an estimated 80% of the riverbed at the site. By contrast, only one site, the Disa on Table Mountain, had high moss cover. The Disa is very narrow (3 m) at the site, with very little disturbance and no known upstream chemical modifiers, and has an 80% canopy cover. A 40% moss cover at one of the disturbed sites (Palmiet) is not understood, but may be a reflection of a recent fire along this river. The highest percentage covers of CPOM and FPOM were at heavily-canopied or disturbed sites.

7.3 Geomorphological, hydrological and hydraulic variables

7.3.1 Discharge

Sites delineated according to the protocol described in Section 4.3.1 were measured in terms of site length, width of the active channel and discharge (Table 5.3). Discharge values were not used directly within this project, but stand as a reference to flow volumes on the days that the flow types were mapped (see below). If all sites had daily hydrological records, the measured discharge could have been related to a flow-duration percentile, which would have related that day's flow to the overall flow range within the river. Instead, we can only report that all discharges were measured at summer low flow, after several weeks of no rain and thus at relatively stable summer base flows. Discharges measured were in the range 0.002-0.587 $m^3 s^{-1}$, with a slight positive correlation between discharge and either stream order or active wetted width. Discharge had a correlation coefficient (r) of 0.51 with stream order, and correlation of $r = 0.61$ with active channel width. Neither stream order nor active channel width was a significant predictor of discharge, however. A linear regression model of discharge with order only described 26% of the variation, whereas discharge with active channel described 37%.

7.3.2 Channel cross-sections

A single cross-section was used at each site for discharge measurements. Its dimensions, measured as described in Section 4.3.2, provided the approximate size and shape of the river channel (Figure 7.3). In order to enhance the size of data sets on physical habitat, each hydraulic measurement along the cross-section for discharge calculations (Section 4.3.4) was accompanied by information on the substratum characteristics (Table 7.2). The nature and extent of riparian vegetation was also recorded, as was the position of the tree line.

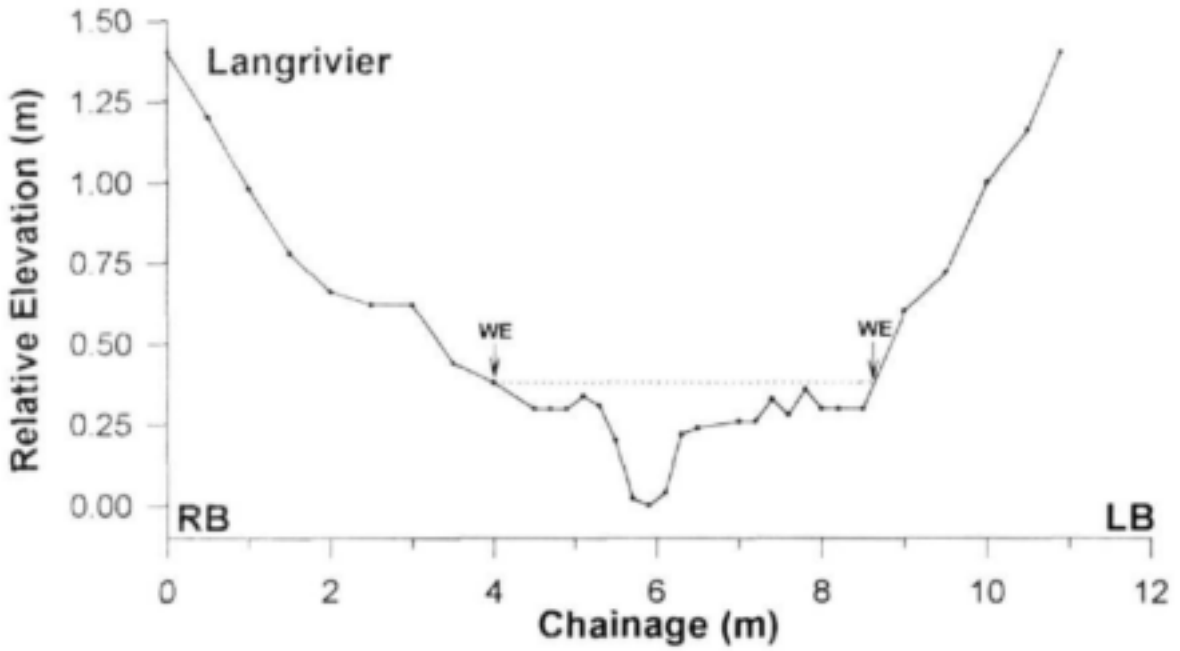


Figure 7.3 An example of the cross-section data available for all sites. RB = right bank and LB = left bank, WE = water edge.

7.3.3 Site maps

Maps of the distributions of different substrata (Table 2.4), flow types (Table 2.3) and morphological units were drawn at each site, using the method described in Section 4.3.1. The maps were digitised using ArcInfo to produce data on the actual and percentage occurrence of different categories, as described in Section 4.6.1.

ArcView was used to provide graphical representation of the maps and later data acquisition. Substrata categories were colour coded, with each unmixed category allocated a solid colour, whilst mixed categories had the dominant substratum (by area) as the base colour and the sub-dominant substratum as a superimposed hatching in the colour of its category. So, for instance, a predominately large-cobble bed with scattered boulders would be coloured blue with green hatching. Flow types were also colour coded, with faster-flow categories in various shades of red, medium categories in oranges and yellows, and slow categories in greens and blues.

The maps provided a first graphic impression of the character of each river. Bedrock sites, such as that on the Jan Dissels, also had small amounts of other substrata, usually in discrete areas (Figure 7.4a). There was little mixing of different sized substrata. The flow pattern, typical of bedrock streams, was dominated by slow-flowing areas over bedrock, with small areas of fast, tumbling flow as water fell from one bedrock

level to a lower one (Figure 7.4b). The morphological units identified were typical of bedrock streams (Table 6.3), being dominated by bedrock pools, bedrock pavements and rapids (Figure 7.4c).

Table 7.2 Table depicts the information gathered at each point on a discharge transect.

Vertical	Chainage (m)	Elevation (m)	Substrata[a]	Depth (m)	Velocity ($m^3 s^{-1}$)	Vegetation	Cover Code[b]
1	0.0	0.00	SA, leaf litter			Riparian trees	1
2	0.5	0.20	SA, leaf litter			Riparian trees	1
3	1.0	0.42	SA, leaf litter			Riparian trees	1
4	1.5	0.62	SA, leaf litter			Riparian trees	1
5	2.0	0.74	SA, leaf litter			Riparian trees	1
6	2.5	0.78	SA			Riparian trees	1
7	3.0	0.78	LC			Riparian trees	1
8	3.5	0.96	SC / LC			Riparian trees	1
9	4.0	1.02	SC / LC			Riparian trees	1
10	4.5	1.10	LG / SG	0.08	0.03	Riparian trees	1
11	4.7	1.10	LG /PG	0.08	0.00	Riparian trees	1
12	4.9	1.10	LC / SG	0.08	0.00	Riparian trees	1
13	5.1	1.06	B	0.04	0.00		0
14	5.3	1.09	B	0.07	0.00		0
15	5.5	1.20	B	0.18	0.04		0
16	5.7	1.38	SC	0.36	0.30		0
17	5.9	1.40	LC / SC	0.38	0.22		0
18	6.1	1.36	LC / B	0.34	0.27		0
19	6.3	1.18	B	0.16	0.24		0
20	6.5	1.16	B	0.14	0.04		0
21	7.0	1.14	SG	0.12	0.00		0
22	7.2	1.14	SC	0.12	0.04		0
23	7.4	1.07	SC	0.05	0.05		0
24	7.6	1.12	SC / LC	0.10	0.05		0
25	7.8	1.04	SC	0.02	0.06		0
26	8.0	1.10	LC	0.08	0.04		0
27	8.2	1.10	B	0.08	0.00		0
28	8.5	1.30	SA / SC			Riparian trees	1
29	9.0	1.10	SC			Riparian trees	1
30	9.5	0.80	SC			Riparian trees	1
31	10.0	0.40	LC			Riparian trees	1
32	10.5	0.24	LC			Riparian trees	1
33	10.9	0.00	LC			Riparian trees	1

[a]Substrata codes: Table 2.4
[b]Vegetation cover codes: 0 = none, 1 = direct overhead, 2 = in-stream

Alluvial mountain streams, such as that on Langrivier (Figure 7.5a-c), were dominated by boulders with all substrata categories well sorted. There were discrete areas of large cobble and fewer areas of small cobble, with little mixing of different sized substrata and almost no sand. The pattern of flow was far more complex than in the bedrock streams, with a high proportion of fast, turbulent flow types. Slow flows occurred in occasional quiet backwaters on the edge of the wetted area, compared to their domination of the flow pattern in bedrock streams. Steps and pools were the dominant morphological units, typical of alluvial headwater streams (Table 6.3).

Alluvial foothill sites, such as that on Rondegat (Figure 7.6a-c), were dominated by large and small cobble. Flow patterns were quite complex, but less so than in the mountain streams, because each flow patch was

larger and tended to be elongated along the line of flow. There were fewer patches of fast, turbulent water, and more areas of fast smooth flow (rippled surface flow-type). The morphological units were also larger than those in the mountain stream, and dominated by plane-bed units. Assessing the alluvial streams as a group, there was a noticeable downstream transition from step-pool formations in mountain zones to plane-bed formations in foothill zones. Additionally, the proportion of areas with mixed substrata was higher in the foothill zones, with sorting of particle sizes decreasing downstream. This topic is re-visited in Section 10.7.

A wide range of ArcView outputs could be produced for each site from the digitised maps, each in m^2. Each table of values, whether for one coverage type (e.g. substrata) or a cross tabulation of the overlay of two coverages (e.g. substrata vs. flow) could then be exported into a spreadsheet package such as Excel or a database. Using these outputs, various manipulations of the data could be carried out, such as calculating percentages, or statistics for wetted area of substrata or morphological units, and breaking down mixed categories (i.e. boulder and large cobble mix) into their main components. As the first maps drawn did not necessarily include sufficient information of the areas outside the wetted (active) channel, the main outputs used were those concentrating on this rather than on the whole site. The relevant outputs were:

- the total wetted area taken up by each of the eight main substratum categories (Table 7.3) and the full range of mixed substratum categories (Table 7.4);
- the total wetted area covered by each of the 14 flow types (Table 7.5);
- the total wetted area covered by each substratum/flow-type combination (Appendix 7.1);
- the total wetted area in each MU (Table 7.6);
- the total wetted area in each MU taken up by each substratum category
- the total wetted area in each MU covered by each flow type

With the data available in many different forms, a range of combinations could be selected to analyse for trends in physical conditions in Western Cape headwater streams.

7.4 Site photographs

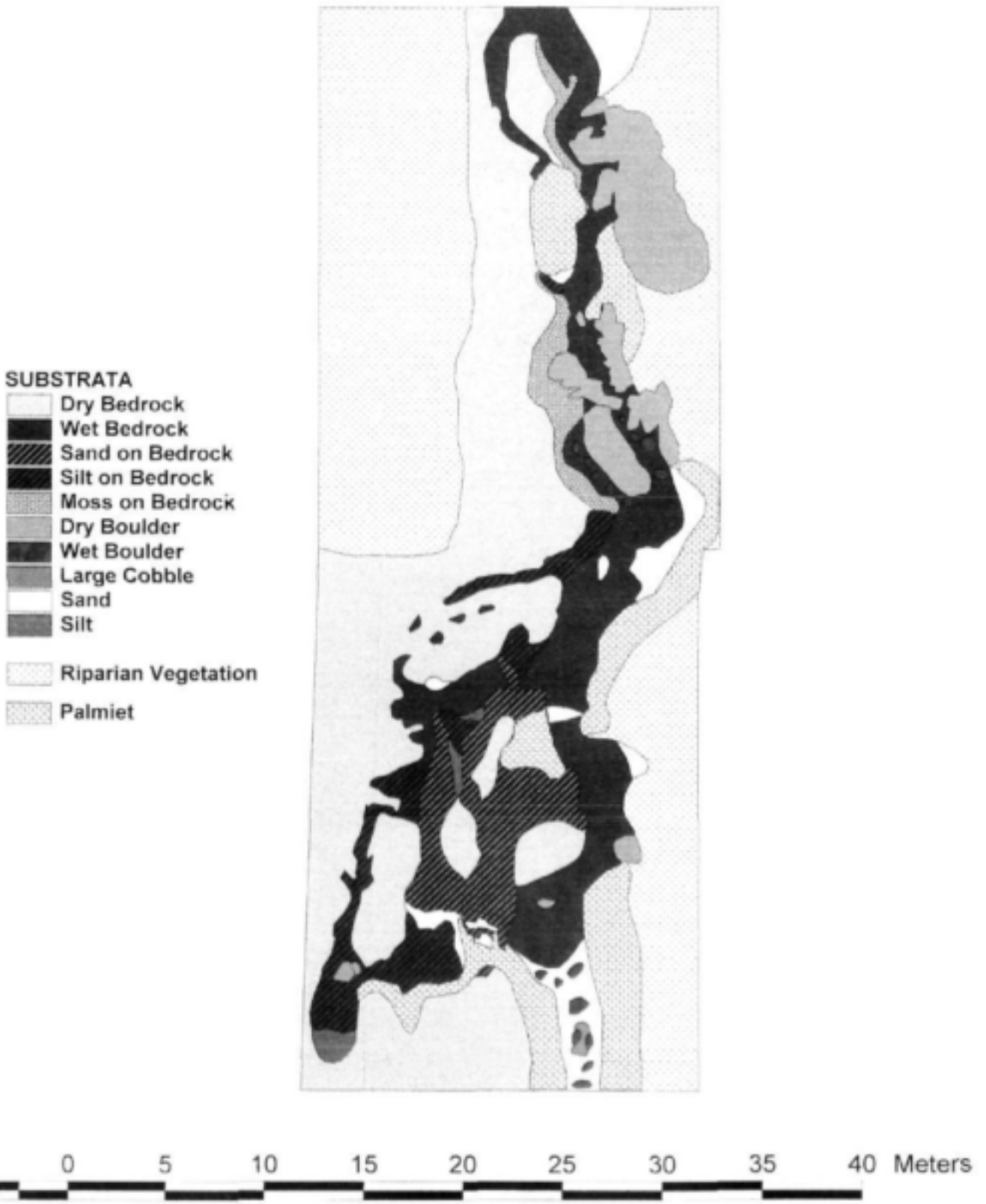
The photographs of each site (Appendix 4.1) illustrate major aspects of channel morphology, sampling methods, flow types, well-sorted substrata, and other distinguishing or relevant features. The location within the site of all morphological and flow photographs was noted. This pictorial record is already being used for teaching purposes, and by engineering students at the Universities of Cape Town and Stellenbosch to investigate the hydraulic nature of flow types.

Figure 7.4a-c GIS maps of a bedrock foothill river, Jan Dissels River

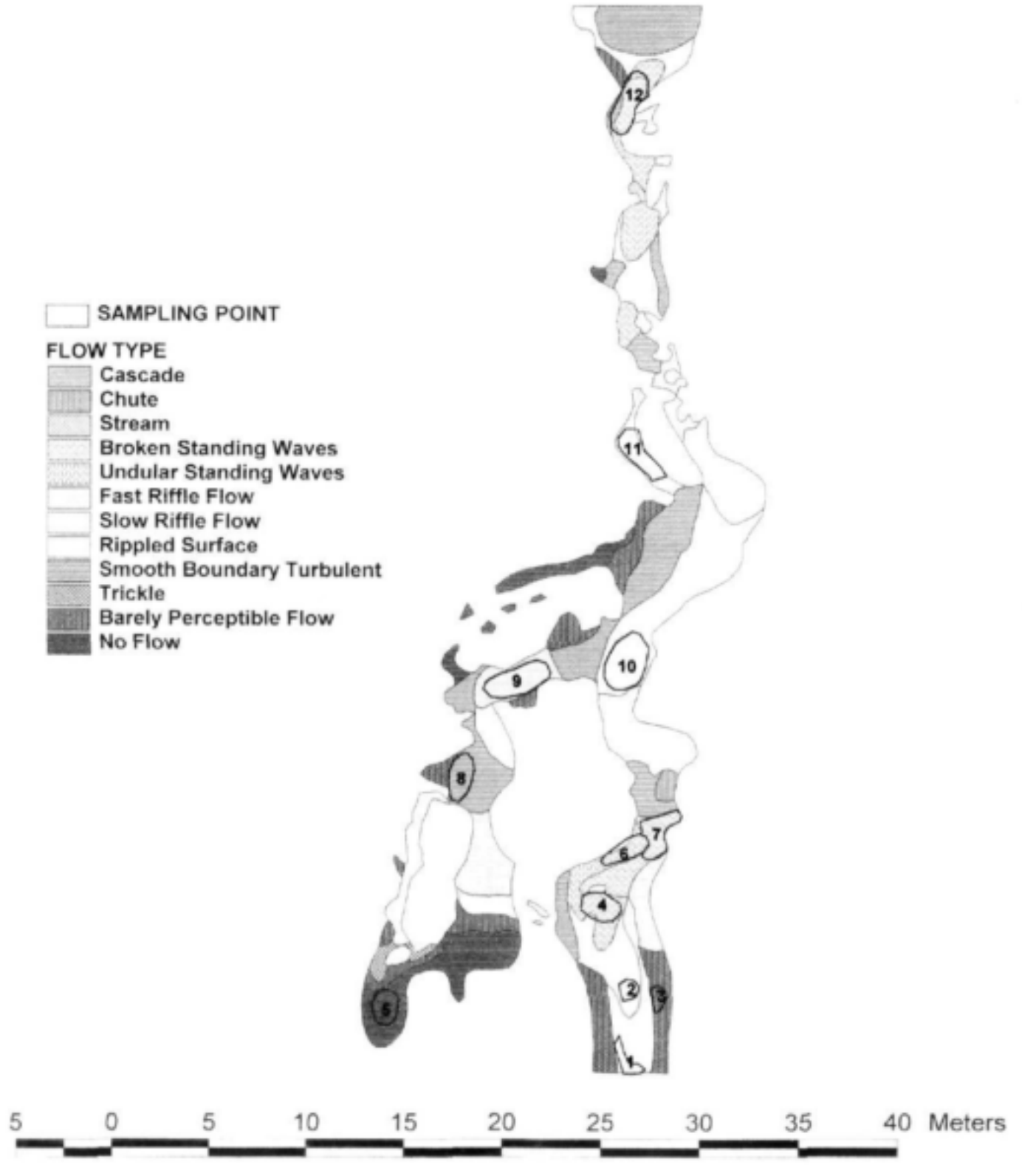
7.4a – Substrata

7.4b – Flow Types

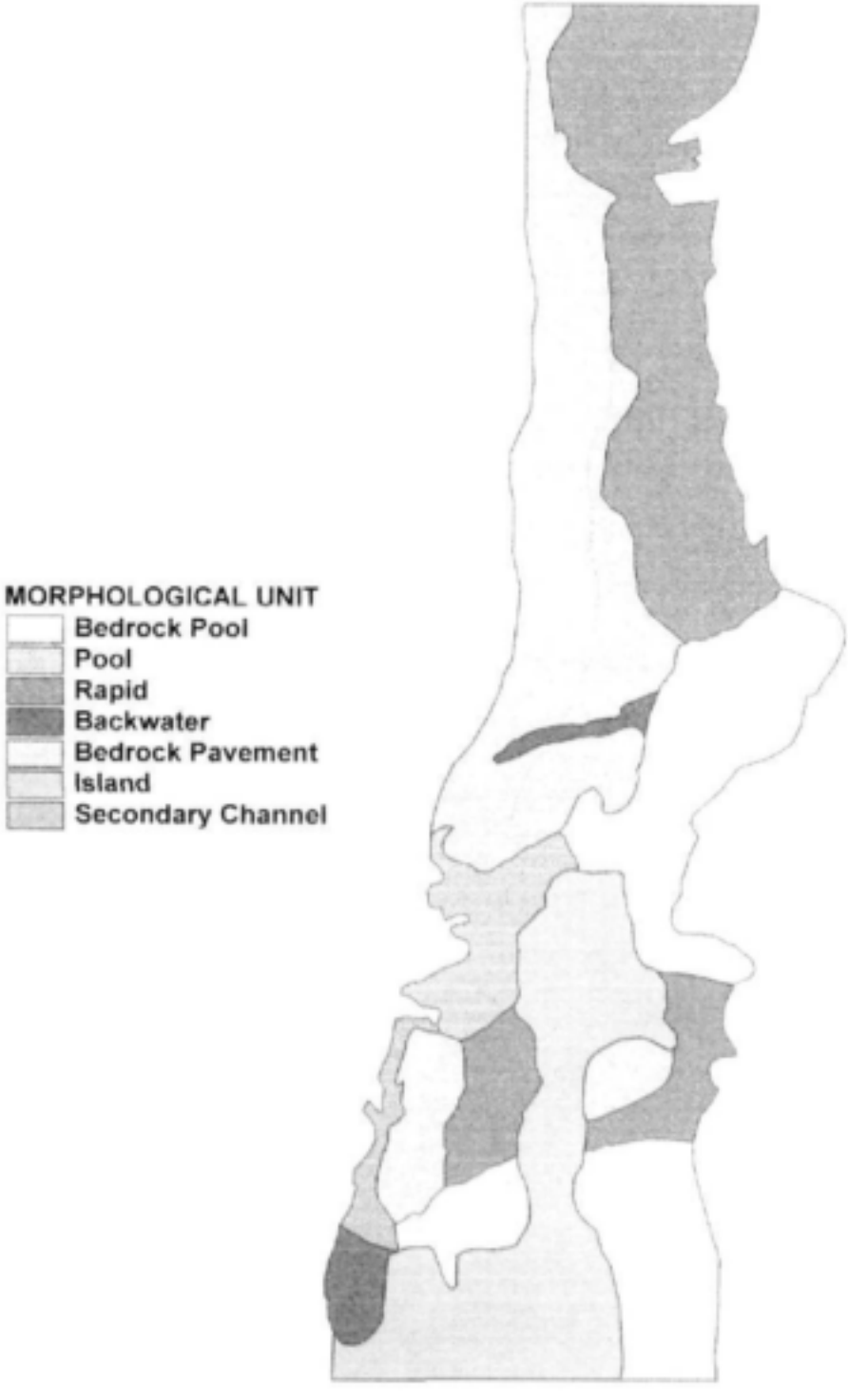
7.4c – Morphological Units

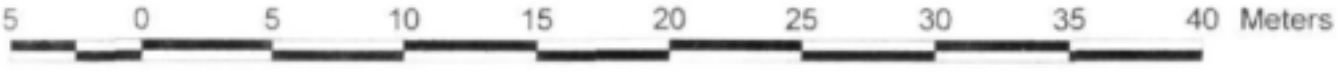


7.4a – Substrata



7.4b – Flow Types





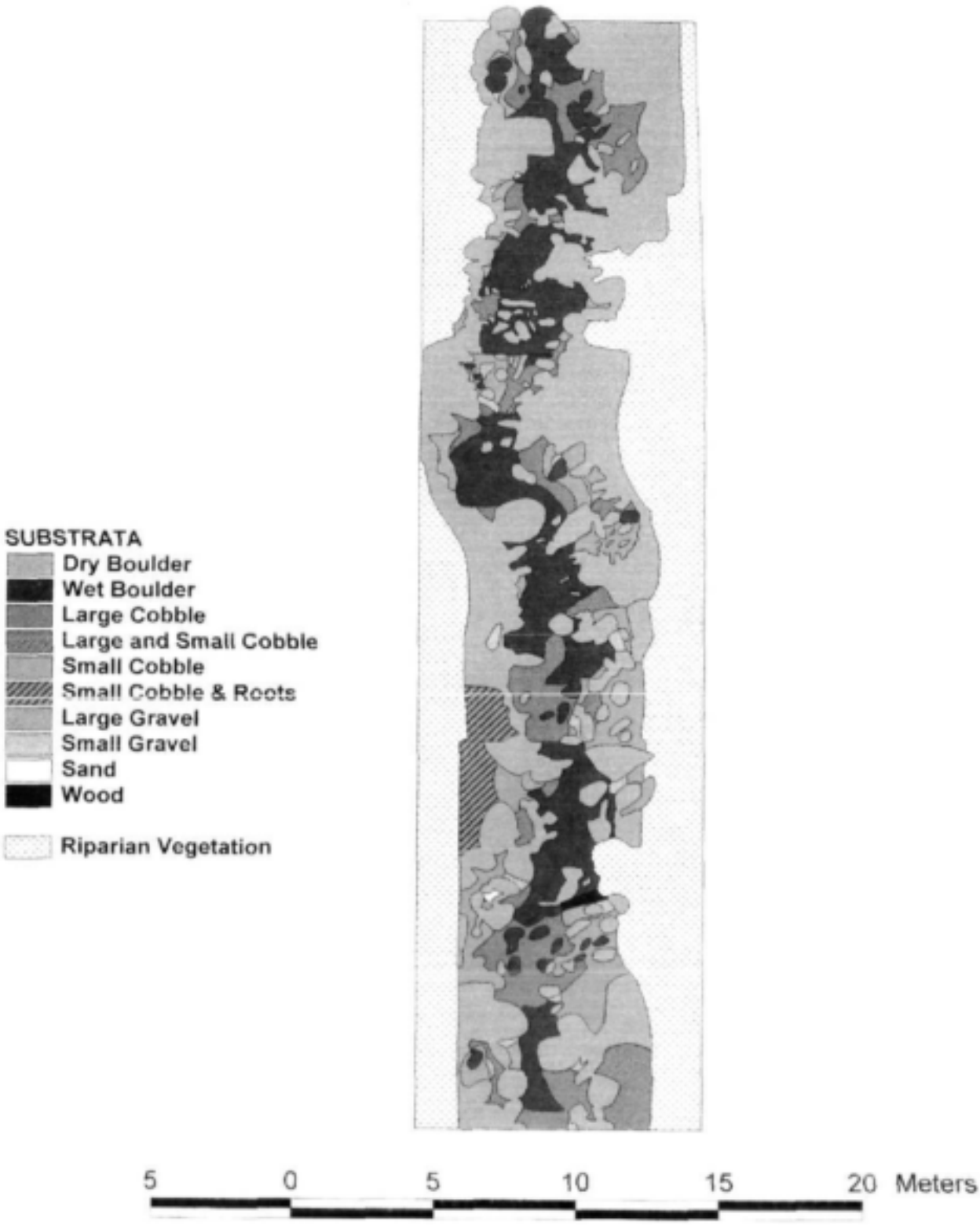
7.4c – Morphological Units

Figure 7.5a-c GIS maps of an alluvial mountain river, Langrivier

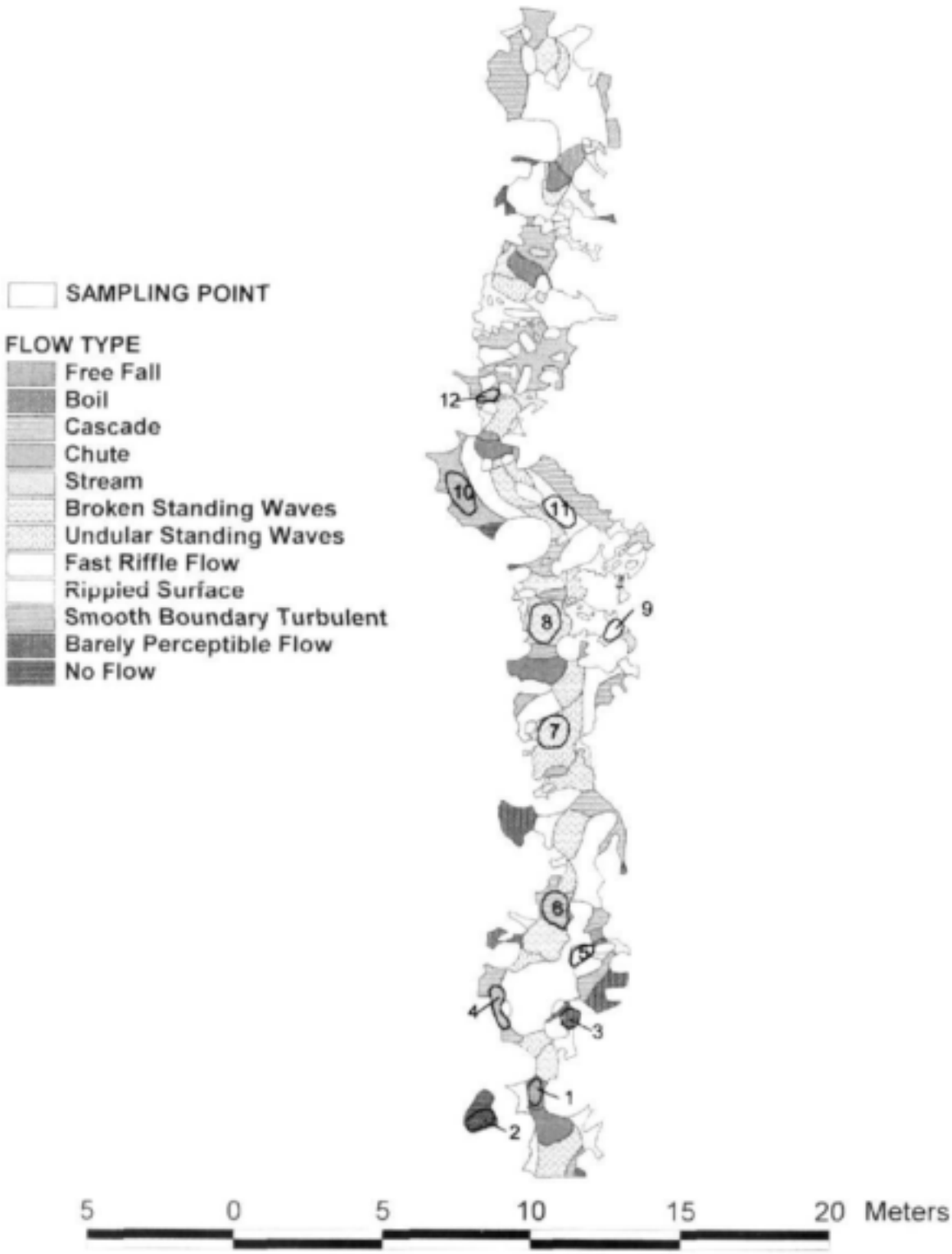
7.5a – Substrata

7.5b – Flow Types

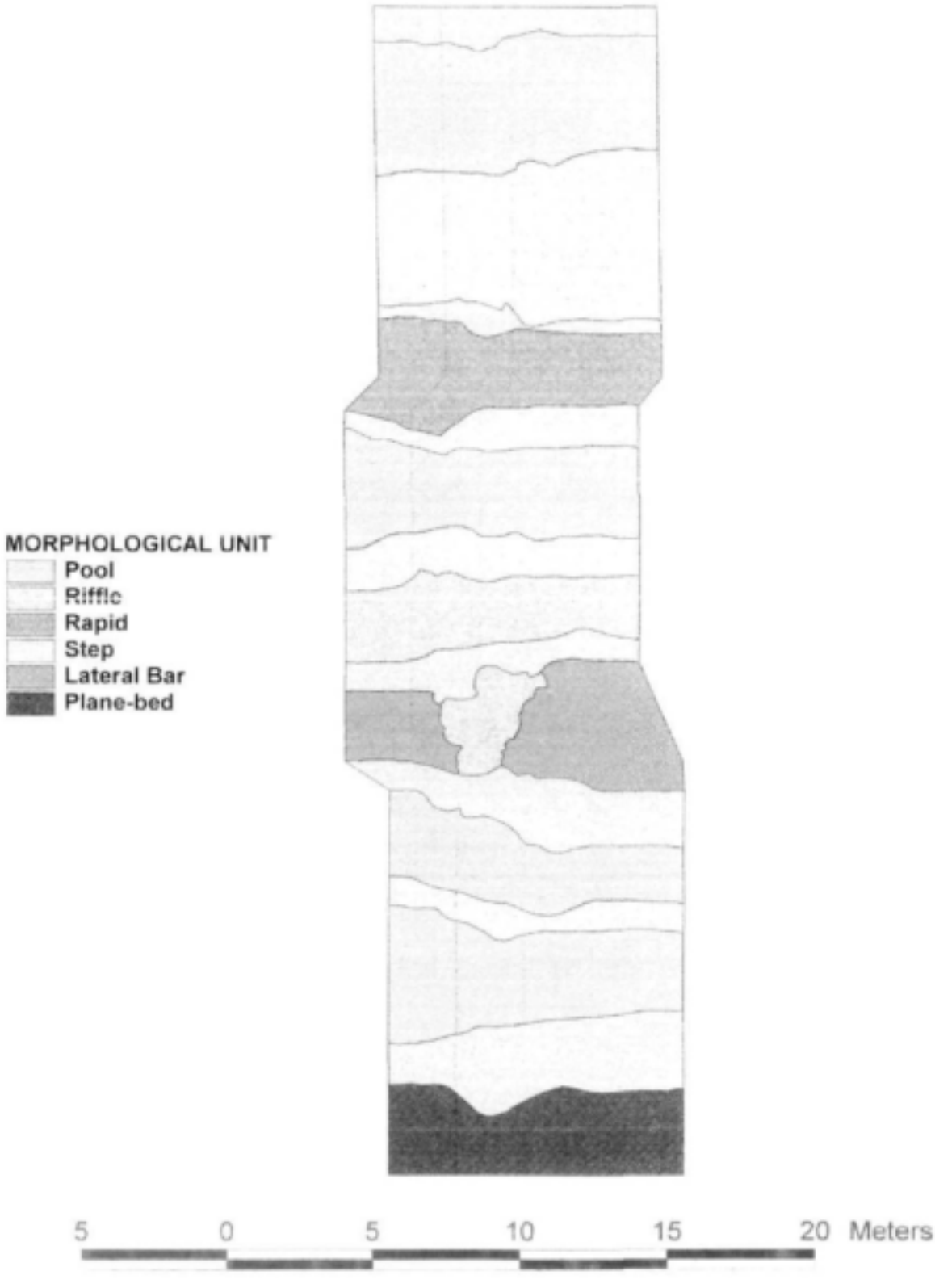
7.5c – Morphological Units



7.5a – Substrata



7.5b – Flow Types



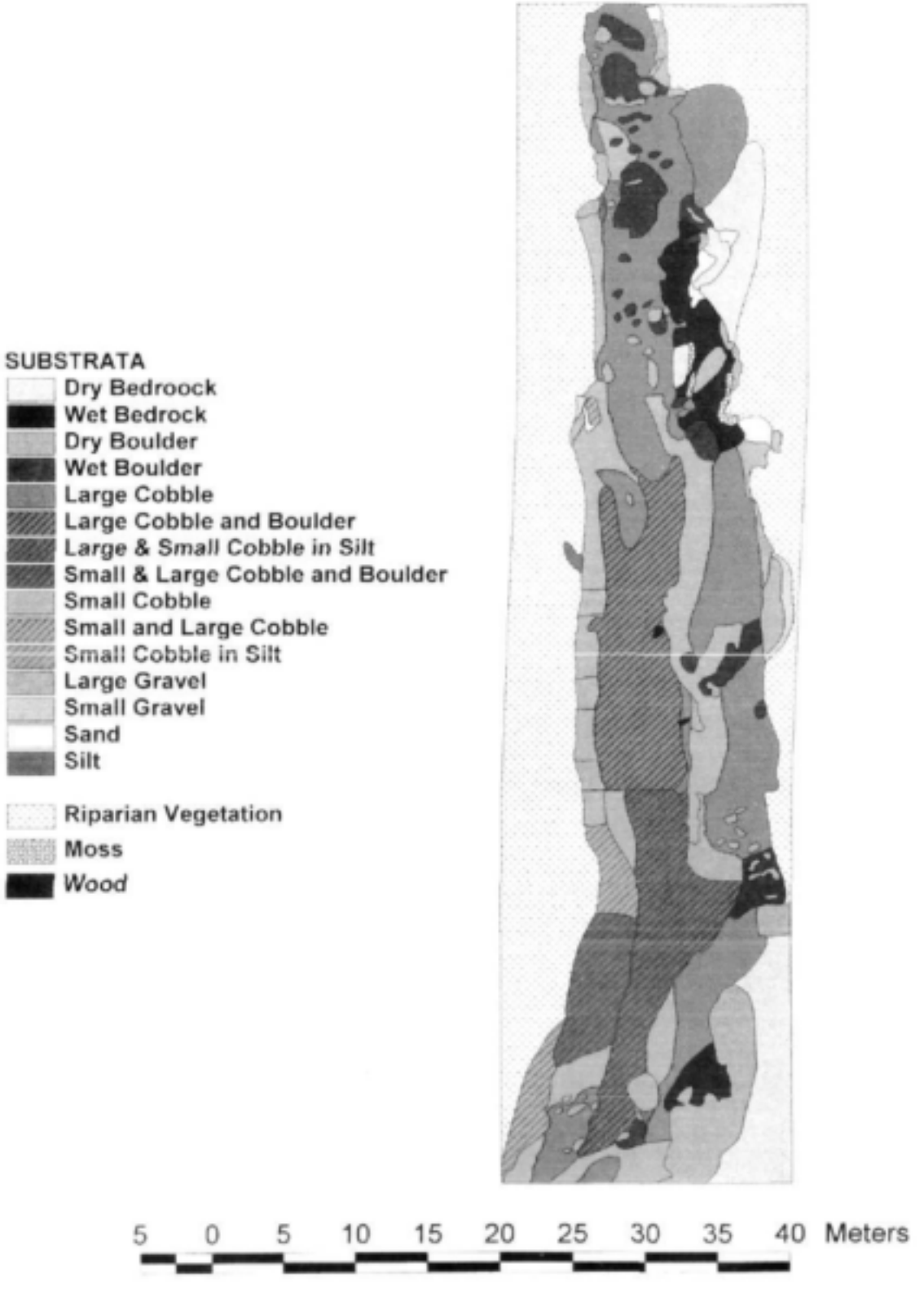
7.5c – Morphological Units

Figure 7.6a-c GIS maps of an alluvial foothill river, Rondegat River

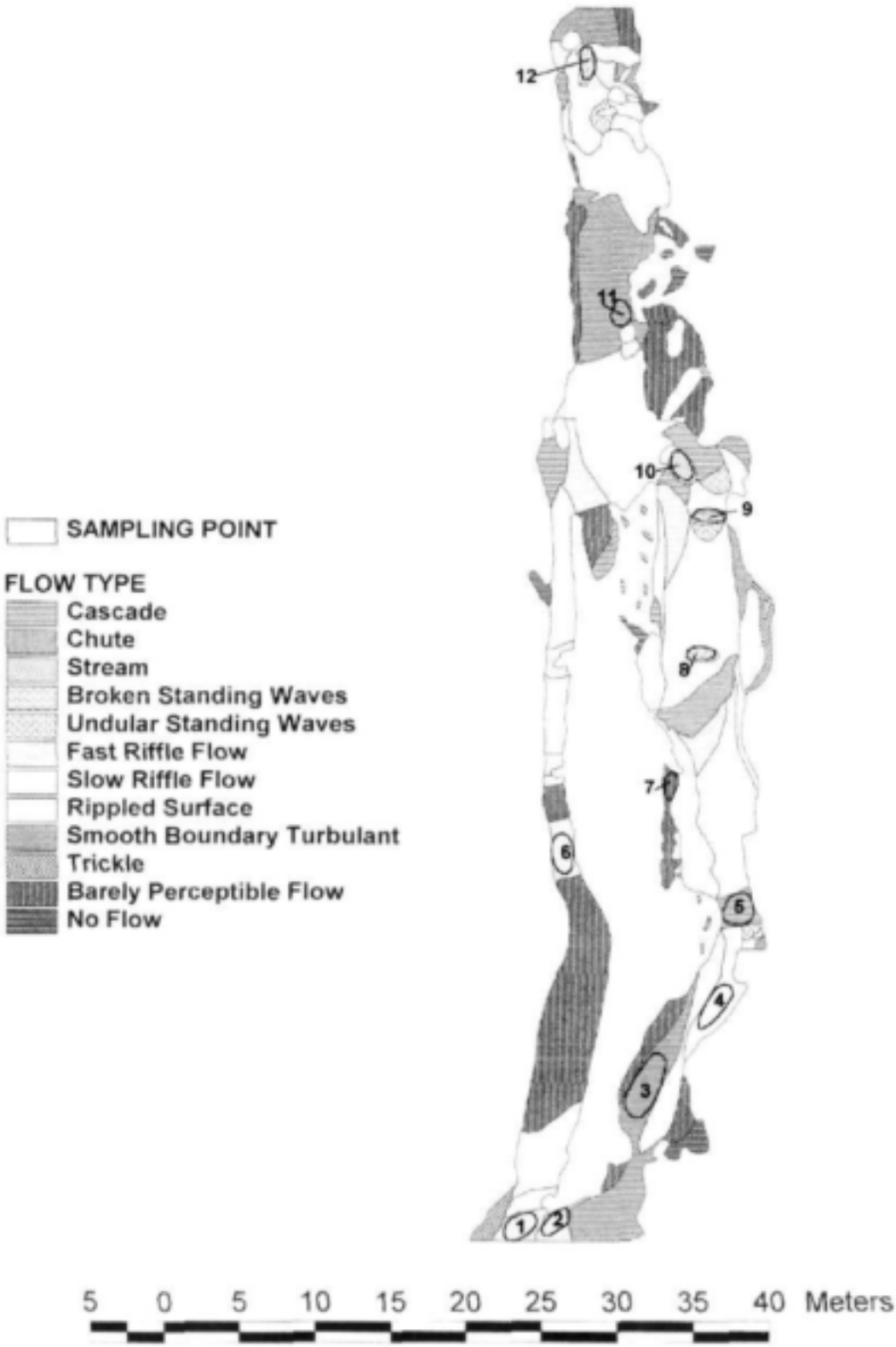
7.6a – Substrata

7.6b – Flow Types

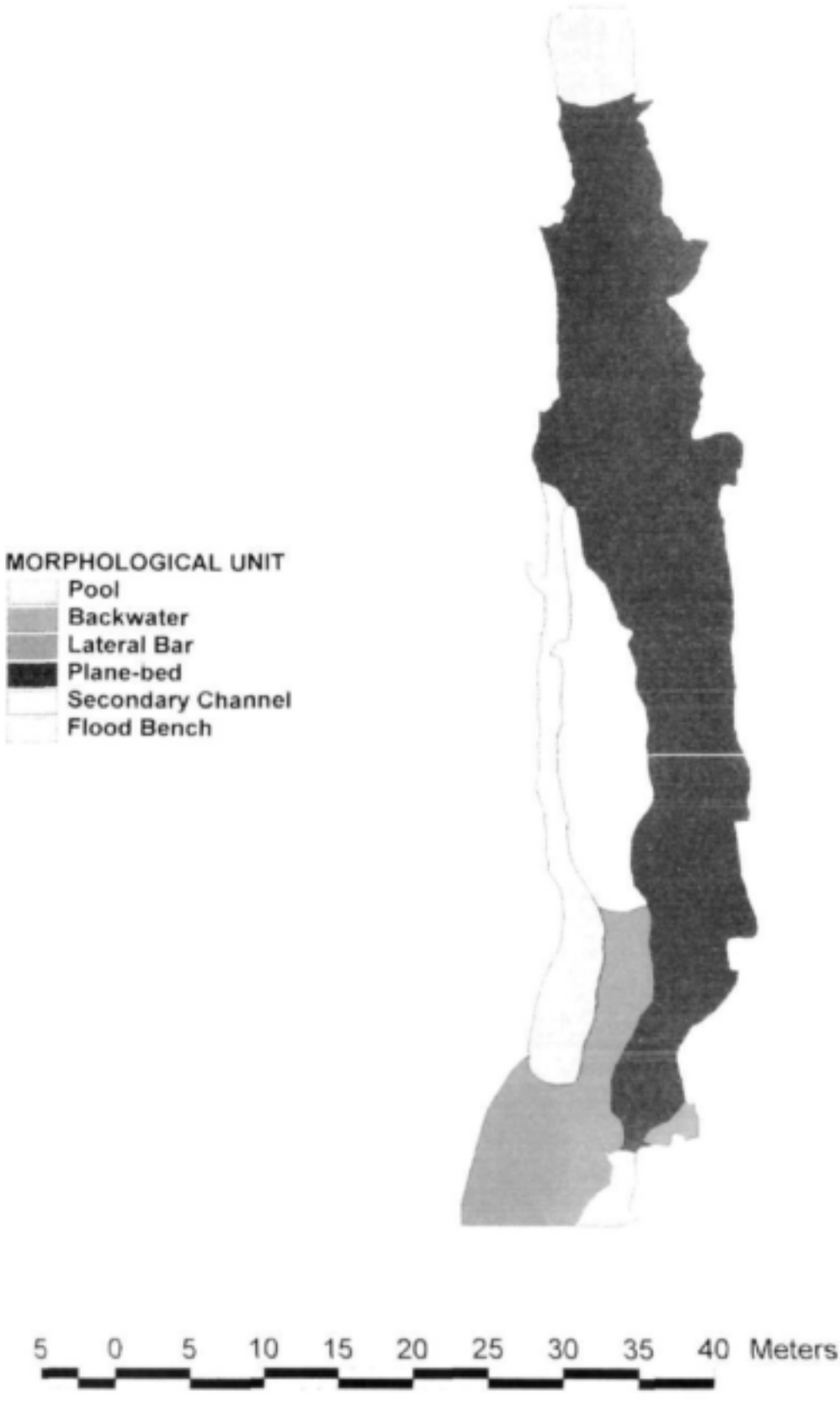
7.6c – Morphological Units



7.6a – Substrata



7.6b – Flow Types



7.6c – Morphological Units

Table 7.3 **Percentages of wetted substrata in 18 least-disturbed rivers mapped with mixed categories allocated equally to one of the eight main categories.** Substratum categories as per Table 2.4.

Substrata	B14#	B17$	B15#	R13#	R06#	R08$	R07#	T29#	E18#	E19#	E20#	T27#	M11#	M10#	M09$	O01$	O02$	P24#
BR	37.9	0.7	24.8	0.0	37.1	13.3	30.5	1.1	6.2	0.0	1.4	0.0	50.9	0.5	0.0	59.9	6.3	47.6
B	14.8	47.8	10.9	22.9	25.8	53.9	22.6	53.0	51.0	56.4	58.1	31.3	16.6	73.1	57.4	3.5	10.5	3.2
LC	12.7	31.0	15.2	57.0	17.5	27.9	25.1	18.5	37.8	26.9	17.6	52.8	1.9	17.6	33.9	0.3	45.2	4.8
SC	5.4	15.9	2.9	13.7	7.7	2.6	17.1	6.2	0.8	11.1	10.5	5.4	0.2	6.9	7.1	0.0	29.0	1.7
LG	10.2	1.6	30.6	3.0	6.9	1.4	1.0	0.0	4.0	3.1	1.5	1.0	0.4	0.9	1.4	0.0	2.7	1.2
SG	15.9	2.5	2.5	1.1	1.9	0.4	1.6	0.7	0.2	0.0	3.0	2.2	0.0	0.3	0.1	0.0	0.7	0.7
SA	3.1	0.6	10.2	2.1	3.2	0.5	1.6	3.4	0.0	1.9	6.7	2.1	0.0	0.1	0.0	26.0	1.5	2.5
SI	0.0	0.0	3.0	0.3	0.0	0.0	0.5	17.0	0.0	0.0	1.1	5.3	0.0	0.0	0.0	10.0	4.0	0.0
RF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0
MOSS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
PALMWT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.8	0.0	0.0	0.0	0.0	3.2
SCIRPUS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24.3	0.0	0.0	0.0	0.0	34.9
WOOD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 7.4 **Percentages of wetted substrata in 18 least disturbed rivers mapped with mixed categories shown.** Substrata categories as per Table 2.4.

Substrata	B14#	B17$	B15#	R13#	R06#	R08$	R07#	T29#	E18#	E19#	E20#	T27#	M11#	M10#	M09$	O01$	O02$	P24#
BR	37.9	0.7	24.8	0.0	37.1	13.3	30.5	0.0	6.2	0.0	1.4	0.0	20.8	0.5	0.0	48.0	6.3	9.5
BR/SA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.7	0.0	0.0
BR/SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.5	0.0	0.0
BR/SCIRPUS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	48.5	0.0	0.0	0.0	0.0	69.8
BR/MOSS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0
BR/PALM/ET	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.6	0.0	0.0	0.0	0.0	6.4
B	14.8	25.6	10.9	22.9	25.8	53.9	20.4	48.0	49.4	56.4	58.1	31.2	16.6	67.2	28.2	3.5	10.2	3.2
B/LC	0.0	39.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B/SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
LC	12.7	8.6	15.2	55.8	17.5	27.9	23.8	8.2	36.2	26.9	19.8	48.6	1.9	12.5	9.1	0.3	42.6	4.8
LC/B	0.0	3.0	0.0	0.0	0.0	0.0	2.5	0.0	3.2	0.0	0.0	0.0	0.0	10.1	47.6	0.0	0.6	0.0
LC/SC	0.0	2.5	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LC/SC/SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.7	0.0
LC/SA	0.0	0.0	0.0	1.3	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LC/SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.0	0.0	0.0	1.7	8.3	0.0	0.0	0.0	0.0	0.0	0.0
SC	5.4	13.6	2.9	12.9	7.7	2.6	16.2	8.2	0.8	11.1	5.0	4.8	0.2	6.0	1.6	0.0	25.4	0.1
SC/B	0.0	2.1	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	8.7	0.0	0.0	0.0
SC/LC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	0.0	0.0	0.0
SC/LC/B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
SC/SG	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SC/SA	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	8.1	0.0	0.0	0.0	0.0	0.0	0.0	3.2
SC/SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	2.8	0.0
LG	10.2	1.6	30.8	3.0	6.9	1.4	1.0	0.0	4.0	3.1	0.0	1.0	0.4	0.9	0.4	0.0	2.7	1.2
LG/B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0
LG/SG	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LG/SA	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SG	15.9	2.5	0.9	1.1	1.9	0.4	1.6	0.5	0.2	0.0	0.0	1.8	0.0	0.3	0.1	0.0	0.7	0.7
SG/SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0
SG/SI	0.0	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SA	3.1	0.6	7.2	1.2	3.2	0.4	1.6	2.9	0.0	1.9	0.6	2.1	0.0	0.1	0.0	22.7	1.5	1.2
SA/LC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SA/SI	0.0	0.0	4.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SA/SG	0.0	0.0	1.7	0.0	0.0	0.0	0.0	0.5	0.0	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.3	0.0	0.0	0.5	0.8	0.0	0.0	0.3	0.0	0.0	0.0	0.0	1.7	0.4	0.0
RF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0
WOOD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 7.5 **Percentages of different flow types in 18 least disturbed rivers.** Flow type categories as per Table 2.3

Flow Type	B14#	B17$	B15#	R13#	R06#	R08$	R07#	T29#	E18#	E19#	E20#	T27#	M11#	M10#	M09$	O01$	O02$	P24#
FF	0.2	0.0	0.3	0.3	0.0	0.0	0.2	0.0	1.8	1.8	0.3	0.7	0.8	0.0	0.0	0.0	0.0	0.0
BOL	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.2	0.0	5.0	0.0	0.7	0.0	0.2	0.0	0.0	0.0	0.0
CAS	3.9	0.9	8.1	3.0	6.3	0.4	4.3	1.9	1.0	12.0	14.8	10.4	1.8	6.6	0.8	2.3	4.2	2.6
CH	0.0	0.0	1.1	0.0	0.4	0.0	0.1	0.0	1.5	0.2	1.6	1.0	0.2	0.0	0.0	0.6	0.2	0.1
SPILL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
STR	1.3	0.2	4.1	0.0	1.5	0.0	4.9	0.0	0.7	0.2	2.4	0.0	3.9	0.0	0.0	0.2	0.5	0.0
BSW	0.0	0.8	0.2	0.8	0.7	0.0	0.4	0.0	10.9	12.4	7.0	0.0	1.3	1.6	2.1	3.6	0.3	0.4
USW	0.6	2.8	4.3	12.4	3.4	0.0	2.5	0.0	16.1	11.3	7.8	2.4	3.2	2.5	1.1	7.5	2.1	2.6
FRF	0.0	5.5	12.2	9.3	13.9	2.5	9.2	12.7	3.5	5.8	2.8	15.8	1.7	9.7	11.0	9.8	8.5	2.0
SRF	0.0	1.4	4.5	1.0	0.9	0.5	0.4	0.0	0.5	0.0	1.2	0.0	2.9	0.1	2.3	2.1	7.9	0.0
RS	5.8	22.1	22.2	59.3	36.3	3.2	28.4	15.2	40.8	31.7	53.1	30.7	7.7	39.6	57.1	35.3	34.4	36.3
SBT	28.5	44.4	27.0	8.4	20.6	2.2	36.3	19.2	10.3	13.7	2.2	14.4	12.0	31.6	16.5	18.1	18.1	31.6
SPF	49.3	20.4	8.8	4.3	12.2	78.9	11.6	47.5	6.4	3.9	2.9	12.9	52.2	8.5	6.9	10.7	20.0	13.7
TR	1.4	0.6	3.5	0.9	2.6	0.9	1.6	0.8	3.0	0.0	0.0	8.8	0.1	0.1	0.1	0.8	1.7	1.1
NF	11.0	0.9	2.6	0.9	1.2	11.5	0.0	2.5	3.3	1.7	3.9	4.1	12.5	2.5	2.3	8.9	1.9	9.7

Table 7.6 **Proportions of wetted morphological units within each of 18 least disturbed rivers mapped.**

Morphological Unit	B14#	B17$	B15#	R13#	R06#	R08$	R07#	T29#	E18#	E19#	E20#	T27#	M11#	M10#	M09$	O01$	O02$	P24#
Backwater	0.0	0.0	0.0	0.0	0.0	6.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.9	0.0
Bedrock Core Bar	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Bedrock Pavement	0.0	0.0	0.0	0.0	26.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.0	0.0
Bedrock Pool	0.0	0.0	0.0	0.0	14.6	0.0	9.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.1	0.0	0.0
Bedrock Rapid	0.0	0.0	29.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bedrock Step	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.7
Boulder Bank	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Boulder Bar	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Boulder Rapid	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0	0.0	0.0	0.0	0.0	28.1	0.0	0.0	0.0	0.0
Bedrock Outcrop	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bedrock Pool	0.0	0.0	0.0	0.0	0.0	62.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Canal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.9
Cataract	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.8	0.0	0.0	0.0	0.0	0.0
Flood Bench	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
Flood Channel	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Island	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1.0	0.0	0.0
Lateral Bar	0.0	0.5	0.0	0.0	0.0	6.1	3.9	0.0	8.0	0.9	0.0	0.0	0.0	0.7	0.0	0.0	8.3	0.0
Lateral Channel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.8	0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0
Lateral Channel Plane-bed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0
Lee Bar	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.7	0.0	0.0	0.0	0.1
Mid-channel Bar	0.0	0.0	2.3	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	9.9	0.0	0.0	0.0
Mid-Channel Bar Remnant	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.6	0.0	0.0	0.0
Plane-bed	0.0	0.0	0.0	78.6	48.5	15.2	26.5	0.0	40.7	6.4	26.7	40.5	0.0	0.0	34.9	0.0	67.5	0.0
Plunge Pool	46.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pool	22.3	0.0	40.4	0.0	0.0	4.7	31.4	80.1	24.8	46.4	43.7	10.7	80.4	52.8	14.3	40.1	8.0	55.9
Proto Step	0.4	0.0	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rapid	6.4	0.0	0.0	0.0	9.4	0.0	18.6	0.0	0.0	7.7	0.0	0.0	15.8	2.8	0.6	33.4	0.0	7.2
Riffle	0.0	22.0	3.7	0.0	0.0	0.0	0.0	0.0	0.0	14.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Run	0.0	77.5	4.9	21.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	28.0	0.0	0.0	0.0
Sandy Lee Bar	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sculptured Bedrock	17.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Secondary Channel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	15.0	0.0
Slump	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Step	4.0	0.0	12.5	0.0	0.0	3.3	9.8	16.9	6.8	24.6	29.6	48.8	0.0	10.1	0.0	0.0	0.0	0.0
Waterfall	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

8. BIOLOGICAL SAMPLES AND ALLIED HYDRAULIC DATA

8.1 Overview

Macro-invertebrate samples were collected at all sites listed in Table 5.1. On average 12 invertebrate samples were collected from each study site, except for the specialist studies of hydraulic biotopes, reaches and discharge-related changes, where more samples were collected as described in Sections 3.3, 3.5 and 3.7. All invertebrates were identified, both on site and in the laboratory, to the lowest possible taxonomic level (Section 8.2). Hydraulic data were collected at each invertebrate sampling point (Section 8.3) as were data on surface heterogeneity for some of the investigations (Section 8.4).

8.2 Invertebrate identifications

Identifications done in the field by project staff allowed an early understanding of the nature of each site's invertebrate community. This level of identification is approximately equivalent to the SASS identification process (Chutter 1998) used for biomonitoring purposes. In the laboratory, the preserved samples were re-assessed, with more detailed identifications, as described in section 4.5. Arrangements were made with a number of specialists to either identify different taxonomic groups or verify identifications done by project staff (Table 8.1 – list of specialists). Some groups, particularly the Chironomidae and Ephemeroptera, are very well identified, due to specialists being available and willing to work on the collections. The Trichoptera will be identified to species level by the specialist at a later stage, but not in time for the analyses here, and so many remain at genus or family level. Many groups, such as the Coleoptera, are identified only to "morph species". For the Coleoptera in particular, because both larvae and adults are aquatic, this means that a species could be represented twice, as two "morph species". Many of the identified specimens are already lodged with the Curator of Freshwater Invertebrates, Albany Museum, Grahamstown. The remainder will be lodged there at the completion of the project.

All identifications have been entered into the database (Chapter 9). Appendix 8.1 provides a summary species list for each river. These are the "biological fingerprints" used in the catchment, segment and zone analyses (Chapter 10). In the database, these species lists are disaggregated down to show the species present in each sample from each river. A separate record exists, on field data sheets and entered in an Excel spreadsheet, of the coarser, SASS-level identifications done in the field. These are not entered in the data base.

Biodiversity patterns and related attributes of this data set are addressed in Chapter 16.

Table 8.1 **Level of taxonomic identification in the laboratory for various orders and families.** Specialists confirming identifications or identifying to finer taxonomic level are listed by their specialised group. Some specialists focussed on a particular family of animals whereas others focussed on an entire order.

ORDER	FAMILY	LEVEL	SPECIALIST
ACARINA		Family / morph type	
AMPHIPODA		Family / genus, species	
ANOMOPODA		Family / morph type	
COLEOPTERA	Dryopidae	Family / genus, species / morph type	
	Dytiscidae	Family / morph type	
	Elmidae	Family / genus, species / morph type	
	Gyrinidae	Family / genus, species / morph type	
	Helodidae	Family / morph type	
	Hydraenidae	Family / genus, species / morph type	
	Hydrophilidae	Family / genus, species / morph type	
	Limnichidae	Family / morph type	
	Noteridae	Family / morph type	
	Torridincolidae	Family / morph type	
CYCLOPOIDA		Order	
DECAPODA		Family / genus	
DIPTERA	Athericidae	Family / genus / morph type	
	Blephariceridae	Family / genus, species / morph type	
	Ceratopogonidae	Family / subfamily / genus, species	
	Chironomidae	Sub-family / genus, species	Prof. Arthur Harrison
	Culicidae	Family / genus / morph type	
	Dixidae	Family / morph type	
	Empididae	Family / genus / morph type	
	Psychodidae	Family / genus / morph type	
	Simuliidae	Family / genus, species	Dr. Ferdy de Moor, in part
	Tipulidae	Family/ genus / morph type	
	Tabanidae	Family / morph type	
EPHEMEROPTERA			Mrs. Helen Barber-James, type specimens
	Baetidae	Family / genus, species / morph types	Mr. Bruce Paxton
	Caenidae	Family / genus, species	
	Ephemerellidae	Family / genus, species	
	Heptageniidae	Family / genus, species	
	Leptophlebiidae	Family / genus, species	
	Tricorythidae	Family / genus, species	

ORDER	FAMILY	LEVEL	SPECIALIST
HEMIPTERA			**Mr. Patrick Reavell, type specimens**
	Corixidae	**Family / genus, species / morph type**	
	Gerridae	Family / morph type	
	Mesoveliidae	Family / genus, species / morph type	
	Notonectidae	**Family / genus, species / morph type**	
	Pleidae	**Family / morph type**	
	Veliidae	**Family / genus, species / morph type**	
LEPIDOPTERA	Pyralidae	Family / genus	
MEGALOPTERA	Corydalidae	Family / genus, species	
NEMOTODA (phylum)		Phylum	
NEMATOMORPHA (phylum)		Phylum	
ODONATA: Anisoptera	Aeshnidae	**Family / genus / morph type**	
	Corduliidae	**Family / genus / morph type**	
	Gomphidae	Family / genus / morph type	
	Libellulidae	**Family / genus / morph type**	
ODONATA: Zygoptera	Chlorolestidae	**Family / genus / morph type**	
	Coenagrionidae	Family / genus / morph type	
	Protoneuridae	Family / morph type	
OLIGOCHAETA	Lumbriculidae	**Family**	
	Enchytraeidae	**Family**	
	Naididae	Family / genus	
PLECOPTERA	Notonemouridae	Family / genus, species	
PODOCOPIDA		Order	
TRICHOPTERA			**Dr. Ferdy de Moor, in part**
	Barbarochthonidae	Family / genus, species	
	Calamoceratidae	**Family / morph type**	
	Ecnomidae	Family / genus / morph type	
	Glossosomatidae	**Family / genus / morph type**	
	Goeridae	**Family / genus, species**	
	Hydropsychidae	Family / genus, species	
	Hydroptilidae	**Family / genus, species / morph type**	
	Hydrosalpingidae	Family / genus, species	
	Leptoceridae	Family / tribe / genus / morph type	
	Petrothrincidae	Family / genus, species	
	Philopotamidae	Family / genus / morph type	
	Polycentropodidae	Family / morph type	
	Sericostomatidae	Family / genus / morph type	
TURBELLARIA	Planaria	Family / genus	

//Table 8.1 continued.

8.3 Hydraulic data for invertebrate sampling-points

A range of hydraulically-related variables was measured wherever invertebrate samples were collected, as per the methods described in Section 4.3.4 (Table 8.2). At four to six points within the area where each invertebrate sample was collected, water depth was recorded and water velocity measured at two or more positions in the water column. Velocity was always measured at 0.6 depth and, if the water was more than 6 cm deep, a second reading was taken close to the substratum. Flow type and substratum categories were also recorded at each point, with the categories of dominant and sub-dominant substrata judged by the area covered in the immediate vicinity of the velocity-meter rod. The degree of embeddedness of large substrata in fines was estimated on a scale of 1-5. All the variables are linked to specific positions in the sites, and thus to specific MUs, through locating the invertebrate sampling points on the GIS maps (Figures 7.4b, 7.5b, 7.6b). Froude numbers were calculated as an ecologically-relevant index of hydraulic conditions (Wadeson 1995).

Table 8.2 **Example of the hydraulic data collected or calculated for each invertebrate sample.** Site code as explained in Table 5.3. Flow type and substrata codes can be found in Tables 2.3 and 2.4. An "." denotes that data were not collected in that category. In most cases 4 – 6 sets of hydraulic readings were taken for each invertebrate sample point.

River	Site Code	Date	MU[1] Type	MI[2] #	Flow Type	Dominant	Sub-Dom	Embed[3]	Depth (cm)	NB[4]	0.6[4]	Froude #
Langvlei	E19#	17-Jan-97	step 1	1	FF	B	B	1	24	0.67	0.74	0.48
			plane-bed 1	2	NF	LC	SC	2	12	0.00	0.00	0.00
			plane-bed 1	2	NF	SC	SG	2	8	0.00	.	0.00
			plane-bed 1	2	NF	SG	SC	2	10	0.00	0.00	0.00
			pool 1	3	BPF	SC	SG	2	15	0.00	0.00	0.00
			pool 1	3	BPF	LC	LG	1	12	0.01	0.00	0.00
			pool 1	3	BPF	LC	LC	1	8	0.01	.	0.01
			pool 1	3	BPF	B	LC	1	20	0.04	0.10	0.07
			pool 1	4	SBT	B	B	1	20	0.34	0.30	0.21
			pool 1	4	SBT	LC	LC	1	24	0.22	0.32	0.21
			pool 1	4	SBT	SC	LC	1	18	0.08	0.19	0.15
			pool 1	4	SBT	LC	SC	1	24	0.21	0.21	0.14
			pool 1	5	FRF	LG	SC	1	6	0.00	.	0.00
			pool 1	5	FRF	LG	SG	1	6	0.25	.	0.33
			pool 1	5	FRF	LG	SC	1	10	0.08	0.08	0.08
			pool 1	5	FRF	LG	LG	1	8	0.07	0.15	0.17
			pool 1	5	FRF	SC	LG	1	11	0.07	0.10	0.10
			step 2	6	CAS	B	B	1	14	0.63	0.63	0.54
			step 2	6	CAS	B	B	1	22	0.45	0.78	0.52
			step 2	6	CAS	B	B	1	12	0.50	0.60	0.55
			step 2	6	CAS	B	B	1	2	2.01	.	4.54
			step 2	6	CAS	B	B	1	12	1.26	1.32	1.22
			riffle 1	7	USW	LC	SC	1	18	0.44	0.56	0.42
			riffle 1	7	USW	LC	SC	1	20	0.27	0.66	0.47
			riffle 1	7	USW	LC	LC	1	12	0.34	0.30	0.28
			riffle 1	7	USW	LC	LC	1	10	0.40	0.53	0.54

[1]MU = morphological unit
[2]MI = macroinvertebrate sample number (provides the link to all identified and catalogued invertebrates, and to a position on the relevant GIS map)
[3]degree of embeddedness of large bed elements in fine sediments in the range 1 to 5: 1 = no embeddedness; 2 = low; 3 = moderate; 4 = high; 5 = large elements barely showing
[4]NB = near bed velocity (m s^{-1}); 0.6 denotes depth at which mean water column velocity (m s^{-1}) was measured from the surface of the water as a ratio of total depth

8.4 Bed heterogeneity for invertebrate sampling points

Physical heterogeneity of the surface of the riverbed in each area where invertebrates were sampled was measured as described in Section 4.3.5 (Table 8.3). An early recognition of the type of river bed described in each case can be obtained by ascertaining the difference between the longest and shortest rod lengths and comparing this with the size range of different substrata categories (Table 2.4).

These data will be used to calculate an index of heterogeneity for each invertebrate sample in the studies of hydraulic biotopes (Chapter 12) reaches (Chapter 13) discharge (Chapter 14). The index is currently being developed by DM Schael as part of her PhD thesis.

Table 8.3 **Example of bed heterogeneity "roughness" trace data for invertebrate sample 4 of the Eerste River Intensive Sampling programme.** Two profiles were completed for each sample point, one perpendicular to the banks and one parallel (RB = right bank; LB = left bank; US = upstream; DS = downstream).

trace code	start	end	rod #	length (mm)
X4	US	DS	1	173
X4	US	DS	2	175
X4	US	DS	3	178
X4	US	DS	4	180
X4	US	DS	5	183
X4	US	DS	6	184
X4	US	DS	7	185
X4	US	DS	8	187
X4	US	DS	9	187
X4	US	DS	10	187
X4	US	DS	11	188
X4	US	DS	12	189
X4	US	DS	13	188
X4	US	DS	14	187
X4	US	DS	15	185
X4	US	DS	16	180
X4	US	DS	17	171
X4	US	DS	18	157
X4	US	DS	19	159
X4	US	DS	20	160
X4	US	DS	21	161
X4	US	DS	22	161
X4	US	DS	23	162
X4	US	DS	24	164
X4	US	DS	25	164
X4	US	DS	26	166
X4	US	DS	27	168
X4	US	DS	28	169
X4	US	DS	29	172
X4	US	DS	30	173
X4	US	DS	31	175
X4	US	DS	32	178
X4	US	DS	33	180
X4	US	DS	34	180
X4	US	DS	35	182
X4	US	DS	36	182
X4	US	DS	37	181
X4	US	DS	38	182
X4	US	DS	39	182
X4	US	DS	40	182
X4	US	DS	41	182
X4	US	DS	42	182
X4	US	DS	43	183
X4	US	DS	44	182
X4	US	DS	45	183
X4	US	DS	46	182
X4	US	DS	47	180
X4	US	DS	48	179
X4	US	DS	49	179
X4	US	DS	50	178

trace code	start	end	rod #	length (mm)
Y4	LB	RB	1	185
Y4	LB	RB	2	178
Y4	LB	RB	3	185
Y4	LB	RB	4	171
Y4	LB	RB	5	169
Y4	LB	RB	6	165
Y4	LB	RB	7	162
Y4	LB	RB	8	159
Y4	LB	RB	9	153
Y4	LB	RB	10	115
Y4	LB	RB	11	95
Y4	LB	RB	12	94
Y4	LB	RB	13	131
Y4	LB	RB	14	135
Y4	LB	RB	15	135
Y4	LB	RB	16	101
Y4	LB	RB	17	118
Y4	LB	RB	18	130
Y4	LB	RB	19	142
Y4	LB	RB	20	150
Y4	LB	RB	21	155
Y4	LB	RB	22	160
Y4	LB	RB	23	165
Y4	LB	RB	24	168
Y4	LB	RB	25	170
Y4	LB	RB	26	172
Y4	LB	RB	27	174
Y4	LB	RB	28	176
Y4	LB	RB	29	178
Y4	LB	RB	30	179
Y4	LB	RB	31	179
Y4	LB	RB	32	182
Y4	LB	RB	33	185
Y4	LB	RB	34	186
Y4	LB	RB	35	188
Y4	LB	RB	36	190
Y4	LB	RB	37	192
Y4	LB	RB	38	194
Y4	LB	RB	39	195
Y4	LB	RB	40	196
Y4	LB	RB	41	198
Y4	LB	RB	42	200
Y4	LB	RB	43	200
Y4	LB	RB	44	201
Y4	LB	RB	45	200
Y4	LB	RB	46	198
Y4	LB	RB	47	192
Y4	LB	RB	48	183
Y4	LB	RB	49	166
Y4	LB	RB	50	151

9. THE DATABASE

9.1 Overview

The database was designed for two primary reasons. Firstly, a facility was needed to efficiently store and access all data generated on this project, especially the descriptive data. Secondly, so many physical-biological linked data were collected within the project, that the opportunity was created to initiate a national database along the same lines as the chemical-biological one created by Dallas *et al* 1998 and Dallas & Janssens (1998). This would enable others collecting similar data to contribute to and access the database for future national studies. In keeping with this second purpose, the database for this project has been developed to be compatible, either for future linkage or as a companion to, the Biobase and SASS databases developed by Dallas *et al.* (1998) and Dallas & Janssens (1998). As these previous databases were designed primarily for linked chemistry and invertebrate data, modifications were made to focus in on physical variables. Although the bulk of the present data refer to once-off visits to river sites, the database has the flexibility for adding additional sampling dates and sites.

9.2 Structure

The database consists of interconnected tables, each table housing a specific set of interrelated data. Each of these tables connects to at least one, if not many, other tables within the database structure. Some variables carry over from one data set to the other, e.g. site code or site name, which then connect different types of data. One table, "Site", forms the root of the database (Figure 9.1). This table contains all the information on reach river site that remains relatively constant, such as river name, site code, altitude, longitude and latitude, access details, stream order, whether the initial visit was a once-off or recurring study. This central table links, for example, to the "Site Visit" table, which lists the dates on which each site was visited, or to the "Site Visit Transect" table which details all the channel cross-section data.

Data tables are often supported by what are referred to as 'look-up' tables. These tables are created to support and streamline data entry. Terms that are often used when entering data can be put into these tables and accessed. This makes the data-entry process faster, as it is not necessary to repeatedly type the same thing, as well as consistent throughout the database, as misspellings are avoided. These 'look-up' tables generally only connect with one specific type of data table.

9.3 Data entry

For ease of data entry, a form-style interface was designed. An initial icon form appears from which the user can choose the type of data that will be entered. There is currently a "Sites" option which will take the user into the list of rivers and sample dates previously entered, as well as giving the user the option to add another river, another site to a river, or another sampling date. From that screen, one can move into a series of tabbed forms to add various site descriptors (for new sites) and other general information. Alternatively, if there are specific data on, say, invertebrates or local hydraulics to be entered, one moves into a different screen. This is menu/button driven, so that the user can choose the required category for data entry.

The second and third options on the main interface refer to background tables that aid in the general data entry. These options are "Picklist" and "Taxonomy". The "Picklist" option is used to add information to the look-up tables. For example, if a new morphological unit is added to the general terminology, it can be entered into the look-up table for morphological units. Units that are not in the look-up table cannot be added into the database linked to a site. The "Taxonomy" interface is much the same as the "Picklist", but at a larger and more complex scale. All possible taxa, both faunal and floral, must be entered into "Taxonomy" before they can be entered into the database linked to sites. This is the heart of the biological component of the database, and its most complex part. The very large look-up table contains its own series of supporting look-up tables, and any mistakes made in creation of this component transfer through the entire database. On the positive side, corrections of mistakes in one area are automatically carried through all interconnected data.

9.4 Using the Database

A "Query Centre" for the database was designed to facilitate access to any required type of data and its linked data. One of the major strengths of a database is the facility it provides to access specific data. The Query Centre is not fully automated, as there are hundreds of possible requirements for linked data. However, there is sufficient structure to answer such queries as "all the flow types in which *Baetis* sp X has been found". With experience, more sophisticated links will be made by users.

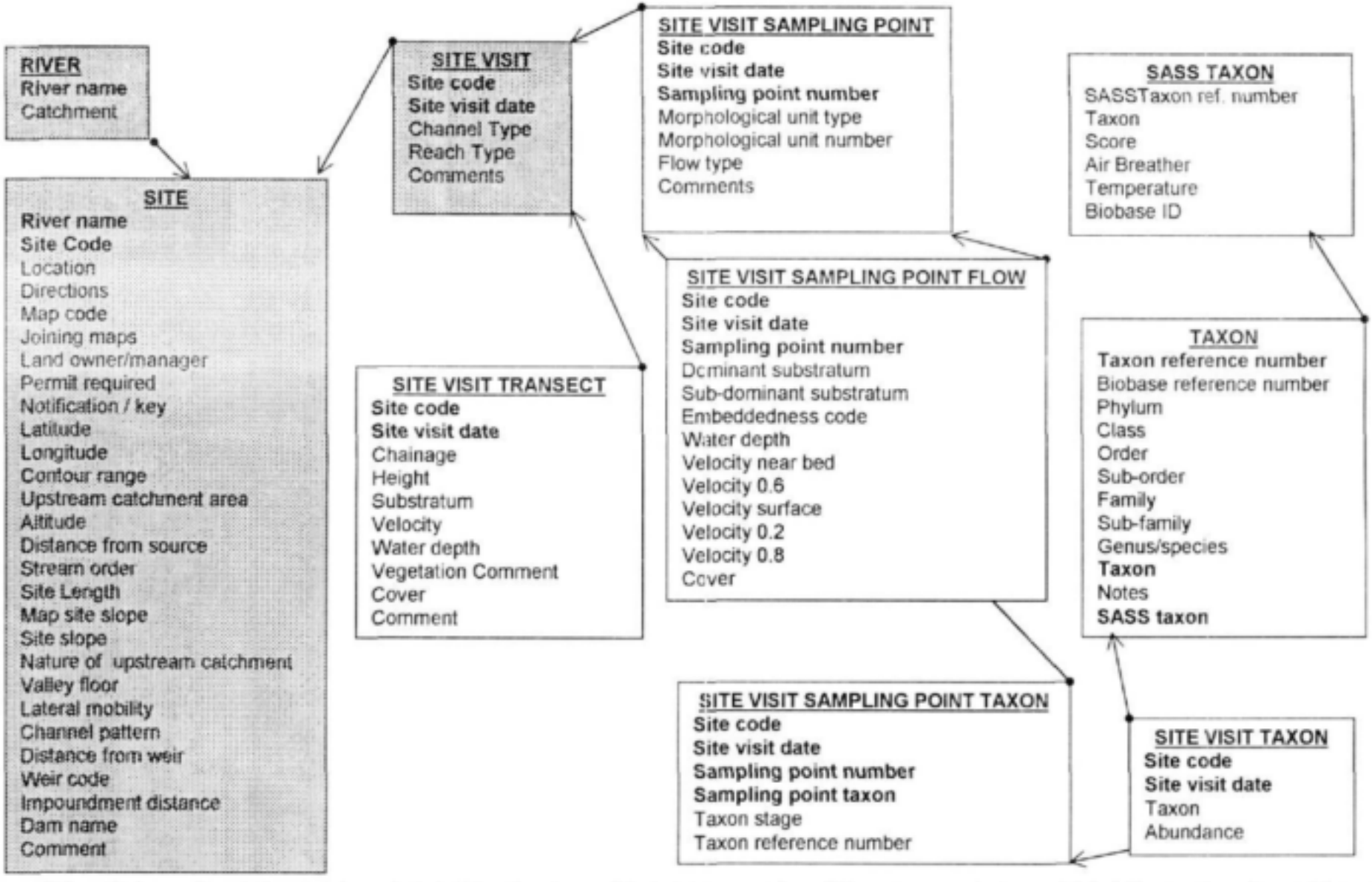


Figure 9.1a **Schematic of the databae data table structure.** Each tab e contains different types of data, which links to other data tables. The bold print indicates linked variables, arrows from each box show connectivity. The "look-up" tables are not included in this schematic because of the complexity. Shaded boxes are repeated in Figure 9.1b to continue linkages.

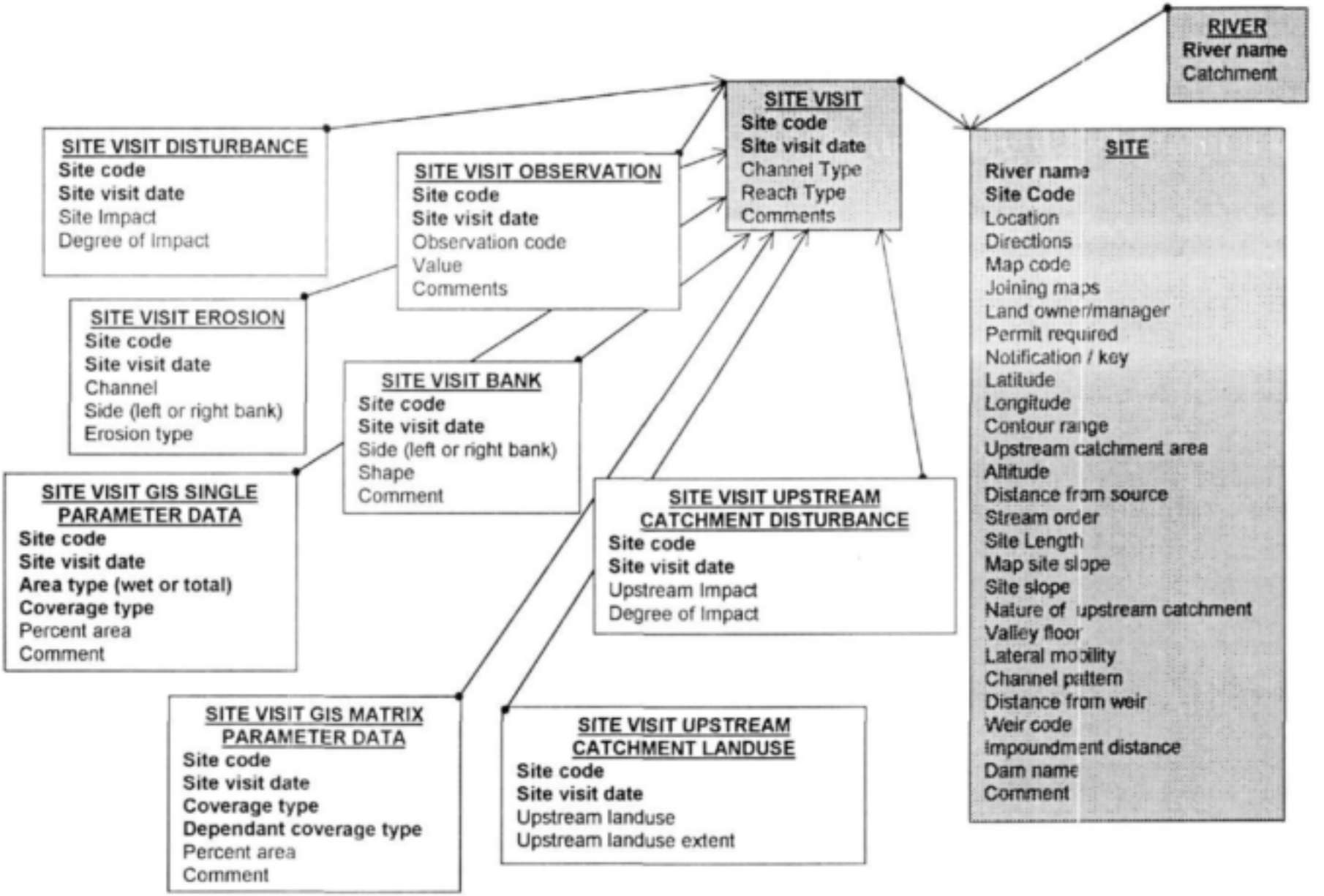


Figure 9.1b As in Figure 9.1b. Shaded boxes presented in Figure 9.1a are shown here to clarify the table linkages.

10. CATCHMENTS, SEGMENTS AND LONGITUDINAL ZONES

10.1 Recap

The first aim listed for this project (Section 3.2) was to test the biological significance of the highest levels of the geomorphological hierarchy – the catchment, segment and longitudinal zones. This would be done by grouping invertebrate data from study sites on many rivers, to identify similar rivers and river zones, and then comparing these with the geomorphological grouping of the sites (Chapter 6). It was assumed that;

- the invertebrate communities would distinguish different kinds of rivers and river zones;
- these communities could be adequately represented by "biological fingerprints" of the sites they inhabited.

Each "fingerprint" would consist of a composite species list, compiled from samples collected from a range of hydraulic conditions of that site.

Twelve invertebrate samples were thus collected from the widest available range of physical-habitat conditions, at a study site on each of 18 least-disturbed Western Cape headwater streams (Chapter 5). All samples were collected during summer low flow, the invertebrates identified to species, and a species list created for each site (Appendix 8.1). Each species was assigned an abundance rating in each sample, on a scale of 1 to 5 (Table 10.1). The average abundance was then calculated for each species at each site by averaging its abundance rating from all twelve samples. It was not possible to make fully quantitative assessments of abundance, because sample points differed in size depending on the nature of the targetted hydraulic habitat, and many were narrow, gorge-like crevices covering little of the plan area of the site.

Table 10.1 Abundance ratings for species.

Rating	Numbers of animals per sample
1	1
2	2 - 6
3	7 - 20
4	21 - 100
5	> 100

An increasingly recognised approach for analysing benthic community data (Field *et al.* 1982; Clarke & Ainsworth 1993) was then employed to analyse the data, in the following sequence:

- species data were transformed, to achieve a balance between the influences of common and rare species;
- species data were converted to a triangular matrix of similarity between every pair of sites, using the similarity coefficient of Bray-Curtis which does not take into account joint absences;
- non-metric Multi-Dimensional Scaling (MDS) techniques were then used to display the biotic relationships between sites;
- patterns in the biotic analyses were interpreted in terms of the environmental data collected at the same time as the biotic data.

PRIMER (Clarke & Warwick 1994) was used to cluster the site samples and produce MDS ordination plots, using data at the taxonomic levels of phylum, family, genus and species. The package was also used to investigate characteristic species assemblages of each group of sites, and relationships between the biotic and environmental data.

The following descriptions of analyses have been guided by extensive reference to *User Guide to PRIMER v3.1b* from the Plymouth Marine Laboratory in England.

10.2 Biologically-defined groups of sites

Based on an initial field identification of invertebrates (mostly at family level), the sites were expected to form three groups of similar rivers: bedrock rivers, alluvial mountain rivers and alluvial foothill rivers. Employing the CLUSTER module in PRIMER to analyse the comprehensive set of laboratory identifications produced a different picture however. Data on abundances were used without transformation, as described in Section 10.1. When phylum-level identifications were used, there was an overall similarity between samples of 70%, but bedrock and alluvial sites were mixed (Figure 10.1). There was no clear grouping of mountain or foothill rivers, although most of the foothill sites were within one of the larger groups.

Family-level identifications of the same invertebrate samples produced a 55% similarity between sites (Figure 10.2). The weak foothill grouping disappeared, bedrock sites were not grouped, but a few sites within specific catchments were grouped. In particular, the two sites on Table Mountain appeared together, as did the three sites from the Jonkershoek valley (Eerste River).

Further identifications to the genus level reduced the similarity between sites to 35% (Figure 10.3). Again, the bedrock sites did not appear as a main grouping, although they tended to cluster together within any one main group. The catchment links were slightly stronger, with the Table Mountain and Eerste groups still present, and a Breede group forming. A Molenaars group was also forming linked to the Eerste group, although one Molenaars site, the bedrock site, remained remote. The two Olifants sites were grouped together, with two Berg sites.

Using species-level identifications, overall site similarity was reduced to 26%, and a clear catchment signature was apparent. Five catchment groups were present: the Olifants-Berg, Table Mountain, Breede, Eerste-Molenaars, and Palmiet (Figure 10.4). The groups of sites that had first become apparent at higher taxonomic levels, showed decreasing similarity through the lower taxonomic levels. The Table Mountain sites, for instance, decreased from a 66% similarity at family level through 45% similarity (genus) to 34% similarity at species level. The three Eerste sites were 77% similar at family level, 65% at genus level and 56% similar at species level.

Three other main trends emerged from the analysis. Firstly, in multi-catchment groupings, the rivers retained their identities: the Berg sites were more similar to each other than to their group's Olifants sites, and similarly the Eerste sites grouped tightly within the Eerste-Molenaars group. This suggests a river signature within the catchment signature, with every river having a distinctive invertebrate community.

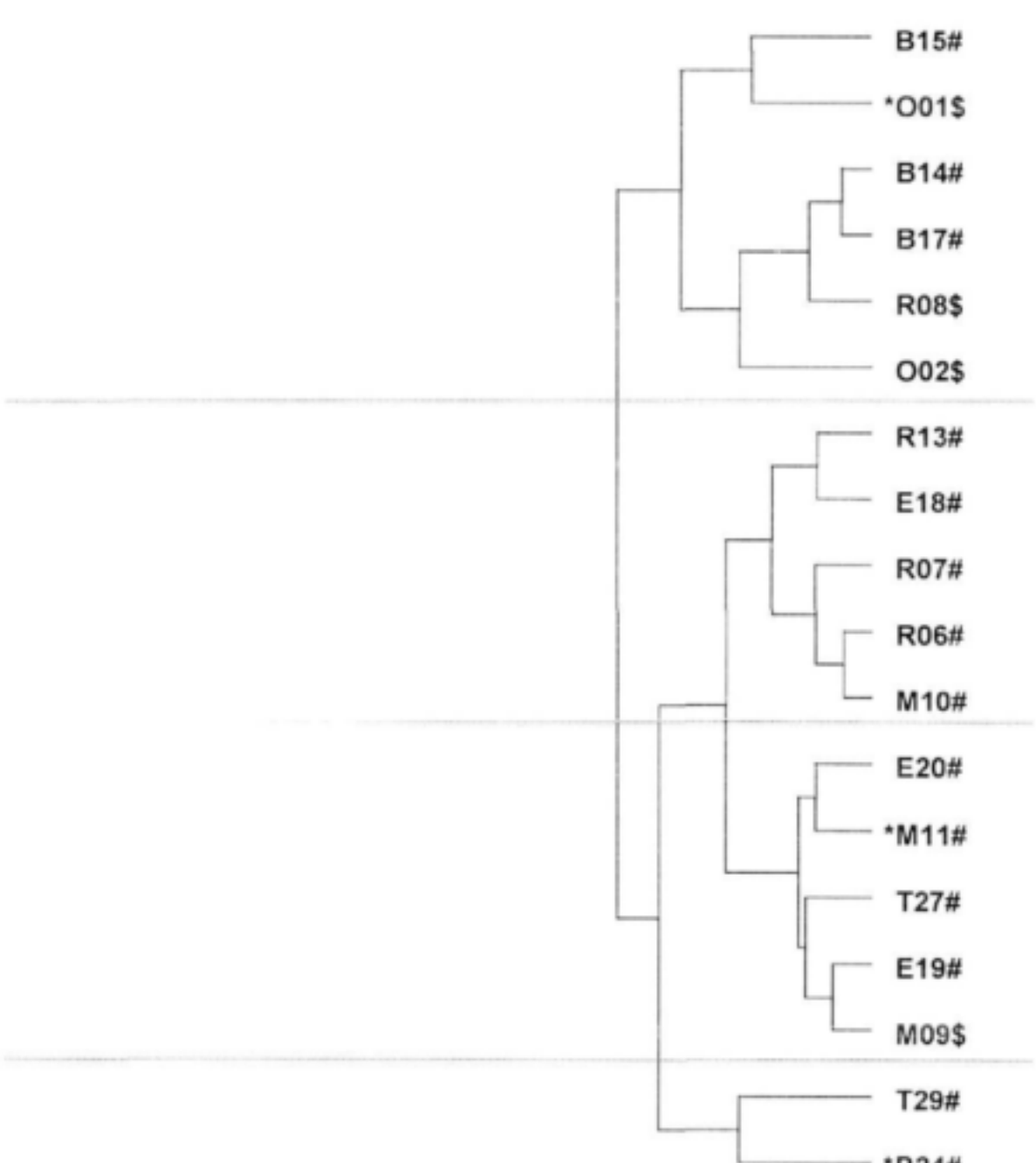


Figure 10.1 **Dendrogram of the 18 sites on least-disturbed rivers, using phylum-level data of invertebrates derived from twelve invertebrate samples at each site.** # = pre-identified as biological mountain zone and $ as a biological foothill zone as per Table 5.1. An * denotes those streams that have bedrock as their dominant substratum.

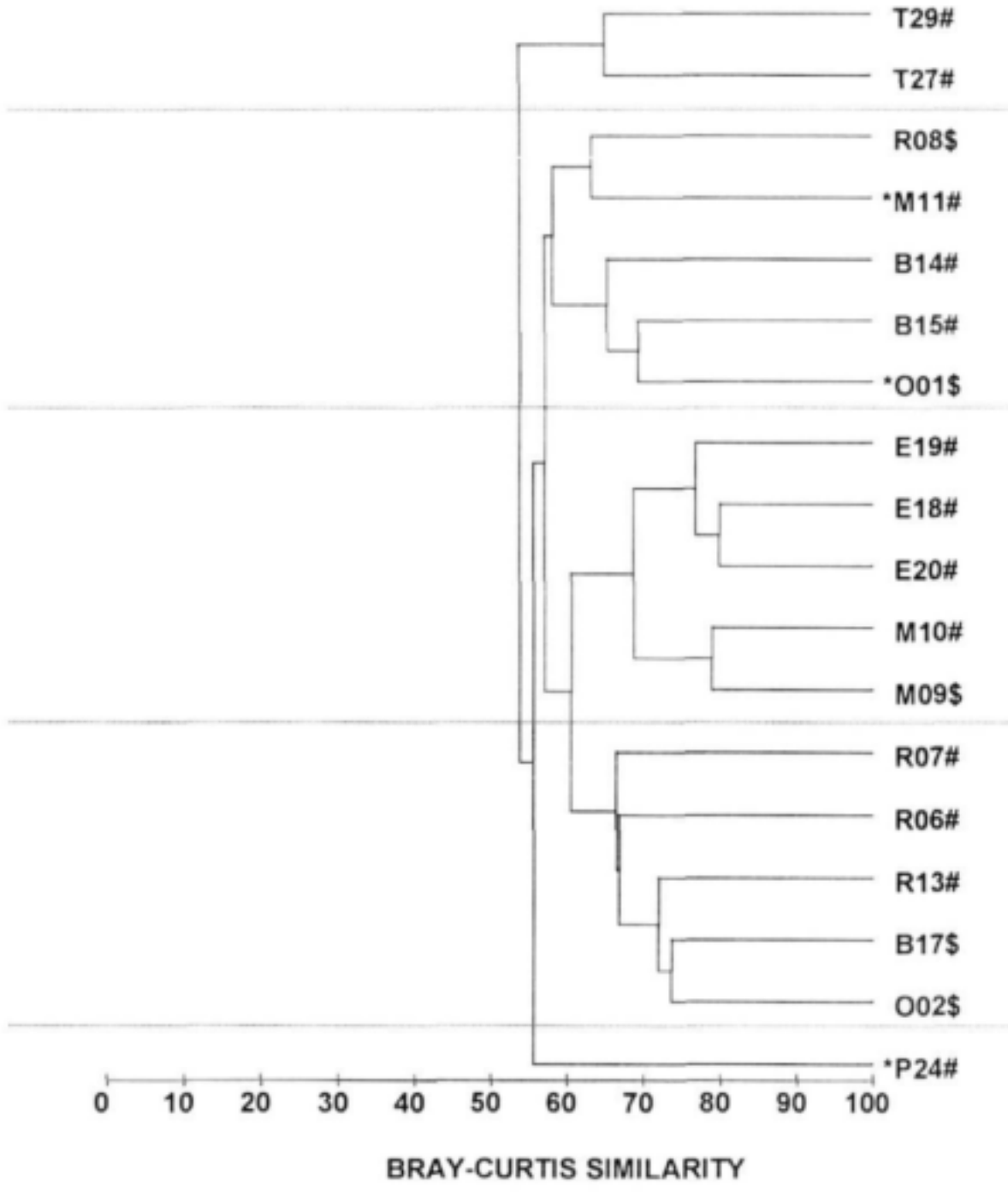


Figure 10.2 Dendrogram of the 18 sites on least-disturbed rivers, using family-level data of invertebrates derived from twelve invertebrate samples at each site. # = pre-identified as biological mountain zone and $ as a biological foothill zone as per Table 5.1. An * denotes those streams that have bedrock as their dominant substratum.

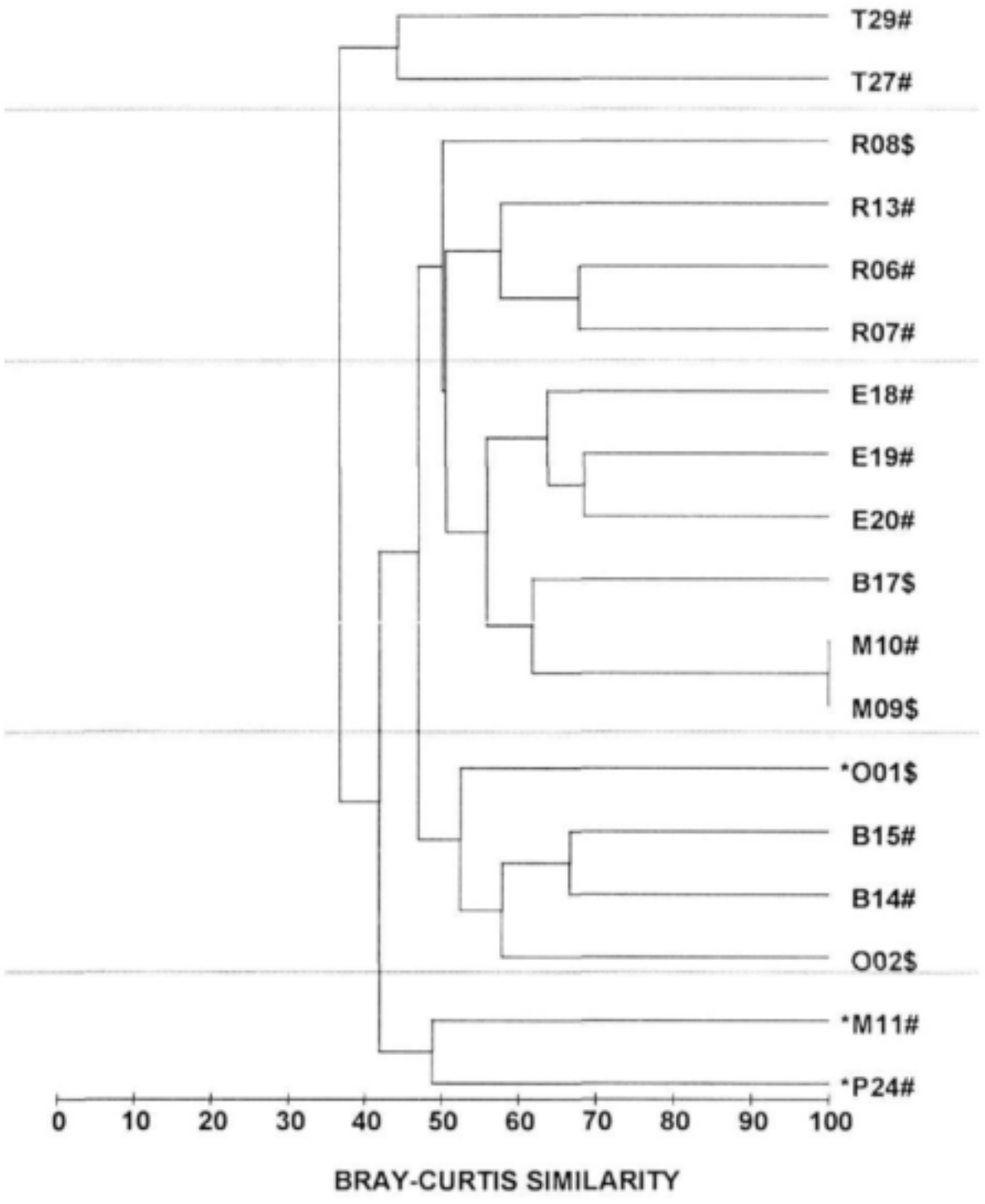


Figure 10.3 Dendrogram of the 18 sites on least-disturbed rivers, using genus-level data of invertebrates derived from twelve invertebrate samples at each site. # = pre-identified as biological mountain zone and $ as a biological foothill zone as per Table 5.1. An * denotes those streams that have bedrock as their dominant substratum.

Figure 10.4 **Dendrogram of the 18 sites on least-disturbed rivers, using species-level data of invertebrates derived from twelve invertebrate samples at each site.** # = pre-identified as biological mountain zone and $ as a biological foothill zone as per Table 5.1. An * denotes those streams that have bedrock as their dominant substratum.

At this stage, no explanation can be offered as to why these two groups, and not others, each consist of two catchments. The catchments are not geographically closest (Figure 5.1), nor is there any obvious underlying geological cause (James Willis, Department of Geology, UCT, pers. comm.)

Secondly, within each catchment group, bedrock sites were least similar to other sites, illustrated by them separating from the other sites at the lowest similarity. Thus, within the Olifants-Berg group, the bedrock site in the Jan Dissels split off first, as did the bedrock Elandspad site in the Eerste-Molenaars group. The bedrock site in the Dwars was the sole member of the Palmiet catchment group.

Thirdly, within the remaining alluvial or mixed bedrock-alluvial sites in each group, the foothill sites then separated from the mountain sites, and usually split from the main group first. This suggests that the mountain sites had greater within-group similarity than any other kind of site, which is perhaps not surprising as headwater reaches are usually less affected by anthropogenic disturbance than are lower reaches.

There is one anomaly in the species-level clusters: a Berg River site within the Breede catchment group. This site is approximately 1 km upstream of an inter-basin transfer (IBT) of water from the Breede catchment. A WRC project on the effects of IBTs used the Berg River immediately downstream of this IBT input as a study reach (B.R.Davies, UCT, pers. comm.). The researchers reported that each summer, when Berg River flow was low and the volume of IBT input high, the invertebrate assemblage in the downstream reach differed from that upstream of the IBT. However, each winter, when Berg River flow was high and IBT releases low, the downstream assemblage reverted to being similar to the upstream one. The samples taken in the project reported on here were collected in summer, i.e. when the invertebrate assemblage was in its "changed" state, but as noted they were taken upstream of the IBT tunnel. We speculated that if the IBT was impacting upstream invertebrate assemblages, it could be through *multivoltine (= more than one generation per year) species with aerial adults. It might be possible for these* species to pass through the tunnel as aquatic eggs, larvae or nymphs, emerge as adults, fly upstream to lay eggs, and produce a new generation in the same summer. One ephemeropteran, *Labeobaetis sp. nov. 1*, possibly met these criteria (we assumed multivoltinism, which is common in baetids). This species occurred in three of the four Breede sites, the linked Berg site but not the other two Berg sites, and was absent from all the 11 sites on other least-disturbed rivers. Other species common at the Breede and linked Berg sites but absent at the other Berg sites were *Elpidelmis sp A, Atherix sp 2,* and *Polypedilum E sp.* These species also occurred in other rivers however. At this stage, we can only offer as an hypothesis for testing, that the IBT is having an upstream impact on aquatic invertebrate assemblages during the summer.

An alternative way of viewing the grouping of samples is through their ordination by multi-dimensional scaling. Using the MDS module in PRIMER and the same invertebrate abundance data, a plot is constructed in a specified number of dimensions, which attempts to satisfy the conditions imposed by the underlying similarity matrix. Similar samples will be closer to each other on the plot than to dissimilar ones. There will be some distortion or stress between the similarity rankings and the corresponding distance rankings, and the MDS module seeks to minimise this in its configuration of the points. Stress increases as dimensionality decreases (i.e. 2-dimensional plots have higher inherent stress levels than 3-dimension ones) and with increasing amounts of data. A rough rule-of-thumb guide for 2-dimensional plots is that a stress level of:

- <0.1 corresponds to a good picture with little chance of mis-interpretation of the data;
- <0.2 corresponds to a potentially useful picture of the relationship between samples;
- >0.3 approaches a random distribution of the points on the plot.

MDS plots of the phylum, family, genus and species are provided (Figures 10.5 – 10.8). The same trend emerges as with the cluster analysis, with the catchment and river signatures becoming increasingly apparent from phylum to species. The stress level is low for phylum (0.06), and somewhat higher for the remaining taxonomic levels though actually decreasing slightly from family (0.17) to species (0.15) despite the increasing amount of data. Two new relationships emerge from the species plot. Firstly, the two Table Mountain sites are placed on opposite sides of the plot, indicating a lower similarity than might be assumed from the cluster plot (Figure 10.4). Although they both have boulder beds, they are indeed, quite different, with the Disa (T29#) being a very small stream under a dense canopy, and the Newlands (T27#) having a wide, scoured bed with no canopy. Secondly, the bedrock streams (Dwars, P24#; Jan Dissels, O01$, and Elandspad, M11#) are located at the periphery of the plot, and furthest from the other rivers in their groups. This results in an inner core of alluvial rivers, with a mild suggestion of cobble-bed rivers closer to the centre than boulder-bed rivers.

10.3 Testing for statistically significant differences between sites

Primer was used to explore the *a priori* assumption that, in terms of invertebrate communities, the sites would group by biological zone (mountain and foothill) and by substratum (alluvial or bedrock). To test this, the species-level similarity data were used in the module ANOSIM2 (Two-way Analysis of Similarity), which is designed for assessing data with no replicates.

The results of the comparison between the pre-determined mountain and foothill sites produced a ρ-value of 0.38 at a significance level of 0.12, showing that there was a slight pattern of significant difference between the two based on zone, but at a low confidence level. No strong conclusion could be made from this test on the effect of biological zone on site, as far fewer of the sites were in the foothill zone (5) than in mountain zone (13), creating an imbalance that lessens the power of the statistical test.

Comparing sites with bedrock, alluvial or mixed substrata produced a ρ-value of 0.0 at a significance level of 0.53, indicating that there were no significant differences in species assemblages between the three types of sites. However there is a high likelihood (53%) that this determination could be incorrect. The result probably stemmed from the fact that only three bedrock and three mixed-substrata sites were included, compared with 11 alluvial sites, causing the power of the test to be low.

ANOSIM2 was then used to test the effect of catchment on site groupings. The results were similar to those obtained for biological zones, with a ρ-value of 0.31 at a significance level of 0.12. Again a pattern of significant difference between catchments was shown, as was seen in the CLUSTER analysis for species level, but not clearly and not with a high level of confidence. The same problems appeared as before, with strong conclusions prohibited by an insufficient number of sites in each catchment.

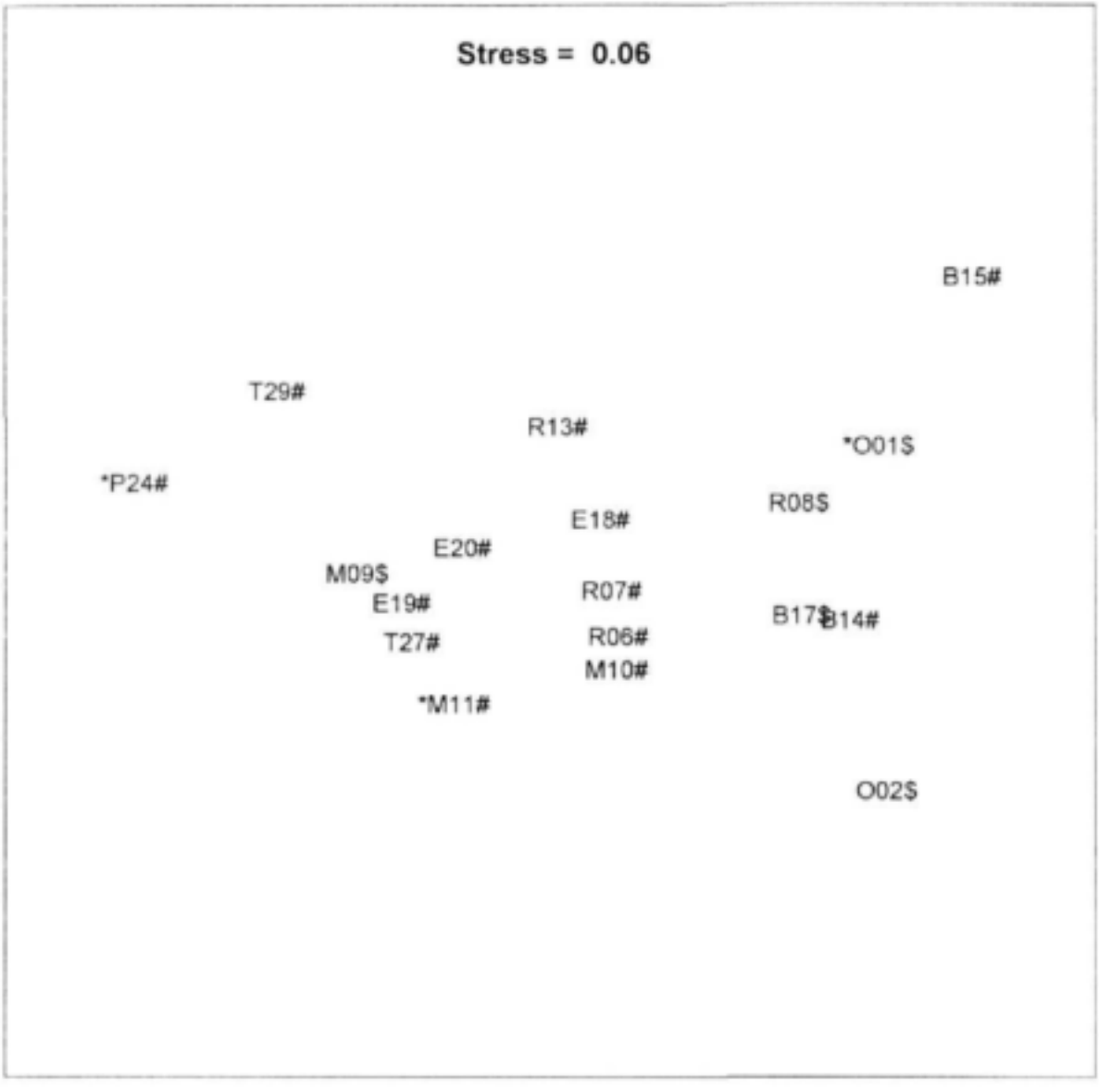


Figure 10.5 Two-dimensional MDS configuration of 18 sites on least-disturbed rivers, using phylum-level data of invertebrates. # = pre-identified as biological mountain zone and $ as a biological foothill zone as per Table 5.1. An * denotes those streams that have bedrock as their dominant substratum.

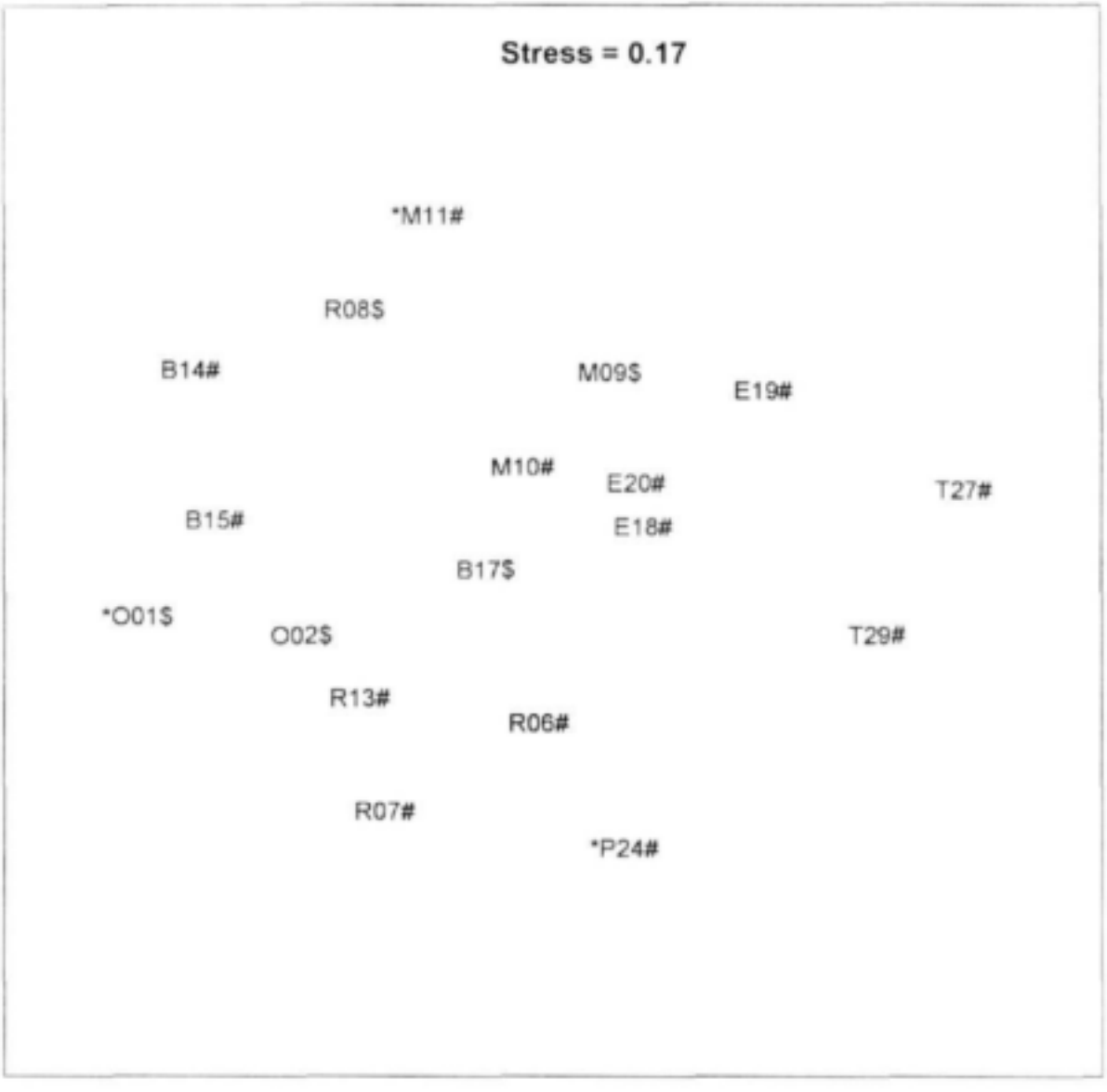


Figure 10.6 Two-dimensional MDS configuration of 18 sites on least-disturbed rivers, using family-level data of invertebrates. # = pre-identified as biological mountain zone and $ as a biological foothill zone as per Table 5.1. An * denotes those streams that have bedrock as their dominant substratum.

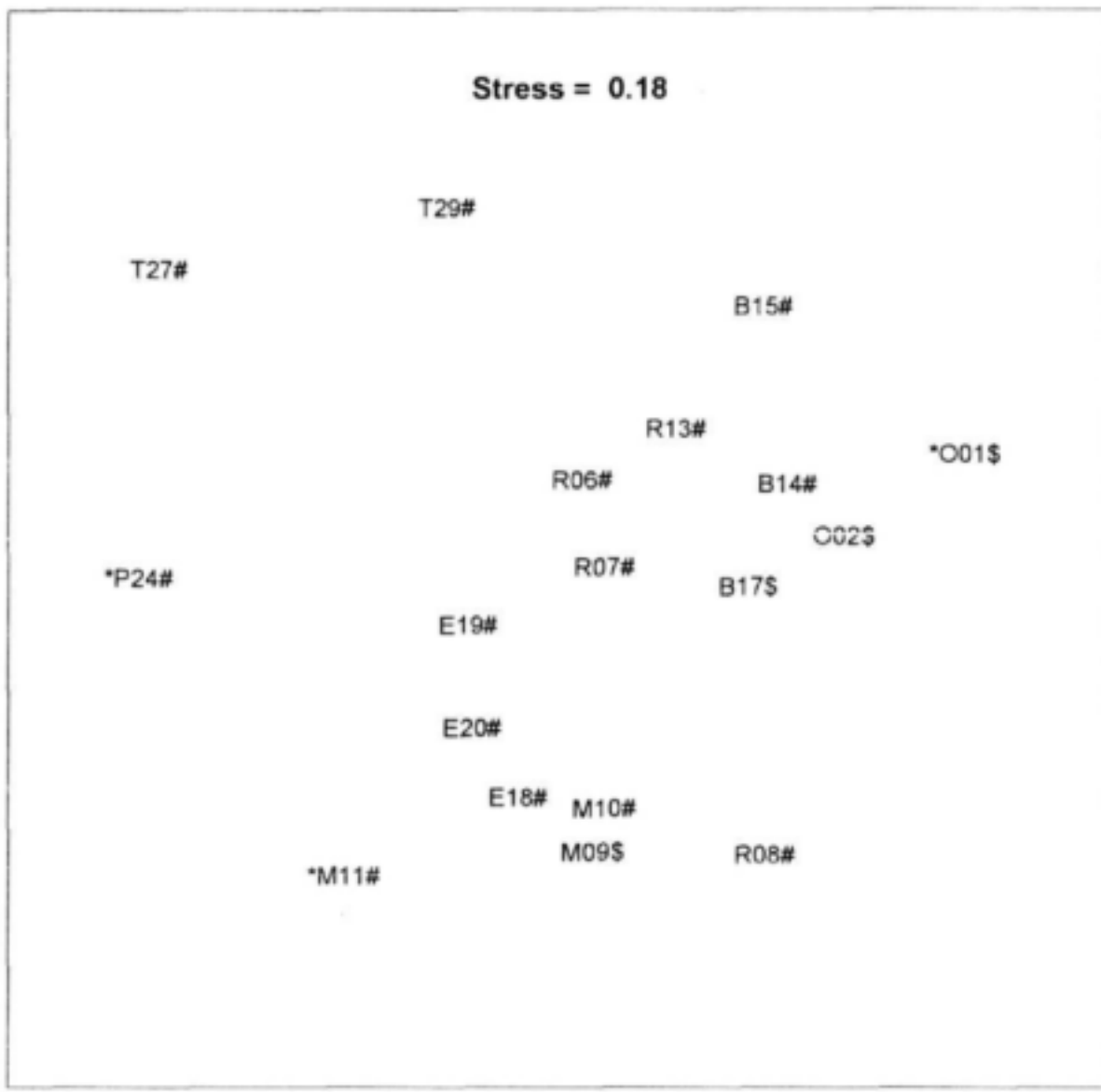


Figure 10.7 Two-dimensional MDS configuration of 18 sites on least-disturbed rivers, using genus-level data of invertebrates. # = pre-identified as biological mountain zone and $ as a biological foothill zone as per Table 5.2. An * denotes those streams that have bedrock as their dominant substratum.

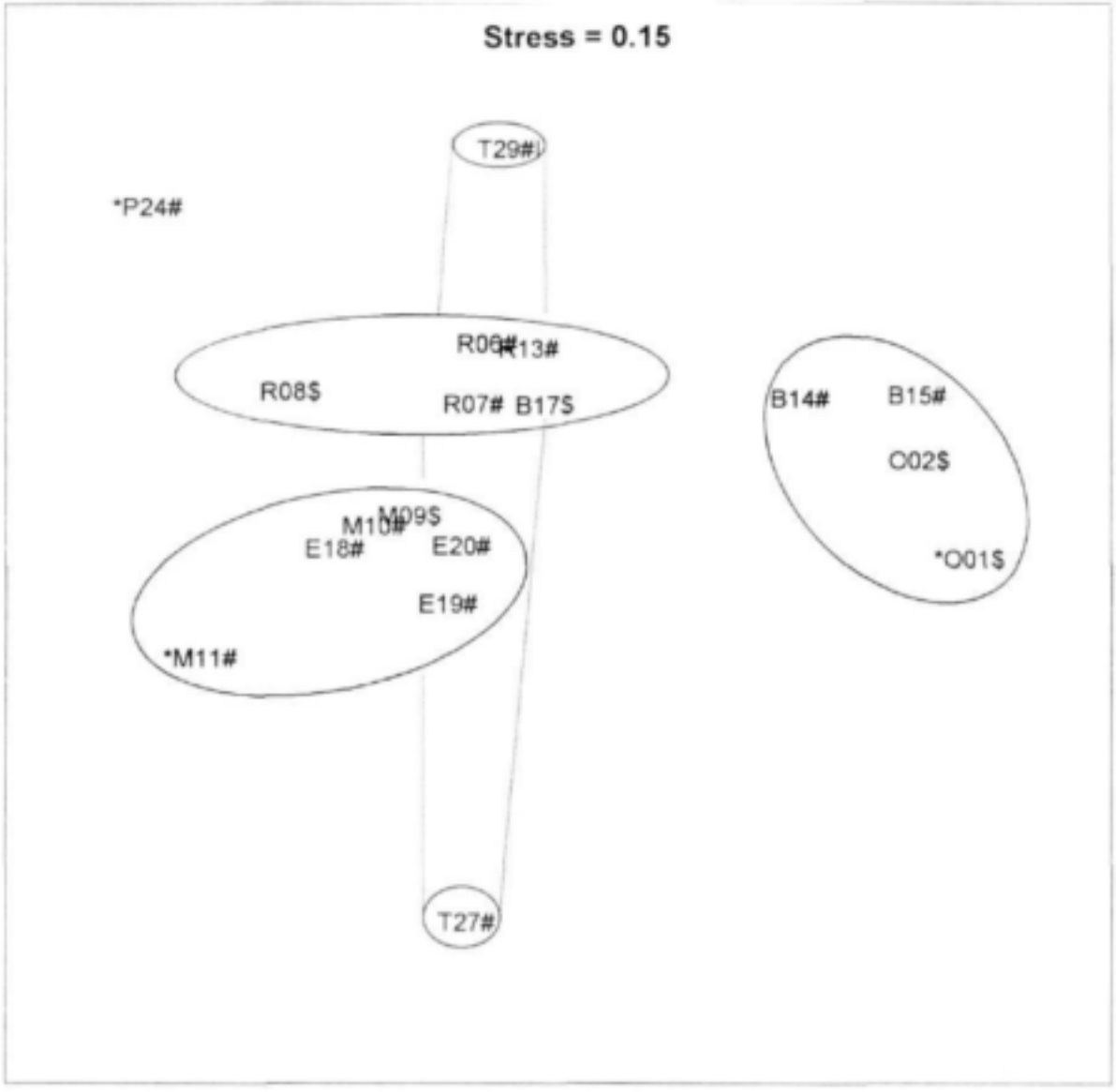


Figure 10.8 Two-dimensional MDS configuration of 18 sites on least-disturbed rivers, using species-level data of invertebrates. Each group identified by the cluster analysis shown in Figure 10.4 is denoted by circles. # = pre-identified as biological mountain zone and $ as biological foothill zone as per Table 5.1. An * denotes those streams that have bedrock as their dominant substratum.

Testing other combinations, such as bed types within biological zone or biological zone within catchment, was not possible. This was because of the low numbers of sites in each combination; for instance, there was only one bedrock river in a foothill zone. It was concluded that in general the data were not well suited to using ANOSIM, and clustering techniques and MDS ordinations were more appropriate.

10.4 Correlation between biological groupings and environmental variables

Clarke & Ainsworth (1993) describe an approach for ascertaining the environmental variables that best "explain" the biological distribution patterns. It is based on the premise that pairs of samples with similar values for a suite of measured environmental variables should have a similar species assemblage, as long as the variables determining assemblage structure – and only those variables – are used. Thus an ordination of sites, using the relevant variables, should resemble one based on the species data. Different combinations of variables can be tested to derive the best match between the two ordinations, i.e. the set of environmental variables that best explain the biotic structure of the sites. The match will be poorer if key environmental determinants of assemblage composition are missing, or if variables are included that have no effect on the species composition of the assemblage. Although the similarity matrix for the biota is created only once, that for the environmental variables is constructed for all possible combinations at each level of complexity (the levels differing in the number of variables included).

Clarke & Ainsworth (1993) stated that comparing the separately constructed biotic and abiotic ordinations in a pattern-matching exercise places few constraints on the nature of the links between species and environment. Unlike the constraints of linear relationships assumed by classical statistical methods, the approach allows a mixed set of biotic-abiotic relationships, with some species linearly related to an environmental gradient, others non-linearly but monotonically related and others non-monotonic over ranges of one or more variables. Similarity between the matrices is measured using the harmonic rank correlation (weighted Spearman coefficient), which would have a value of 1.000 if there was a perfect match.

Using the BIOENV module in PRIMER, a suite of environmental variables for the 18 river sites was analysed for combinations that could account for the groupings shown in Figures 10.4 and 10.8. Initially, 13 variables were analysed for all 18 least-disturbed sites. These included variables linked to location (stream order, distance to source, channel width), topography (altitude, slope), physico-chemistry (conductivity, water temperature, colour) and to general vegetative appearance of the site (percent cover of algae, macrophytes, mosses, CPOM and FPOM). This produced a poor weighted Spearman rank correlation with the biotic matrix, with the best value of 0.408 provided by conductivity, algae and mosses. In a second run, all the vegetative variables were excluded and one new one (*Scirpus*) added along with geomorphological variables describing substratum (bedrock, boulders, cobbles, gravel) (Table 10.2). The single variable then best explaining the biotic groupings was *Scirpus*, which occurs primarily as a mat on bedrock streambeds. The correlation value was a low 0.334, indicating that this variable poorly reflected the biotic groupings. Four topographical or geomorphological variables (altitude, boulder, cobble and gravel) and one water-quality variable (conductivity) produced the overall best value of the correlation index (0.491). Water temperature and slope contributed least to the biotic pattern, and were discarded in a third run, whilst moss, macrophytes and algae were re-introduced. The same five variables produced the

same correlation value. The four geomorphological variables alone produced a slightly lower correlation value of 0.475.

Table 10.2 Variables used and coefficients derived from the BIOENV matching exercise of biotic and abiotic similarity matrices of the 18 least-disturbed rivers. An "*" indicates overall best match.

Number of variables	Best variable combinations (ρ_w)
1	*Scirpus* (0.334)
2	Cobbles and gravels (0.)
3	Cobbles, gravels, and conductivity (0.)
4	Cobbles, gravels, boulder, and altitude (0.475)
5*	**Cobbles, gravels, boulder, altitude, and conductivity (0.491)**
6	Cobbles, gravels, boulder, altitude, conductivity, and *Scirpus* (0.484)

An MDS plot based on the suite of variables responsible for the species distribution should have much the same groupings as that based on the species. The poor match between such plots (Figure 10.9) confirms that the measured variables do not adequately explain the species distributions. Figure 10.9e illustrates the variables producing the highest score of the correlation index (0.491), but the catchment groups are poorly distinguished.

Following these initial analyses, a core group of variables that had been identified as important in at least some runs was chosen: algae, conductivity, macrophytes, moss, colour, site slope, altitude, bedrock, boulder, cobble, gravel and *Scirpus*. These were used to analyse the best abiotic-biotic matches within catchment groups. The correlation values were much higher than when the analyses was done across catchment groups, with the contribution of geomorphological variables increasing in importance. For example, in the Eerste/Molenaars group, the single variable with the largest rank correlation was altitude (0.618) (Table 10.3), followed by site slope (0.545) or conductivity (0.545). The best combination of variables was site slope, altitude, bedrock, boulders and moss (0.941) (Figure 10.10e). With only topographical and geomorphological variables included, the correlation value was 0.732.

Table 10.3 Combinations of 12 environmental variables yielding the best matches of biotic and abiotic similarity for the Eerste/Molenaars catchment grouping. An "*" indicates overall best match.

Number of variables	Best variable combinations (ρ_w)
1	Altitude (0.618)
2	Conductivity, site slope (0.727)
3	Conductivity, altitude, bedrock (0.816)
4	Moss, site slope, bedrock, boulder (0.864)
5*	**Moss, site slope, altitude, bedrock, boulder (0.941)**
6	Algae, moss, site slope, altitude, bedrock, boulder (0.901)

Similarly, in the Breede catchment (including the anomalous Berg site), the single most important variable was cobble (0.467), whilst the highest correlation value of 0.800 was provided by three variables (conductivity, macrophyte and bedrock) (Table 10.4). When only the topographical and geomorphological variables were included, the correlation was still 0.682, based on site slope, altitude, bedrock and cobbles.

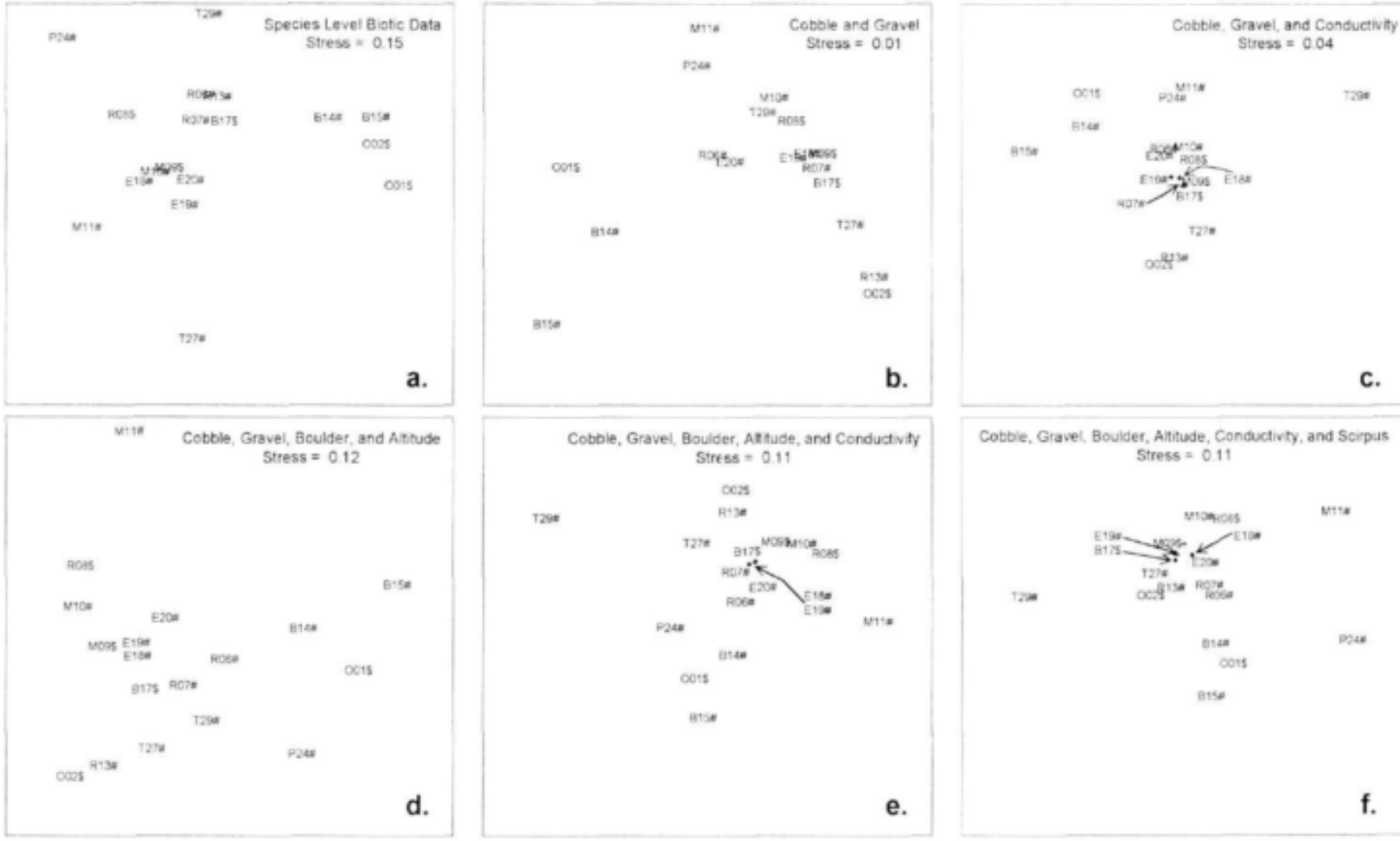


Figure 10.9 MDS plots for the 18 least-disturbed river sites, based on (a) species rated abundances, (b - f) different combinations of environmental variables.

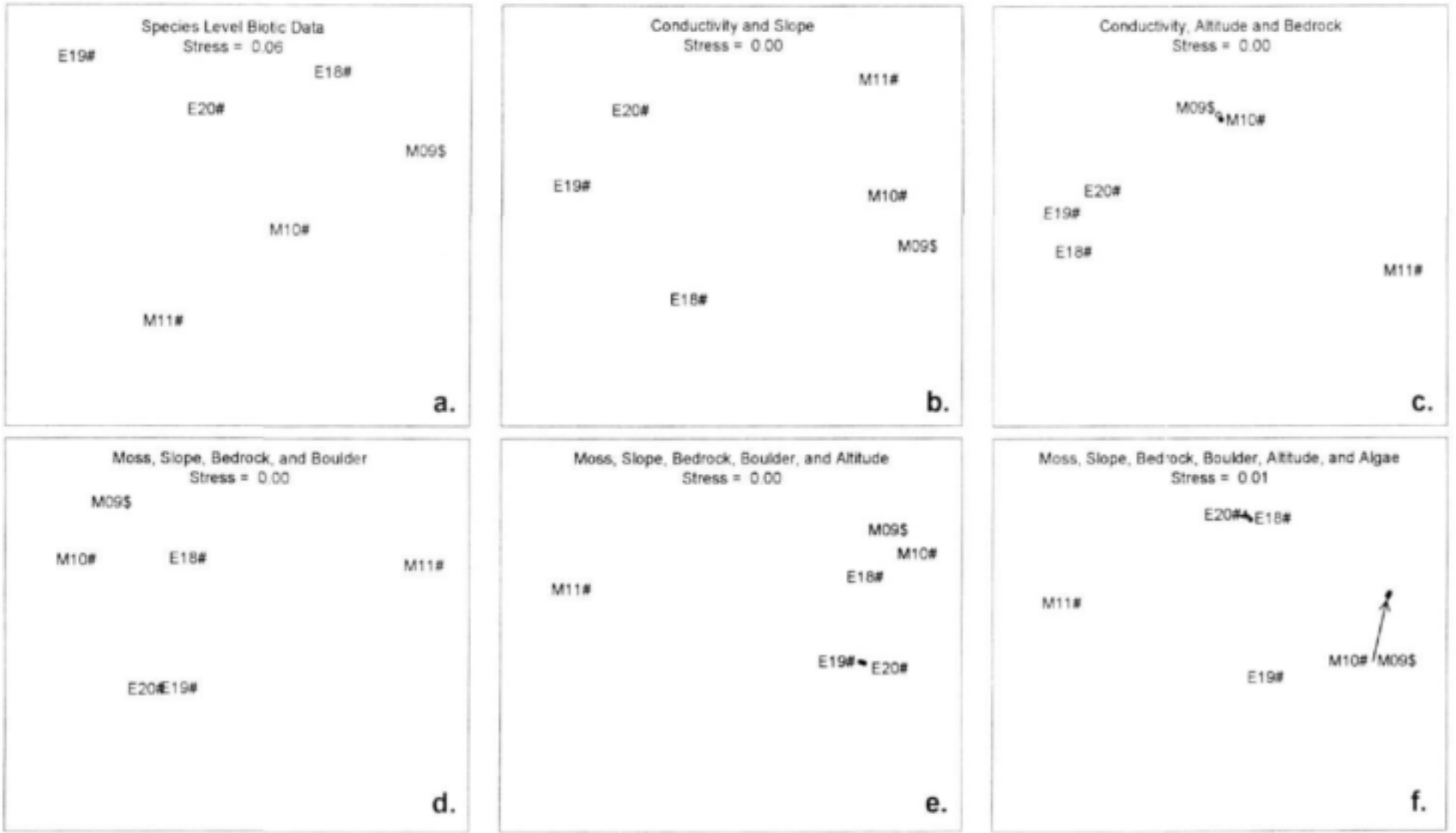


Figure 10.10 MDS plots for the Eerste/Molenaars catchment group, based on (a) species rated abundances, (b - f) different combinations of environmental variables.

The single best variable was, obviously, still cobble (0.467). MDS plots were not produced because the number of sites was too small to create meaningful patterns.

Table 10.4 Combinations of 12 environmental variables yielding the best matches of biotic and abiotic similarity for the Breede catchment grouping. An "*" indicates overall best match.

Number of variables	Best variable combinations (ρ_w)
1	Cobble (0.467)
2	Conductivity, macrophytes (0.773)
3*	**Conductivity, macrophytes, bedrock (0.800)**
4	Algae, conductivity, macrophytes, bedrock (0.800)
5	Conductivity, macrophytes, site slope, bedrock, and cobbles (0.731)

In the Olifants/Berg group, the single variable with the largest correlation value was boulders (0.505), followed by moss (0.435) and site slope (0.358) (Table 10.5). Four variables (site slope, boulders, conductivity and macrophyte) produced the best combination, with a match of 1.000. Such a high value is possible with a small number of sites. The topographical and geomorphological variables alone produced a correlation value of 0.798, from data on site slope and boulders.

Table 10.5 Combinations of 12 environmental variables yielding the best matches of biotic and abiotic similarity for the Olifants/Berg catchment grouping. An "*" indicates overall best match.

Number of variables	Best variable combinations (ρ_w)
1	Boulder (0.505)
2	Macrophytes, and site slope (0.798)
3	Macrophytes, boulder, and gravels (0.849)
4*	**Conductivity, macrophytes, site slope, boulder (1.000)**
5	Conductivity, macrophytes, colour, site slope, and boulder (1.000)
6	Conductivity, macrophytes, moss, site slope, boulder, and gravels(1.000)

In summary, data on the 12 variables most successful in accounting for the differences in biotic grouping of sites still only "explained" about 50% of the distribution pattern. Once within a catchment grouping of sites, however, the same variables scored far higher, accounting for 80-100% of the distribution pattern in different catchments, and between 68-80% of the pattern if only geomorphological and topographical variables were used. Important variables that could help explain the distinct catchments groupings clearly were not measured, and it is suggested that the missing element is either a subtle chemical signature for each catchment, or past biogeographical characteristics of linked or isolated catchments. This topic is re-visited in Chapter 16. Within the catchment groups, the mixture of measured variables producing the best fit included two that could be gleaned from maps (site slope and altitude) but most would emerge from site visits (the proportions of bedrock, boulders, cobbles, macrophytes and moss, and the conductivity).

10.5 Testing the biological significance of the geomorphological grouping of sites

At this point, the results of the biological classificatory exercise can be compared with those from the geomorphological one. The relevant comparison is between the species groups for least-disturbed rivers

(Figures 10.4 and 10.8) on the one hand, and the catchment/segment/zone groups (Table 6.8). Table 6.8 is derived from Tables 6.1 and 6.7, and is the final grouping from the desktop geomorphological exercise. In the table, the sites are grouped primarily by catchment size and SCT index – that is, by segment. They are then further divided by zone class and valley form, that is, by zone. Thus, sites 14, 15, 7 and 6 are all in segments with a small catchment and high SCT, 14 and 15 being mountain headwater streams, 7 a mountain stream and 6 a transitional mountain stream.

Figures 10.4 and 10.8 reveal that Table 6.8 recognises some of the tightly grouped pairs of sites: sites 14 and 15 in the upper Berg catchment; 6 and 7 in the upper Breede; 18, 19 and 20 in the upper Eerste; and 9 and 10 in the lower Elands/upper Molenaars. This is perhaps not surprising as the sites within each pair/trio are geographically very close within a single catchment, and will have much the same catchment, segment and zone characteristics.

Further than that, however, the geomorphological classification does not identify the more complex biological groupings. The distinctive catchment signatures emerging from the biological groups are not picked up, perhaps understandably so if, as speculated, they are largely of chemical or biogeographical origin. Further, until they are understood, these catchment signatures cannot be identified by reference to maps, as rivers from widely separated catchments may join in a catchment group (e.g. the upper Berg with the Olifants; the Eerste with the Molenaars) that cannot logically be predicted with present understanding. Thus, for instance, the geomorphological grouping of the Eerste sites (18,19, 20) in Chapter 6 fails to extend to include three other biologically similar sites from the Molenaars catchment (9, 10 and 11).

Additionally, within each catchment group, at the second level of biological division, the bedrock sites split off first, as least similar in biological terms. This characteristic of rivers cannot be supplied from maps, but needs on-site verification, and so forms no part of the geomorphological desk-top classification.

The third level of biological division – into mountain or foothill sites – is picked up quite well in the geomorphological classification. All the sites were pre-allocated to one of these two biological zones based on recorded data from many studies (Chapter 5 and Table 10.6), and formed logical groupings based on that (Section 10.2).

Table 10.6 Guidelines on ranges of altitude and slope for longitudinal biological zones in Western Cape rivers. (Extracted from several Cape studies by J.M. King, pers. comm.)

Zone	Altitude (m)	Slope	Substratum
Mountain torrent	>500	>0.400	boulder, bedrock
Mountain stream	200 – 500	0.100 – 0.400	boulder, cobble
Foothill	100 – 200	0.050 – 0.200	cobble
Transitional	10 – 100	0.010 – 0.050	cobble, sand
Lowland	0 – 10	0.001 – 0.010	sand, silt

In the geomorphological classification of sites (Table 6.8), the geomorphological zone classes A (mountain headwater) and B (mountain stream) contain all but two of the biological mountain-stream sites. Zone class C (mountain transitional) contains the remaining mountain-stream sites and a few foothill sites; and zone class D (upper foothills and rejuvenated foothills) contains the remaining foothill site and one transitional mountain-foothill site.

The same pattern for the third-level division is repeated in the reach-type classification (Table 6.9), which reflects the field validation of the desk-top geomorphological analysis. The second-level division of bedrock sites may also be detected here, through reference to the bedrock column, although one biologically-identified bedrock site (no 24, Dwars) is misclassified into the "mixed" column. Thus, ***if*** the catchment groupings could be pre-identified, this table could be used for a tentative classification of sites into bedrock versus alluvial, and mountain versus foothill sites. However, as the table relies on a site visit, the same information on zones could be picked up anyway and more accurately albeit not so quickly, by directly sampling the biota.

10.6 Physical and biological reference condition

A second objective within this activity was to assess if the physical (substratum and flow-type) conditions at each site correlated with the site's position within the landscape (Section 3.2). If distinct ranges of conditions emerged for mountain and foothill sites, these could be used to describe a Physical Reference Condition for each. Similarly, the faunal assemblage at each site could be used to define a Biological Reference Condition for mountain and foothill sites. Here we address the Physical Reference Condition; the Biological Reference Condition is addressed in Chapter 16.

The results of this project reveal that the Physical Reference Condition, if it could be described, could not act as a comprehensive indicator to the likely biota of a river, the composition of which is determined by other factors also. However, simply in terms of physical features of the channel, it might be a useful concept for guiding on limits within which the physical conditions should lie. For instance, it might be possible to provide some guidelines on what proportions of different sized substrata lie within the realm of "normal" for mountain or for foothill zones.

Using data on the proportions of different categories of substrata (Table 2.4), the sites group clearly at quite high similarity levels (Figure 10.11). The same groups appear in the MDS ordination plot. The three groups are: bedrock, mixed bedrock-alluvial, and alluvial sites – indicating a split at the second level of the biologically-derived division of the rivers. In the alluvial group, which reflects the third level of site division, sites do not group clearly by biologically-defined mountain or foothill zone. Nor do they group by map gradient, site gradient or altitude. This precludes the possibility of using the substrata data in Table 7.3 and 7.4 to define ranges of proportions of different size substrata that are typical of each of the two zones. However, within the alluvial group as a whole, when mixed categories were allocated to the main substratum categories (Table 7.3), boulders and cobble constituted 84-98% of the substrata, with the exception of the Disa (78%). Sand and silt constituted <1-7% of the substrata, and gravels 1-4%.

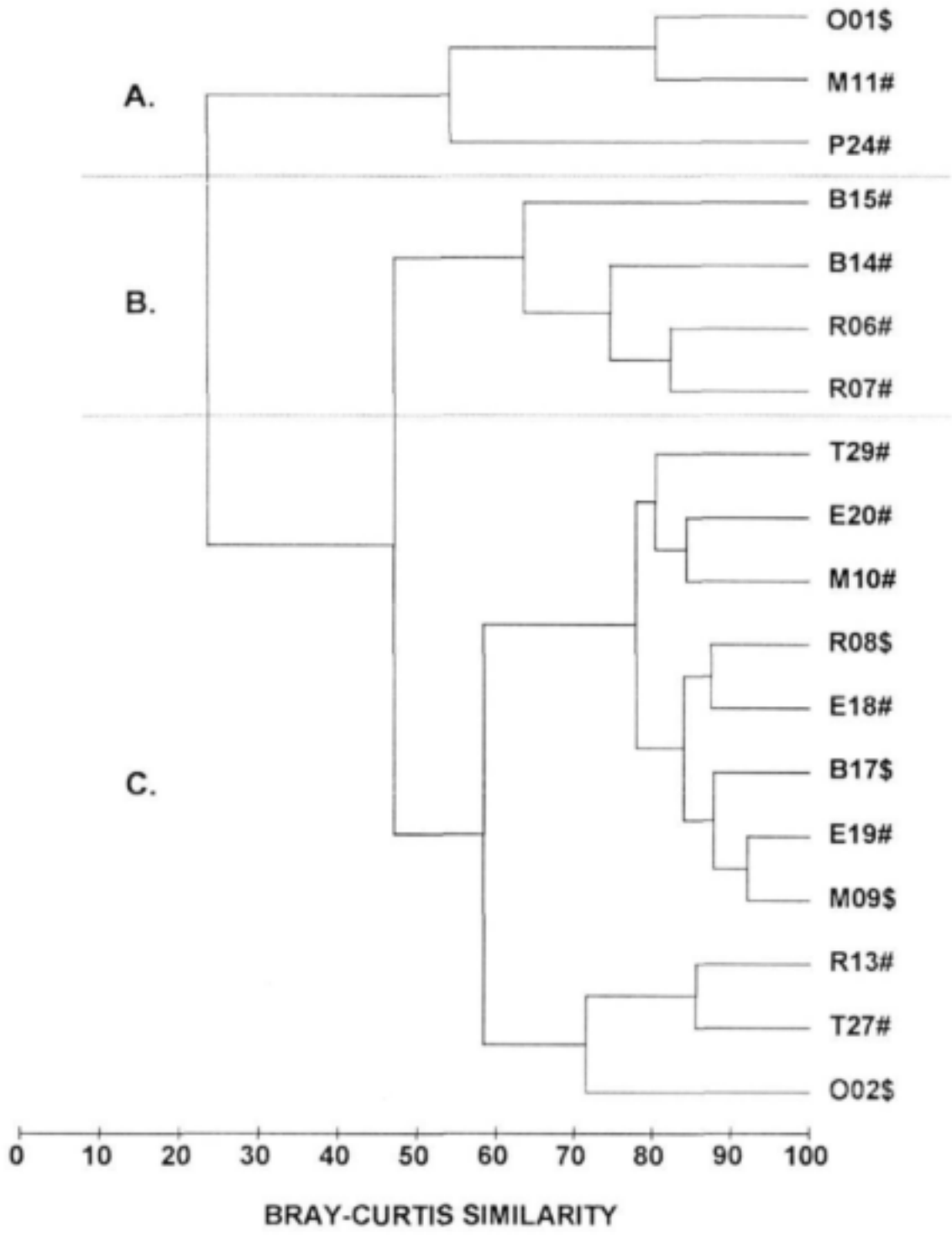


Figure 10.11 Dendrogram of the 18 sites on least-disturbed rivers, based on the categories of substrata listed in Table 2.4. A = bedrock rivers, B = mixed alluvial-bedrock rivers, and C = alluvial rivers. # = pre-identified as biological mountain zone and $ as a biological foothill zone as per Table 5.1.

Table 7.4 provides a slightly more realistic picture, with the mixed categories shown as well as the main categories. Particles were well sorted by size, with very low levels of mixed substrata. The main exceptions were the two large foothill rivers (Berg and Molenaars), where 39-48% of the substrata consisted of mixed boulders and cobbles, and the Disa, which had an unusually high level of silt-embedded cobbles (20%). In all the other alluvial sites, the substratum was characteristically well sorted, consisted mainly of boulders and cobble and had very low levels of sand and silt.

Flow types also were used to group sites (Figure 10.12). Again, strong groups of sites appeared, but these were not obviously related to the bedrock or alluvial nature of the bed or to its presence in a mountain or foothill zone. Bedrock and alluvial rivers appeared in all three major site groups, and mixed bedrock-alluvial sites in two. Group 1 consisted of three mountain streams and one foothill stream. One was bedrock, one mixed bedrock-alluvial river and two alluvial ones, and all were dominated by slow flows (>47% Barely Perceptible Flow). Group 2 consisted of four mountain streams and three foothill streams. One was bedrock, three mixed bedrock-alluvial and three alluvial sites. The dominant flow in this group as a whole was slow smooth flow (8-44% Smooth Boundary Turbulent), but there was a substantial proportion of fast smooth flow (Rippled Surface) at some sites. Group 3 consisted of six mountain and one foothill sites. One was bedrock and six alluvial, and all were dominated by fast, smooth flow (>30% Rippled Surface).

In summary, no patterns of substrata and flow types emerged that could be used to detail Physical Reference Conditions for Western Cape mountain or foothill streams. At best, general guidelines could be provided of the limits within which the proportions of large (boulder, cobble), medium (gravel) and small particles (sand and silt) could be expected to be in undisturbed headwater streams.

10.7 Conclusion

The first determinant of biotic groupings in Western Cape headwater streams is a semi-unique catchment signature, which is probably due either to subtle chemical signals, or to historical biogeographical distribution patterns. At present, there is insufficient understanding of the underlying cause for this catchment signature to be able to predict in a desktop exercise which catchments might be similar, as geographically close ones do not necessarily group together. Thus, at the highest level of the hierarchy, we cannot presently predict the species composition of catchments within an essentially homogeneous bioregion by extrapolation from nearby studied catchments. Nor, searching for a rapid guide, can we use family-level data to identify similar catchments. The management implications of catchment and river signatures are addressed in Chapter 16, as are biodiversity patterns, and related ecological concepts.

The second-level determinant of biotic groupings in Western Cape headwater streams is channel type: bedrock versus alluvial streams. This is a geomorphological feature, which has to be ascertained in the field, and so cannot form part of a desktop exercise.

The third-level determinant of biotic groupings in Western Cape headwater streams is the position along the long profile, which can be detected with some degree of accuracy from maps.

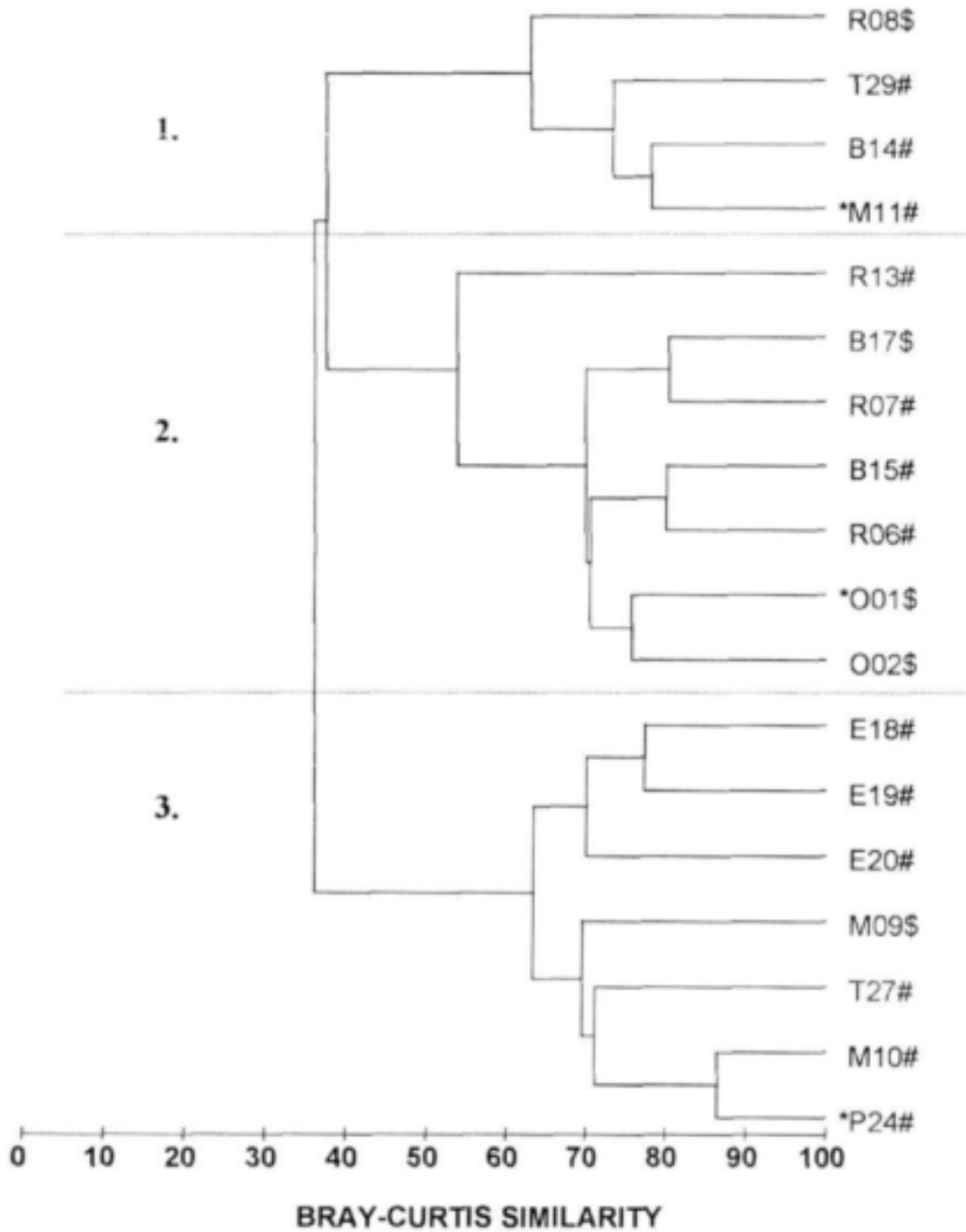


Figure 10.12 Dendrogram of the 18 sites on least-disturbed rivers, based on the categories of flow type listed in Table 2.3. # = pre-identified as biological mountain zone and $ as a biological foothill zone as per Tabl 5.1. An * denotes those streams that have bedrock as their dominant substratum. See text for group details.

Environmental data collected "explained" about 50% of the overall distribution pattern of invertebrates, and 80-100% in individual catchments, with 68-80% of the within-catchment pattern explained by geomorphological and topographical variables alone. Useful variables in distinguishing sites within any one catchment group were two that could be gleaned from maps (site slope and altitude) and several that required site visits (the proportions of bedrock, boulders, cobbles, macrophytes and moss, and the conductivity).

The concept of Physical Reference Conditions could only be developed into a practical guide at the most coarse level, guiding on the proportions of substrata and flow types expected at undisturbed sites.

11. HYDRAULIC BIOTOPES

Prof. John Field of the Zoology Department, UCT acted as advisor for the data analyses.

11.1 Recap

The second aim listed for the project (Section 3.3) was to test the biological significance of geomorphologically derived hydraulic biotopes. It is necessary to move from the highest to the lowest levels of the geomorphological hierarchy (Chapter 6) because the hydraulic biotopes are the "building blocks" of the intermediate levels: the morphological units (Chapter 12) and reaches (Chapter 13). Definitions derived for hydraulic biotopes are critically important as they affect all ensuing parts of the testing process.

Two assumptions were investigated.

- That within sites in the same bioregion and river zone, the same combinations of substrata and flow types would support the same assemblage of invertebrate species;
- Different assemblages of species could be used to identify different biologically-derived hydraulic biotopes. These would be assessed for correlation with geomorphologically-derived hydraulic biotopes.

To recap, testing this lowest level was done by mapping all the 18 least-disturbed river sites, in terms of substrata and flow types (Section 4.3). Twelve invertebrate samples were then collected from a wide range of conditions at each site (Section 4.5), and the location of the samples marked on the maps. Fifty-two invertebrate samples were also collected from one site (Eerste: river number 18), as replicates of a range of substratum-flow combinations. Thus, 268 invertebrate samples were available for this analysis, each identified to species where possible, and each located at a specific point on the GIS maps. Each of the 268 samples had accompanying records of substrata, flow type, water depth, mean column velocity and near-bed velocity, all taken at 2-6 points within the area of the sample. These samples, excluding the replicate ones from the Eerste, were combined by river to provide the species lists used in Chapter 10.

The same data-analysis approach employed in Chapter 10 was then used to search for hydraulic biotopes. Initially, the samples had to be divided into logical groupings, as certain analysis packages within PRIMER have limitations as to how many samples can be analysed. Guided by the results described in Chapter 10, the catchment groupings were used.

11.2 First analysis: grouping samples by catchment

With samples grouped by catchment, the general pattern that emerged was that, within any catchment group, there was a major split between samples from fast flow types and those from slow flow types. In all but the Table Mountain group, this was the first division of the samples. In the Table Mountain group, however, the first division was by river, and only then by fast and slow flow types. This may reflect a trend that, where the rivers in a catchment group were quite dissimilar (the two rivers in the Table Mountain group had species lists that were 33% similar; Figure 10.4), river identity preceded local hydraulics in

determining sample groupings. On the other hand, where rivers in the catchment group were more similar (42% or more; Figure 10.4), local hydraulics was more important than river identity in dictating species groupings.

The Eerste-Molenaars group of samples gave a typical picture of the kind of result obtained (Figure 11.1). The Elandspad River was initially included into the run but, as in all other analyses, was shown as quite different from the others in the group. It was therefore excluded in a second run, in order to concentrate on differences illustrated by the remaining sites, namely the Eerste, Langrivier, Swartboskloof, Molenaars and Elands. The fast-flow group had two main divisions, both of which contained samples from at least three of the five sites. Fast-flow group A tended to have the more turbulent flow forms (cascade (CAS), broken standing waves (BSW) and undular standing waves (USW)) and to be from boulder areas (13 of 18 samples were from boulder). The foothill site (Molenaars) was not represented in this group. Fast-flow group B tended toward a more flickering type of flow (fast riffle flow (FRF)) and the samples were mainly from cobble areas (13 of 21 samples). The Molenaars foothill site was well represented in this group, as was the Eerste, whilst the latter's two steep tributaries (Langrivier and Swartboskloof) were not. Of interest were the fairly clear sub-groups within these main groups, formed by samples from any one site.

The slow-flow group consisted mainly of samples from areas of no flow (NF), barely perceptible flow (BPF) or smooth boundary turbulent flow (SBT). Three sites were represented, again in clear river groupings, and mostly over cobble (8 of 12 samples). The two sites not represented here, Swartboskloof and Eerste, had respectively no slow-flow and few slow-flow areas sampled.

Nine samples were excluded from these main groups. They represented a mixed range of flow types, but were almost exclusively taken from boulder areas. Though some were similar to each other, most were strongly dissimilar from the main groups. A possible explanation for this dissimilarity is that boulders may have a variety of different species assemblages, exploiting light and dark, deep and shallow areas, in or out of hydraulic cover, only part of which was sampled on any one occasion. Alternatively, the samples may be poor in species because of the difficulty of reaching around and under immovable boulders, and of ensuring that nets catch all dislodged animals. Lastly, although the flow types indicate that the boulder samples come from several different hydraulic conditions, it may be that surface flow type is not a good indicator of conditions deep among the boulders, and that the animals were from more uniform conditions than implied. This does not explain why they were outliers on the dendrogram, but could explain why there was no consistent picture of flow type.

The same kinds of pattern emerged from all the catchment groups. Samples were always divided into fast-flow and slow-flow groups, and always with a few outlying dissimilar samples. The outliers were usually from very quiet waters, or boulders, or both. Within the two main groups, river signatures were always obvious. Catchment signatures were also apparent, with samples from a single river often tending to group together, and then join with a group of samples from a site in the same catchment, before joining fast-flow groups from another catchment.

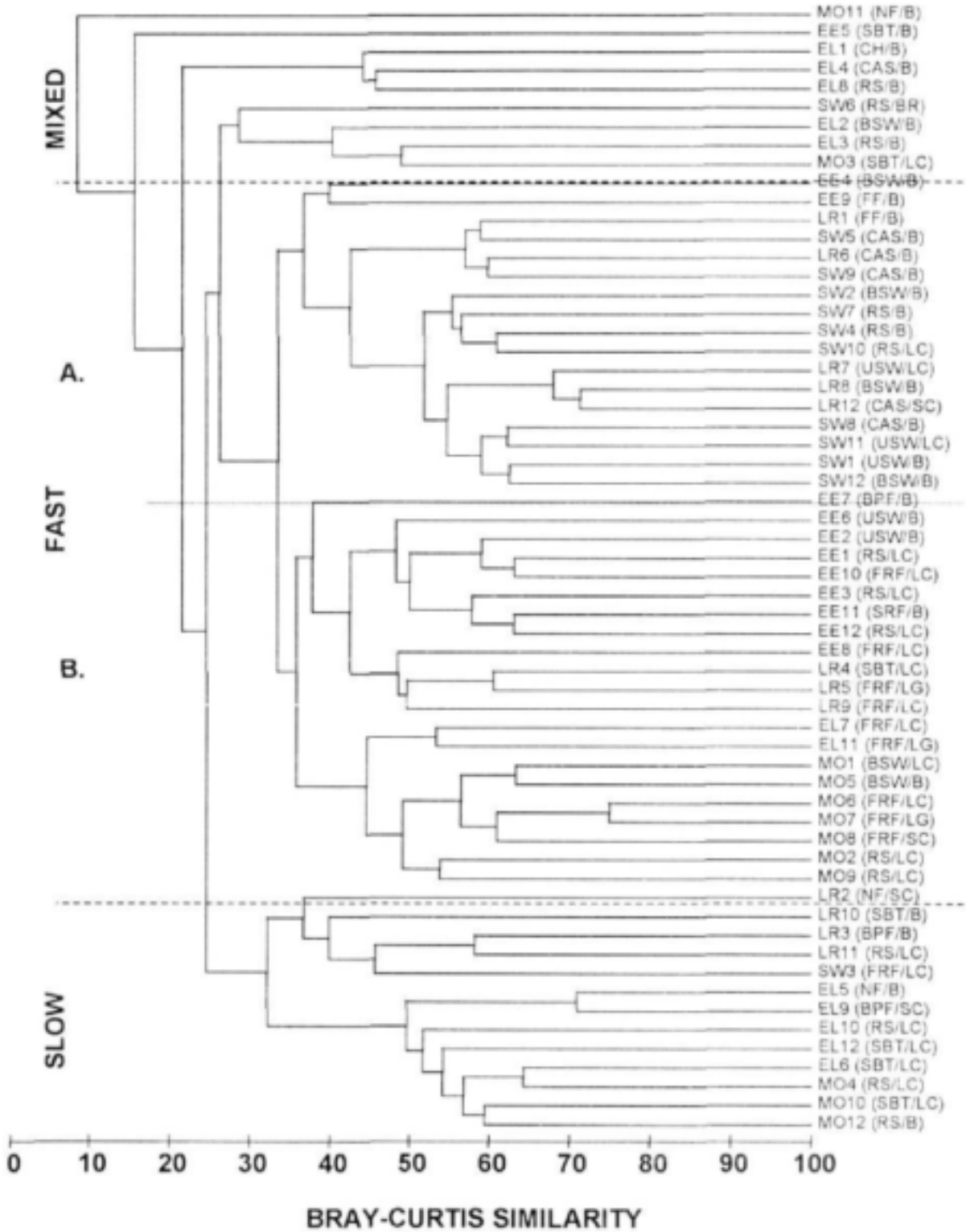


Figure 11.1 Dendrogram of the Eerste-Molenaars group of samples, with the exception of those from Elandspad. Samples are coded by river and invertebrate sample number. MO = Molenaars; EE = Eerste; SW = Swartboskloof; LR = Langrivier. Substrata and flow categories as per Tables 2.3 and 2.4.

Of concern was an expected grouping of samples into what ecologists had historically referred to as runs and riffles, that was not emerging. These are characteristic features of physical habitat long used by ecologists to guide location of sampling points, and are common features of some parts of river systems. Wadeson (1995) reviewed the use of these and other habitat terms by river ecologists, and concluded there was general agreement on what the terms meant but little in the way of supporting statistics which delineate water depths, velocities and other hydraulic characteristics. King & Tharme (1994) described a riffle as: *An area with typical shallow depth relative to bed particle size. High-velocity area, with turbulent flow, indicated by broken water surface. Substrate predominantly cobbles and boulders, with limited deposition of fines. Generally noticeable change in slope from head to foot of riffle. Spatially and temporally variable in that the riffle can migrate upstream or downstream with changes in flow, and transform into a run at high flows.*

The same document defined a run as: *A feature representing an area of transition between a pool/rapid and a riffle. Depth variable from fairly shallow to deep. Velocity general moderate, but can be low or high depending on flow conditions. Substrate conditions variable. Characterised by smooth flow with no broken surface water. No obvious change in stream bed gradient. Higher ratio of depth to stream bed roughness elements than for riffle.*

At the beginning of this project, riffles as described above were seen as channel-spanning areas with turbulent flow types (FRF, BSW and USW) and runs as areas with smoother-flowing water (rippled surface (RS) and SBT). Although such areas did occur at some sites, and single samples with these combinations of flow and substratum were common, grouping of samples by these characteristics did not occur. This was of concern because of the many publications illustrating that the invertebrate fauna does distinguish between the two physical habitats (e.g. Emery 1994).

A possible reason for the non-recognition of riffle and runs was the pre-grouping of sites by catchment, resulting in a mix of foothill and mountain sites in any one analysis. This may have been a problem because the zones tend to have different characteristic physical habitats: mountain zones are characterised by step-pool sequences, and foothills by the classic riffle-run sequences (see Chapter 6 for a geomorphological classification of sites). To reduce the possible noise in the data set from such a mix, the data were re-analysed, dividing the sites across catchments based on substrata and zones.

11.3 Second analysis: grouping samples by zone and substrata

Bedrock sites were placed in one group, and mixed alluvial-bedrock sites in a second group (Table 11.1). All of the mixed sites were in pre-identified mountain streams, and so made a logical grouping by zone as well as by substratum. One of the three bedrock rivers had been designated foothill (Jan Dissels), but the bedrock sites had consistently grouped by substratum in terms of species distributions rather than by zone, and so the three were left together. From the alluvial sites, foothill sites were selected based on the following criteria:

- those that had been mapped by Prof. Rowntree as having riffle and/or run morphological units (Berg, Molenaars, Du Toits);
- those that had a map gradient (Table 5.3) of ≤ 0.020 (the earlier three, plus the Wit, Rondegat and Elands).

To reduce noise, the Wit was excluded as it was consistently an outlier within its group in all of the grouping exercises. This was probably due to the site being dominated by a long pool, resulting in very low overall numbers and taxa.

The remaining alluvial sites were classed as being in the mountain zone. This division of alluvial rivers mirrored the zone designation of sites at the beginning of the project (Table 5.1), except that two sites (Elands, Du Toits) had been designated mountain based on slope, but thought by their appearance in the field to be transitional mountain-upper foothill. This later status was confirmed by the various analyses presented to this point, so they are here treated as foothill sites.

Table 11.1 Allocation of river sites to analysis classes based on zone and substratum. *excluded from further analyses.

Analysis class	River No.	River name
Bedrock	1	Jan Dissels
	11	Elandspad
	24	Dwars
Mixed alluvial-bedrock	6	Steenbok
	7	Wolwekloof
	14	Bakkerskloof
	15	Zachariashoek
Alluvial mountain	18	Eerste
	19	Langrivier
	20	Swartboskloof
	27	Newlands
	29	Disa
Alluvial foothill	2	Rondegat
	8*	Wit*
	9	Molenaars
	10	Elands
	13	Du Toits
	17	Berg

The different groups were then run through the sequence of analyses described in Chapter 10, to produce dendrograms and MDS plots indicating the similarity between individual samples from all the included rivers.

11.3.1 Alluvial foothill rivers

The dendrogram showed a typical separation of fast-flow and slow-flow samples, with a scattering of mixed slow-flow samples lying dissimilar from each other and from the main groups (Figure 11.2a). The foothill sites that are geographically closest (Berg, Du Toits, Elands and Molenaars) formed the main group (28% similarity), containing fast and slow samples. Samples from the more distant Cedarberg site (Rondegat) grouped into fast and slow groups at lower similarity levels (25% and 17% respectively).

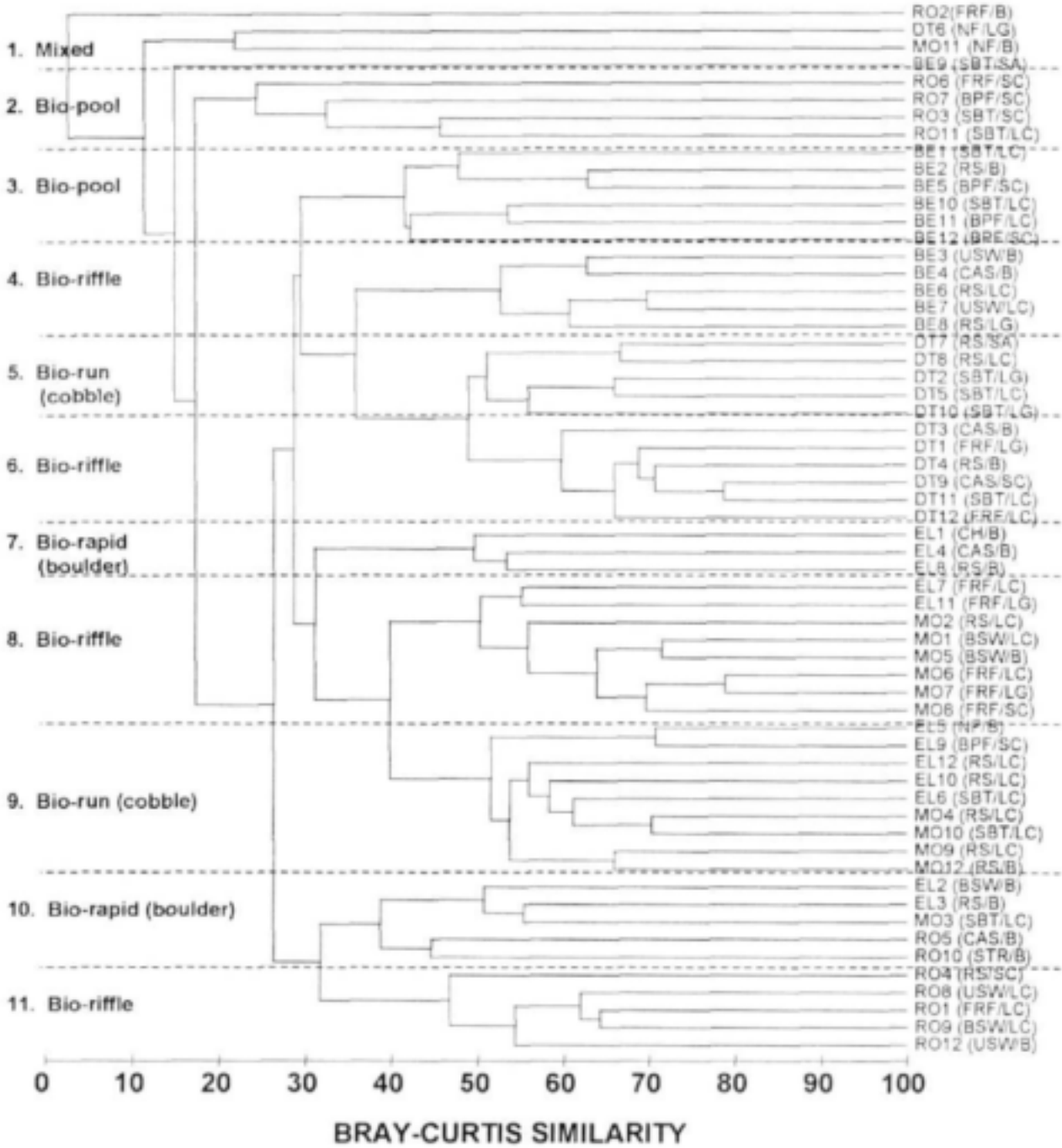


Figure 11.2a Identification of similar invertebrate samples from five alluvial foothill sites. Dendrogram from cluster analysis. Samples are coded by river and invertebrate sample number. MO = Molenaars; EL = Elands; DT = Du Toits; BE = Berg; RO = Rondegat. Substrata and flow categories as per Tables 2.3 and 2.4.

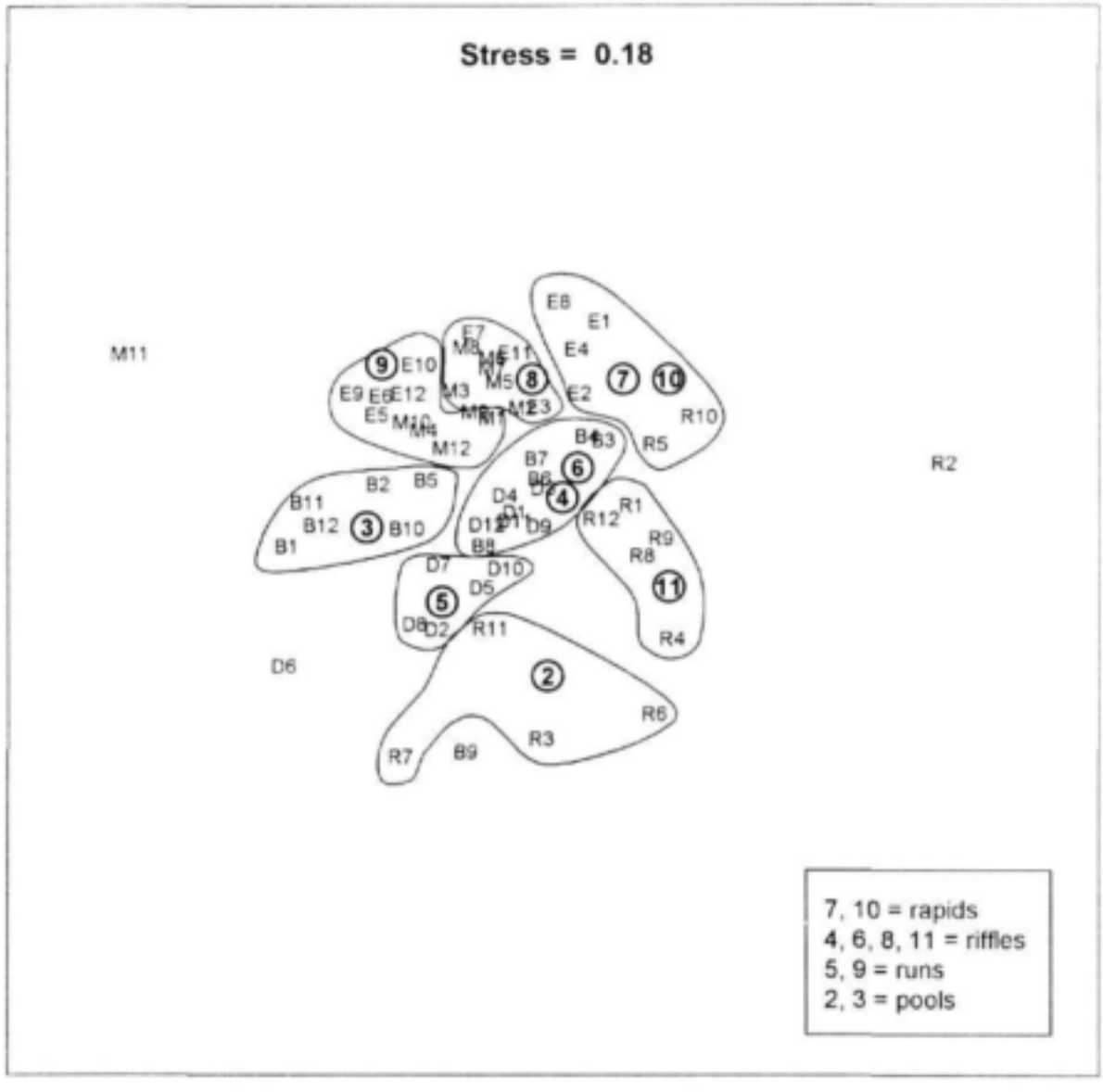


Figure 11.2b Identification of similar invertebrate samples from five alluvial foothill sites. MDS ordination plot. Samples are coded by river and invertebrate sample number. M = Molenaars; E = Elands; D = Du Toits; B = Berg; R = Rondegat.

Eleven main sub-groups were distinguished in the dendrogram, all but one clearly characterised by local hydraulics (Table 11.2). As the dendrogram groups were based on faunal distributions, the groupings they reflect are, for the purposes of this project, described using familiar terms such as riffle but with the prefix "bio" (e.g. bio-riffle). Where geomorphologically derived areas with the same name are referred to in subsequent chapters, they will be designated with the prefix "geo" (e.g. geo-riffles).

Table 11.2 Hydraulic characteristics of the 11 groups of samples from five alluvial foothill sites, as recognised in Figure 11.2. The sub-groups are recognised as biologically derived hydraulic biotopes. Depth (m); Mean-column (0.6) and near-bed (NB) velocity (m s^{-1}).

Sub-group	Hydraulic biotope	Sample Code	Flow/Substrata	Depth	0.6	NB	Froude No.
1	Mixed	RO2	FRF/B	0.06	0.11	0.13	0.218
		DT6	NF/LG	0.03	0.00	0.00	0.000
		MO11	NF/B	0.11	0.00	0.00	0.000
		BE9	SBT/SA	0.23	0.00	0.00	0.000
2	Bio-Pool	RO6	FRF/SC	0.04	0.24	0.24	0.366
		RO7	BPF/SC	0.04	0.01	0.01	0.023
		RO3	SBT/SC	0.29	0.06	0.02	0.036
		RO11	SBT/LC	0.40	0.09	0.01	0.047
3	Bio-Pool	BE1	SBT/LC	0.37	0.00	0.00	0.000
		BE2	RS/B	0.45	0.07	0.02	0.034
		BE5	BPF/SC	0.13	0.00	0.00	0.000
		BE10	SBT/LC	0.15	0.01	0.01	0.011
		BE11	BPF/LC	0.08	0.00	0.00	0.000
		BE12	BPF/SC	0.31	0.00	0.00	0.000
4	Bio-riffle	BE3	USW/B	0.19	0.47	0.35	0.375
		BE4	CAS/B	0.15	0.33	0.22	0.324
		BE6	RS/LC	0.15	0.37	0.30	0.327
		BE7	USW/LC	0.16	0.26	0.30	0.483
		BE8	RS/LG	0.20	0.32	0.14	0.225
5	Bio-run (cobble)	DT7	RS/SA	0.20	0.08	0.04	0.058
		DT8	RS/LC	0.09	0.08	0.06	0.062
		DT2	SBT/LG	0.07	0.02	0.05	0.069
		DT5	SBT/LC	0.13	0.02	0.03	0.014
		DT10	SBT/LG	0.07	0.01	0.00	0.002
6	Bio-riffle	DT3	CAS/B	0.10	0.34	0.31	0.338
		DT1	FRF/LG	0.04	0.23	0.23	0.396
		DT4	RS/B	0.16	0.56	0.41	0.472
		DT9	CAS/SC	0.06	0.56	0.55	0.750
		DT11	SBT/LC	0.09	0.08	0.11	0.151
		DT12	FRF/LC	0.09	0.09	0.09	0.106
7	Bio-rapid (boulder)	EL1	CH/B	0.05	0.60	0.45	0.633
		EL4	CAS/B	0.28	0.44	0.25	0.291
		EL8	RS/B	0.52	0.34	0.11	0.152
8	Bio-riffle	EL7	FRF/LC	0.07	0.06	0.14	0.170
		EL11	FRF/LG	0.08	0.07	0.25	0.336
		MO2	RS/LC	0.14	0.17	0.16	0.148

Sub-group	Hydraulic biotope	Sample Code	Flow/Substrata	Depth	0.6	NB	Froude No.
8	Bio-riffle	MO1	BSW/LC	0.10	0.52	0.43	0.474
		MO5	BSW/B	0.15	0.28	0.09	0.226
		MO6	FRF/LC	0.04	0.44	0.44	0.734
		MO7	FRF/LG	0.04	0.23	0.23	0.376
		MO8	FRF/SC	0.04	0.20	0.20	0.408
9	Bio-run (cobble)	EL5	NF/B	0.15	0.00	0.00	0.000
		EL9	BPF/SC	0.11	0.00	0.00	0.002
		EL12	RS/LC	0.29	0.30	0.25	0.178
		EL10	RS/LC	0.94	0.07	0.00	0.023
		EL6	SBT/LC	0.68	0.02	0.00	0.008
		MO4	RS/LC	0.11	0.21	0.15	0.142
		MO10	SBT/LC	0.22	0.03	0.00	0.015
		MO9	RS/LC	0.30	0.25	0.16	0.015
		MO12	RS/B	0.49	0.18	0.04	0.083
10	Bio-rapid (boulder)	EL2	BSW/B	0.58	0.22	0.05	0.093
		EL3	RS/B	0.38	0.11	0.05	0.059
		MO3	SBT/LC	0.16	0.15	0.15	0.121
		RO5	CAS/B	0.07	0.74	0.64	0.897
		RO10	STR/B	0.06	0.87	0.94	1.331
11	Bio-riffle	RO4	RS/SC	0.32	0.33	0.23	0.190
		RO8	USW/LC	0.17	0.31	0.23	0.248
		RO1	FRF/LC	0.10	0.37	0.17	0.368
		RO9	BSW/LC	0.18	0.39	0.23	0.323
		RO12	USW/B	0.12	0.69	0.34	0.521

//Table 11.2 continued

Sub-groups 4, 6, 8 and 11 (Figure 11.2a) were recognised as bio-riffles. A total of 24 samples were contained within these sub-groups, heavily dominated by fast flow-types (3 CAS; 3 BSW; 4 USW; 8 FRF; 5 RS; 1 SBT), and cobble substrata (6 boulder; 11 large cobble; 3 small cobble; 4 large gravel). Water depths ranged 0.04-0.32 m (mean 0.12), with only one sample from deeper than 0.20 m. The range of mean column velocities was 0.06-0.69 m s^{-1}, with only four values < 0.10 m s^{-1}, and 19 of 24 values ≥ 0.20 m s^{-1} (mean 0.32). River identities held true in these four groups. Bio-riffle 4 consisted of five samples from the Berg; bio-riffle 6, six samples from the Du Toits; bio-riffle 8, six samples from the Molenaars, and two from the Elands site approximately 1 km upstream on the mainstem; and bio-riffle 11, five samples from the Rondegat.

Sub-groups 5 and 9 (Figure 11.2) were recognised as bio-runs. Fourteen samples resided in this category, generally reflecting noticeable flow but with less turbulence (6 RS; 6 SBT; 1 BPF; 1 NF). The substrata were predominately cobbles (2 boulder; 8 large cobble; 1 small cobble; 2 large gravel; 1 sand). Water depths tended to be greater than in bio-riffles, with a range of 0.07-0.94 m and 50% of samples from > 0.20 m (mean 0.27 m, SD 0.26). The range of mean column velocities was <0.01-0.30 m s^{-1} (mean 0.09 m s^{-1}). Slow-flow areas predominated, with ten of the fourteen samples having velocities <0.10 m s^{-1}. Again, the river identities held true, with bio-run 5 consisting of five samples from the Du Toits River, and bio-run 9 of four samples from the Molenaars and five from the Elands.

Two other small sub-groups (7 and 10) occurred in the fast-flow group, which have tentatively been named bio-rapids. Seven of the eight samples in these were from boulder substrata and, as previously with such samples, they presented a slightly more confused picture. The predominant flow types were turbulent or typical of boulder and bedrock areas (2 CAS; 1 CH (chute); 1 BSW; 1 STR (stream); 2 RS, 1 SBT), and velocities tended to be high (six samples > 0.20 m s^{-1} mean 0.43 m s^{-1}). Boulder beds and rapids tend to occur higher in the system than do cobble riffles, and these two small sub-groups might represent a habitat that is abundant in the mountain zone (see Section 11.3.2) but becoming increasingly rare downstream through the foothill zone.

Sub-groups 2 and 3 were recognised as bio-pools (cobble). The ten samples were from quiet waters (1 FRF; 1 RS; 4 SBT; 4 BPF), and over relatively small substrata (1 boulder; 4 large cobble; 5 small cobble). Apart from the outlier collected in FRF, velocities were very low, ranging <0.01-0.24 m s^{-1} at 0.6 depth (mean 0.05 m). Again the river identities held true, with bio-pool 2 consisting of four samples from the Rondegat River and bio-pool 3, six samples from the Berg.

Sub-group 1 contained four samples <17% similar to the main sub-groups. Two (B9 and MO11) were from backwaters, well sheltered from the current and one (DT6) from an isolated pool. The remaining one (RO2) was <2% similar to any other sample, probably because it was extremely low in species and numbers.

The MDS ordination (Figure 11.2b) provided essentially the same picture, at a stress for this two-dimensional plot of 0.18, which is acceptable. There is a gradient from top right to bottom left of fast-flow to slow-flow samples, and a gradient from bottom right to top left that could be linked to geographical location or climatic conditions. Three of the rivers were identified with bio-runs and no bio-pools, and two with the opposite, for reasons not yet understood.

In summary, these five alluvial foothill sites reflected a pattern of invertebrate distributions that was dominated by catchment signatures and distinction between fast and slow-flow areas. Clear correlation occurred between the sub-groups and their prevailing local hydraulic conditions. Four biologically-based hydraulic biotopes may be derived from this analysis: bio-riffle, bio-run, bio-rapid and bio-pool, with one other possible: bio-backwater. Within each of the four, river identities were clearly maintained.

11.3.2 Alluvial mountain rivers

Five alluvial mountain rivers, represented by 60 samples, were included in the analysis. Two were from Table Mountain and three from the Eerste catchment (Table 11.1). It was expected that trends might be more difficult to detect from this group, as the pattern of physical heterogeneity in steep mountain sites is far greater than in foothill ones. Figures 7.5b and 7.6b respectively illustrate the mosaic of flow types in a mountain site (Langrivier) and a foothill site (Rondegat). The mapped mosaic patches of Rondegat are visibly larger, and would be even more so if the maps had the same scale. In the mountain sites, the patches are stacked close together, and it may be that they are too small to sustain any hydraulic integrity and are continuously changing from the influence of neighbouring patches. The smaller ones may, in fact, be "all boundary", with no central area of characteristic conditions that allows a typical fauna to exist. The influence of patch size on invertebrate distributions is not well understood, although Giller *et al.* (1992)

record the growth of interest in this field. Another possible reason why a confused picture might emerge was that, in these kind of turbulent waters, flow types at the surface may bear little relation to mean column or near-bed velocities because of the complex patterns of flow.

Initial study of the dendrogram and MDS plot for the alluvial mountain sites revealed an over-riding division of Table Mountain from Eerste sites, with a complex pattern of grouping within the three sites from the Eerste catchment. To aid interpretation of this, the 52 samples from the intensive sampling programme at the same site on the Eerste River were first analysed. These 52 invertebrate samples consisted of replicates from a range of flow-substratum combinations, taken during the same summer as the 12 routine samples for this site (Table 5.1).

Using both the dendrogram (Figure 11.3a) and the MDS ordination (Figure 11.3b) to search for patterns, six subgroups of samples were recognised, with one outlier (no. 37) that is not considered further here. In the dendrogram, the major pattern of division was again into fast-flow and slow-flow groups, with a substantial number of samples from boulders lying outside. The boulder samples were allocated to groups with reference to their position on the MDS ordination.

Sub-group 1 samples were recognised as coming from bio-rapids (boulder). The eight samples had a low similarity to most other samples, and all came from boulder areas. Their flow types were typically "turbulent" (3 CAS; 3 CH; 2 BSW). Depths were very shallow, ranging from 0.01 to 0.16 m, and velocities were high (mean of mean-column velocities 0.65 m s^{-1}).

Table 11.3 Hydraulic characteristics of the six groups of samples from the replicate set collected at the Eerste site, as recognised in Figure 11.3. The sub-groups are recognised as biologically derived hydraulic biotopes. Depth (m); Mean-column (0.6) and near-bed (NB) velocity (m s^{-1}).

Sub-group	Hydraulic biotope	Sample Code	Flow/Substrata	Depth	0.6	NB	Froude No.
1	Bio-rapid (boulder)	41	BSW/B	0.13	0.18	0.02	0.171
		4	BSW/B	0.06	0.97	0.92	1.238
		5	CH/B	0.12	0.93	0.80	0.922
		2	CH/B	0.03	0.36	0.36	0.393
		36	CAS/B	0.16	0.37	0.37	0.925
		22	CAS/B	0.02	0.65	0.65	1.377
		39	CAS/B	0.01	1.25	1.25	3.992
		40	CH/B	0.05	0.85	0.85	1.298
2	Bio-pool (boulder)	26	BPF/LC	0.14	0.01	0.00	0.011
		48	BPF/B	0.09	0.05	0.04	0.047
		9	SBT/B	0.10	0.04	0.67	0.043
		25	SBT/B	0.33	0.04	0.03	0.022
		44	RS/B	0.25	0.14	0.11	0.092
		30	RS/B	0.18	0.07	0.05	0.056
		24	BPF/B	0.07	0.01	0.01	0.017
		47	SBT/B	0.28	0.04	0.03	0.025
		49	SBT/BR	0.19	0.10	0.07	0.074
		52	SBT/LG	0.09	0.00	0.00	0.000

Sub-group	Hydraulic biotope	Sample Code	Flow/Substrata	Depth	0.6	NB	Froude No.
3	Bio-riffle	20	BSW/LC	0.07	0.24	0.24	0.292
		32	FRF/LC	0.11	0.27	0.16	0.272
		17	FRF/B	0.09	0.39	0.37	0.430
		13	CAS/B	0.08	0.46	0.36	0.521
		33	FRF/B	0.07	0.25	0.23	0.278
		3	USW/LC	0.18	0.25	0.25	0.264
		1	USW/LC	0.07	0.30	0.30	0.382
		19	USW/B	0.07	0.30	0.29	0.364
		21	USW/B	0.12	0.12	0.01	0.114
		38	CAS/LC	0.04	0.17	0.17	0.253
		35	CAS/LC	0.05	0.32	0.31	0.486
		46	FRF/LC	0.06	0.28	0.28	0.363
4	Bio-run	15	RS/B	0.20	0.12	0.05	0.086
		8	USW/LC	0.11	0.24	0.24	0.249
		45	USW/B	0.14	0.27	0.20	0.236
		6	FRF/LC	0.07	0.24	0.24	0.313
		7	RS/LC	0.12	0.05	0.01	0.045
		14	FRF/B	0.12	0.25	0.18	0.229
5	Bio-pool (cobble)	16	BPF/B	0.10	0.00	0.00	0.002
		10	SBT/LC	0.15	0.09	0.06	0.076
		18	BPF/LC	0.22	0.02	0.00	0.013
		27	SBT/LG	0.28	0.01	0.00	0.004
		28	SBT/LC	0.56	0.09	0.04	0.040
		12	RS/LC	0.22	0.18	0.14	0.124
		31	SBT/LG	0.16	0.04	0.02	0.031
		34	RS/LC	0.41	0.05	0.01	0.028
		11	SBT/LC	0.16	0.03	0.01	0.025
		23	BPF/LC	0.08	0.02	0.02	0.019
		29	BPF/LG	0.12	0.01	0.00	0.012
		42	BPF/LG	0.10	0.00	0.00	0.002
		43	BPF/LG	0.09	0.00	0.01	0.003
6	Bio-run (bedrock)	50	SBT/BR	0.14	0.21	0.19	0.196
		51	SBT/BR	0.21	0.08	0.05	0.053

//Table 11.3 continued

Sub-group 2 were recognised as coming from bio-pools (boulder). Six of the ten samples were grouped in the dendrogram, whilst the other four were scattered among the boulder outliers, but all ten formed a loose but discrete group in the MDS plot. The substratum was typically of large clasts (1 bedrock; 7 boulder; 1 large cobble; 1 large gravel), with medium water depths (range: 0.07-0.33 m; mean: 0.17 m). Velocities were slow (mean column: range 0.00-0.67 m s^{-1}; mean 0.10 m s^{-1}). One sample (number 9) illustrates that mean-column velocities can be misleading, having a high value (0.67 m s^{-1}), but a low near-bed velocity (0.04 m s^{-1}). Although the samples do not form as cohesive a sub-group as the following ones, either in the dendrogram or on the MDS plot, they do have a separate identity from these, justifying their recognition as an entity.

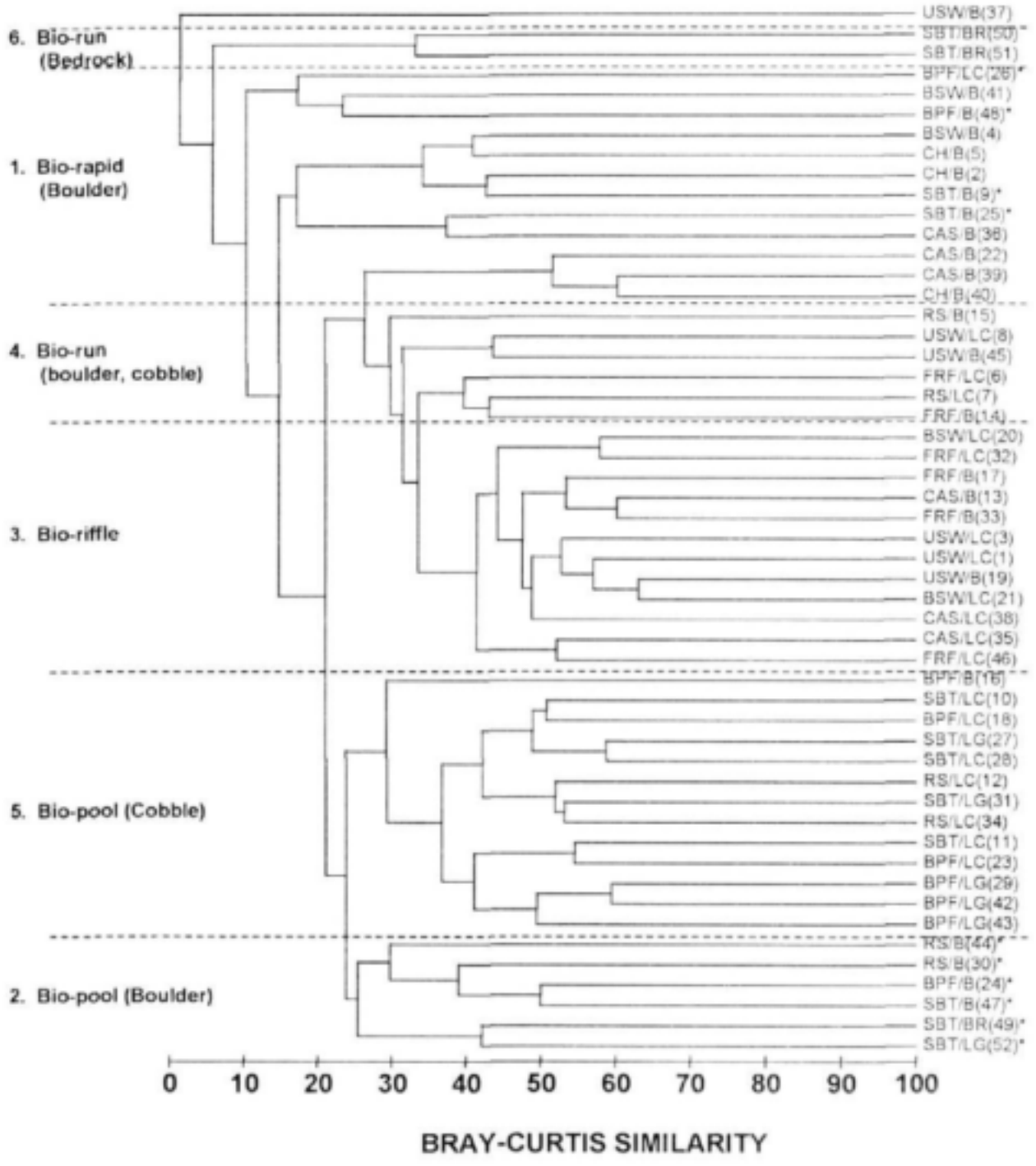


Figure 11.3a Identification of similar invertebrate samples within a group of 52 samples taken from replicate flow-substratum conditions. Dendrogram from cluster analysis. Samples are coded by invertebrate sample number, and flow and substratum categories. Substrata and flow categories as per Tables 2.3 and 2.4. Sub-groups 1 and 2 are interspersed; members of sub-group 2 are denoted with * (see text).

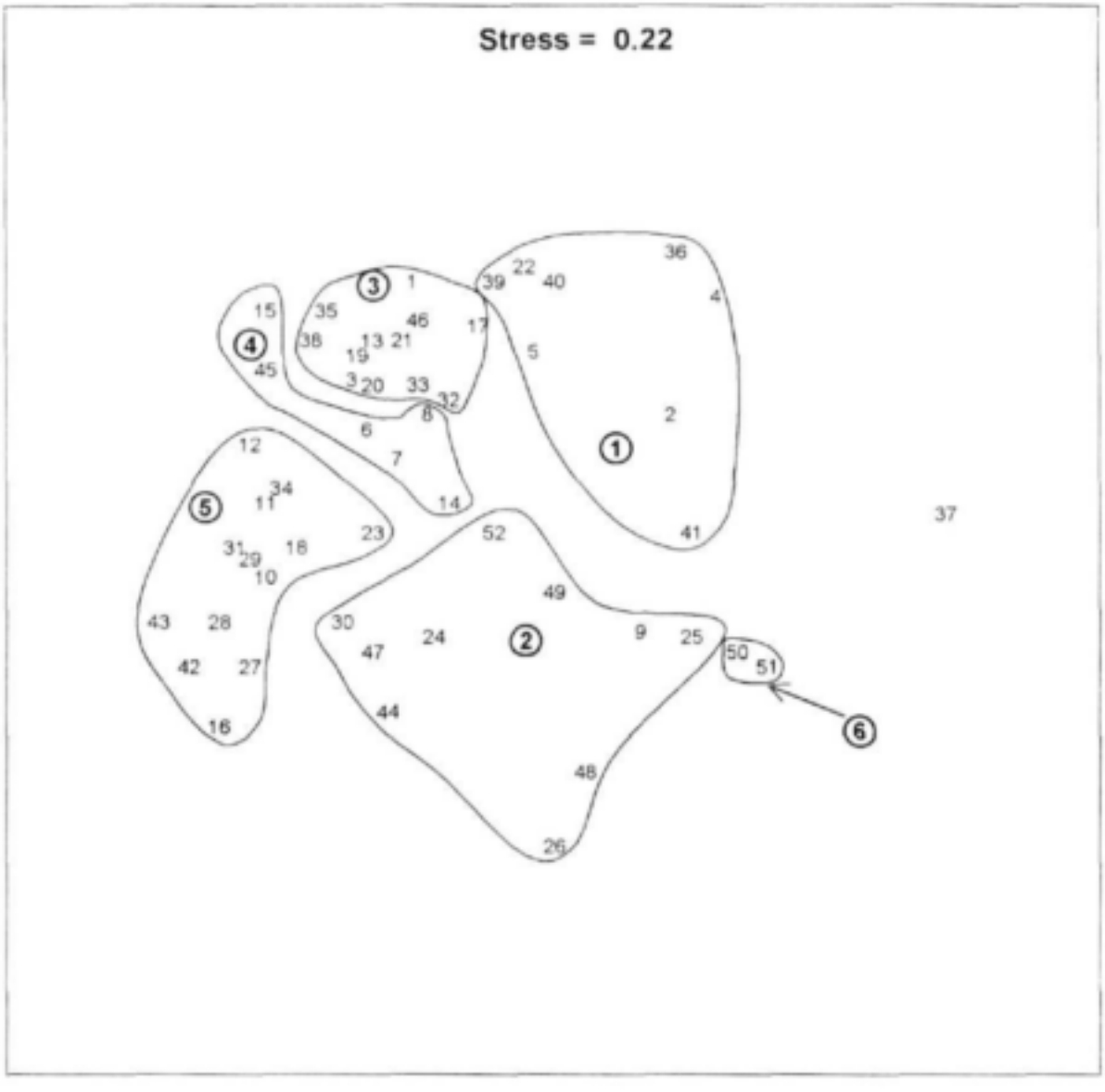


Figure 11.3b Identification of similar invertebrate samples within a group of 52 replicate samples taken from flow-substratum conditions. MDS ordination plot. Samples are coded by river and invertebrate sample number.

Sub-group 3 consisted of samples from bio-riffles. The twelve samples were all from fast-flowing areas, with a high proportion of flickering flow (3 CAS; 2 BSW; 3 USW; 4 FRF) and cobbles (4 boulder; 8 large cobble). Water depths were shallow, ranging from 0.04 to 0.18 m (mean 0.08 m), and velocities high (mean-column velocity: range 0.01-0.37 m s^{-1}; mean 0.25 m s^{-1}). This was the most tightly clustered group of samples, suggesting either more consistent hydraulic conditions with a consequent more consistent species assemblage in bio-riffles or, perhaps, the ability to sample more thoroughly in shallow areas of smaller bed elements.

Sub-group 4 consisted of 6 samples from bio-runs. This was a more poorly defined sub-group of six samples within the main fast-flow cluster, which appeared to be somewhat different from the bio-riffle sub-group. Flow was a little less turbulent (2 USW; 2 FRF; 2 RS), and the substratum less obviously dominated by cobbles (3 boulder; 3 large cobble). Water depths were slightly deeper than in bio-riffles (range 0.07-0.20 m; mean 0.13 m), and velocities slower but still faster than in pools (mean-column velocities: range 0.01-0.24 m s^{-1}; mean 0.15 m s^{-1}). On the MDS ordination, these six samples formed a loose cluster between the riffles and pools.

Sub-group 5 was recognised as a bio-pool (cobble). Its 13 samples were from slow-flowing areas (2 RS; 5 SBT; 6 BPF), and cobble-gravel substrata (1 boulder; 7 large cobble; 5 large gravel). The water was deeper than in bio-riffles and bio-runs (range 0.08-0.56 m; mean 0.20 m), with slow current speeds (mean column velocity: range 0.00-0.14 m s^{-1}; mean 0.02 m s^{-1}).

The final sub-group consisted of two samples (50 and 51) from bedrock. They have been recognised as representing a bio-run (bedrock). With a 33% similarity to each other but <10% to any other sample, they were gathered in water of moderate depth (0.14 and 0.21 m), in currents most typical of bio-runs (mean-column velocity 0.05, 0.19 m s^{-1}).

The MDS plot shows a gradient from right to left of boulder to cobble, and from top to bottom of fast flow to slow flow.

With mountain-zone hydraulic sub-groups defined, the less distinct pattern from the five alluvial mountain sites was re-assessed (Figure 11.4a and b). As mentioned, the first division was geographical, separating the Table Mountain from Eerste areas. With the catchment having such an overwhelming influence, groups of samples that might be representing different hydraulic biotopes were divided between three, if not four, main sub-groups (Disa, Newlands, Eerste and Eerste tributaries (Langrivier and Swartboskloof)) instead of clustering together. The very small divisions within the Disa and Newlands sub-groups then became essentially inadequate for good recognition of hydraulic biotopes. This was because in each analysis, any one hydraulic biotope was characterised by the *majority* of its samples, with a few outliers showing the spread of recorded conditions. Groups with very few samples could consist mainly of outliers. The following analysis therefore concentrates on the Eerste sites, with the Disa and Newlands sites mentioned briefly afterwards.

Within the Eerste group of sites, the major split was between the Eerste, and its two steep tributaries (Langrivier and Swartboskloof). Using both the dendrogram and the MDS ordination, four sub-groups were recognised.

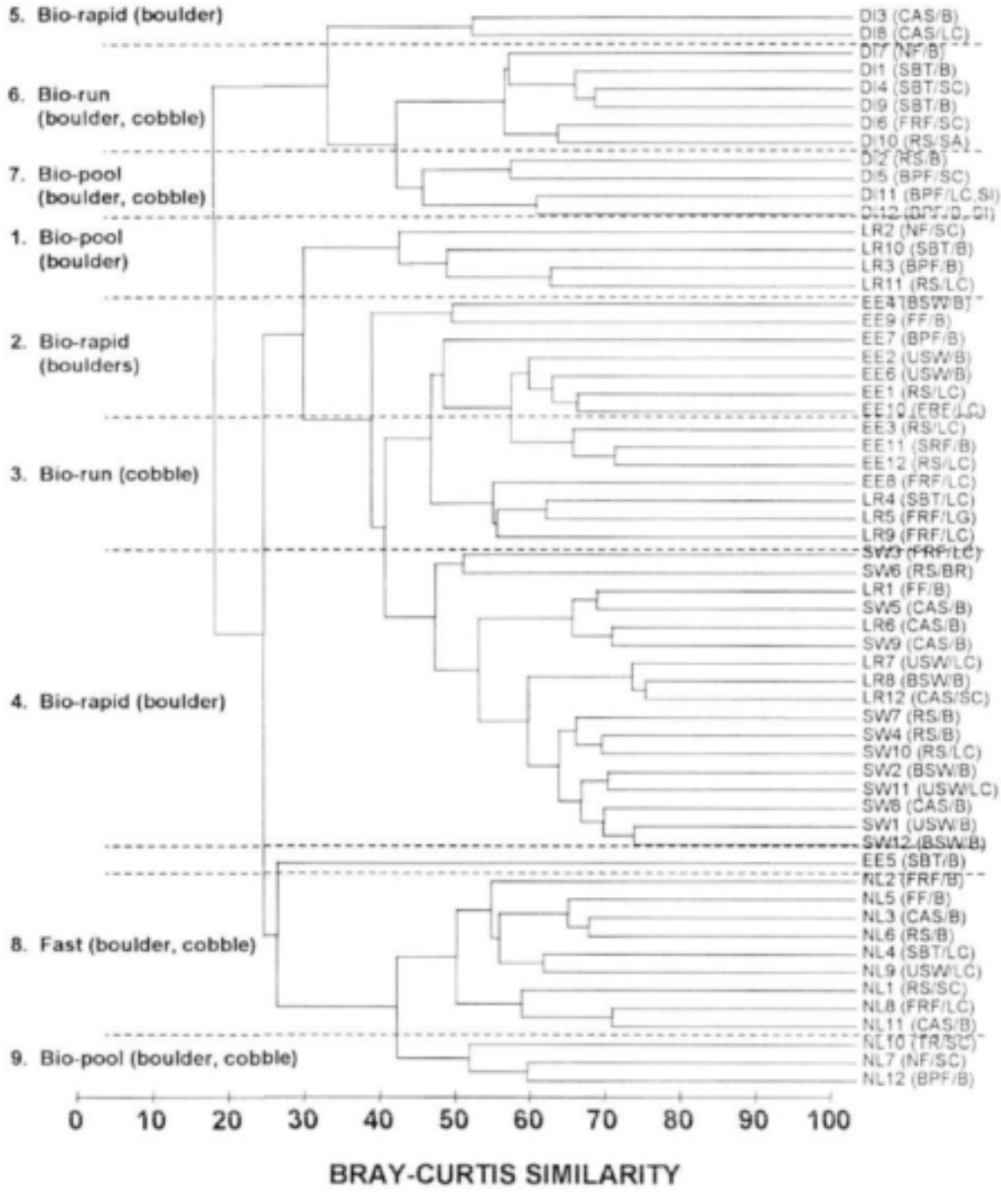


Figure 11.4a **Identification of similar invertebrate samples from five alluvial mountain sites. Dendrogram from cluster analysis.** Samples are coded by river and invertebrate sample number. *Eerste group*: EE = Eerste; LR = Langrivier; SW = Swartboskloof. *Table Mountain group*: DI = Disa; NL = Newlands. Substrata and flow categories as per Tables 2.3 and 2.4.

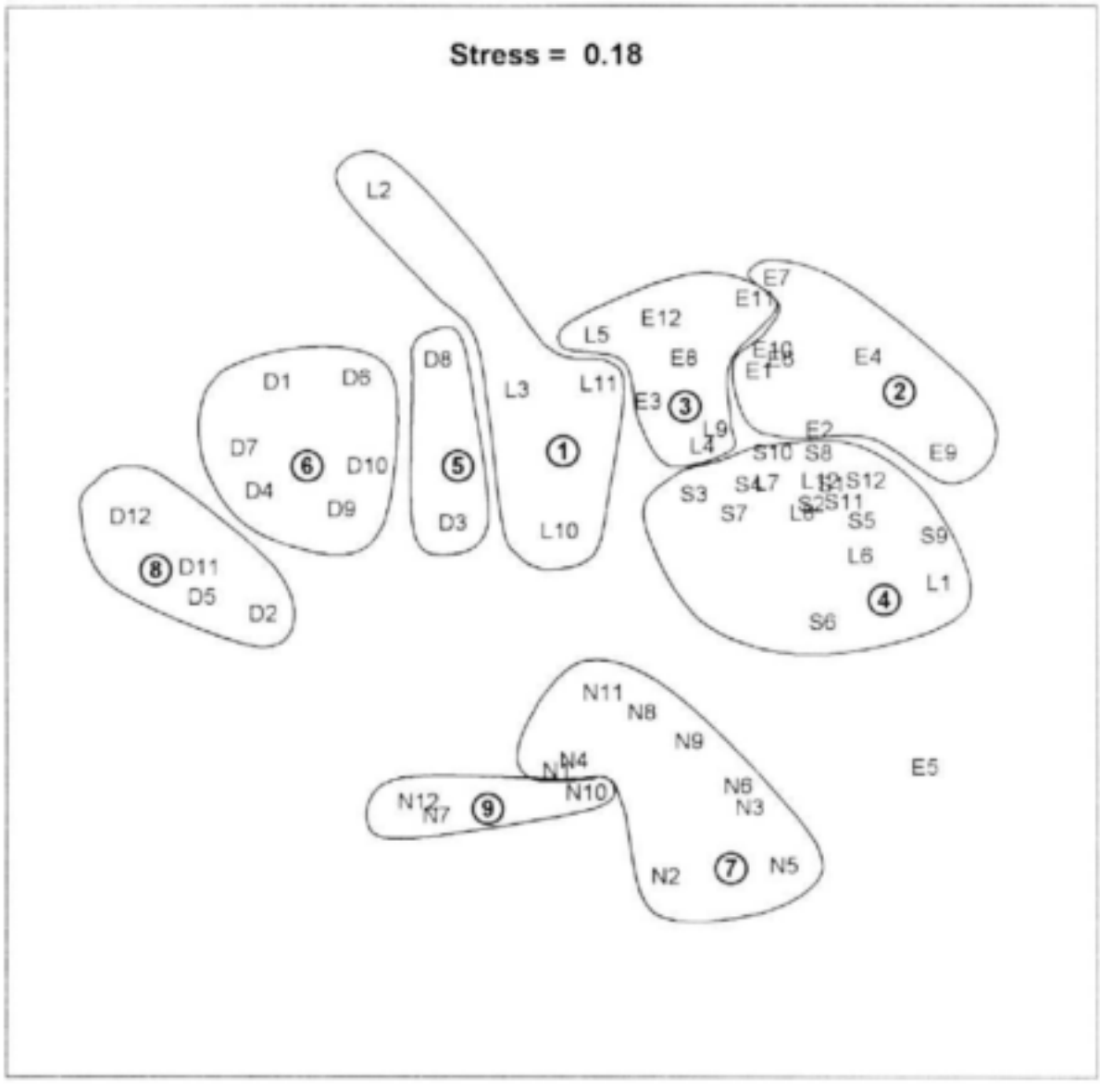


Figure 11.4b Identification of similar invertebrate samples from five alluvial mountain sites. MDS ordination plot. Samples are coded by river and invertebrate sample number. *Eerste group*: E = Eerste; L = Langrivier; S = Swartboskloof. *Table Mountain group*: D = Disa; N = Newlands.

Table 11.4 **Hydraulic characteristics of the eight groups of samples from alluvial mountains sites, as recognised in Figure 11.4.** Subgroups are recognised as biologically-derived hydraulic biotopes. Depth (m); Mean-column (0.6) and near-bed (NB) velocity (m s^{-1}).

Sub-group	Hydraulic biotope	Sample Code	Flow/Substrata	Depth	0.6	NB	Froude No.
1	Bio-pool (boulder)	LR2	NF/SC	0.09	0.00	0.00	0.000
		LR10	SBT/B	0.41	0.01	0.00	0.008
		LR3	BPF/B	0.13	0.03	0.02	0.021
		LR11	RS/LC	0.19	0.14	0.10	0.111
2	Bio-rapid	EE4	BSW/B	0.27	0.52	0.43	0.313
		EE9	FF/B	0.13	1.08	0.98	1.061
		EE7	BPF/B	0.45	0.08	0.00	0.035
		EE2	USW/B	0.20	0.47	0.36	0.374
		EE6	USW/B	0.22	0.27	0.15	0.213
		EE1	RS/LC	0.18	0.35	0.19	0.268
		EE10	FRF/LC	0.07	0.43	0.42	0.544
3	Bio-run	EE3	RS/LC	0.21	0.09	0.07	0.060
		EE11	SRF/B	0.08	0.07	0.06	0.077
		EE12	RS/LC	0.71	0.07	0.02	0.027
		EE8	FRF/LC	0.28	0.26	0.05	0.159
		LR4	SBT/LC	0.21	0.26	0.21	0.178
		LR5	FRF/LG	0.08	0.12	0.09	0.134
		LR9	FRF/LC	0.07	0.04	0.05	0.052
4	Bio-rapid	SW3	FRF/LC	0.16	0.08	0.05	0.075
		SW6	RS/BR	0.35	0.14	0.06	0.078
		LR1	FF/B	0.24	0.74	0.67	0.482
		SW5	CAS/B	0.23	1.06	0.73	0.777
		LR6	CAS/B	0.12	1.06	0.97	1.473
		SW9	CAS/B	0.05	0.25	0.31	0.720
		LR7	USW/LC	0.16	0.52	0.37	0.413
		LR8	BSW/B	0.08	0.48	0.42	0.610
		LR12	CAS/SC	0.10	0.85	0.76	0.936
		SW7	RS/B	0.11	0.09	0.07	0.087
		SW4	RS/B	0.20	0.19	0.12	0.137
		SW10	RS/LC	0.20	0.36	0.26	0.289
		SW2	BSW/B	0.17	1.01	0.78	0.837
		SW11	USW/LC	0.21	0.52	0.20	0.341
		SW8	CAS/B	0.20	0.61	0.42	0.484
		SW1	USW/B	0.25	0.66	0.40	0.416
		SW12	BSW/B	0.25	0.27	0.11	0.178
5	Disa (rapid)	DI3	CAS/B	0.04	0.20	0.20	0.322
		DI8	CAS/LC	0.06	0.31	0.31	0.408
6	Disa (pool)	DI7	NF/B	0.03	0.00	0.00	0.000
		DI1	SBT/B	0.18	0.09	0.07	0.064
		DI4	SBT/SC	0.12	0.08	0.05	0.069
		DI9	SBT/B	0.07	0.06	0.06	0.087
		DI6	FRF/SC	0.05	0.19	0.19	0.293
		DI10	RS/SA	0.05	0.08	0.08	0.117
7	Disa (run)	DI2	RS/B	0.09	0.07	0.06	0.095
		DI5	BPF/SC	0.08	0.03	0.02	0.032

Sub-group	Hydraulic biotope	Sample Code	Flow/Substrata	Depth	0.6	NB	Froude No.
7	Disa (run)	DI11	BPF/LC,SI	0.14	0.05	0.03	0.041
		DI12	BPF/B,SI	0.11	0.04	0.03	0.036
8	Newlands (fast)	NL2	FRF/B	0.09	0.43	0.34	0.554
		NL5	FF/B	0.02	1.35	1.35	3.572
		NL3	CAS/B	0.06	0.52	0.52	0.661
		NL6	RS/B	0.17	0.30	0.17	0.243
		NL4	SBT/LC	0.11	0.09	0.08	0.099
		NL9	USW/LC	0.14	0.10	0.11	0.091
		NL1	RS/SC	0.13	0.08	0.06	0.067
		NL8	FRF/LC	0.11	0.15	0.15	0.204
		NL11	CAS/B	0.08	0.31	0.29	0.369
9	Newlands (Bio-pool)	NL10	TR/SC	0.03	0.05	0.05	0.092
		NL7	NF/SC	0.19	0.00	0.00	0.000
		NL12	BPF/B	0.14	0.09	0.04	0.077

//Table 11.4 continued

Sub-group 4 consisted of 17 samples, all from the tributaries, and all from bio-rapids (boulder). These were very high-velocity areas characterised by turbulent, tumbling flow (1 FF (free fall); 5 CAS; 3 BSW; 3 USW; 4 RS; 1 FRF). The substratum consisted of large clasts (1 bedrock; 11 boulder; 4 large cobble; 1 small cobble). Water depths ranged 0.05-0.71 m (mean 0.21 m) and mean column velocity 0.08-1.06 m s^{-1} (mean 0.45 m s^{-1}). The wide range indicates quiet water occurring in hydraulic cover downstream of the boulders and very fast flow between boulders.

Sub-group 2 also represented bio-rapids (boulder), but from the Eerste site. With a similar composition of substrata and flow types, hydraulic conditions tended to be about the same (mean depth 0.22 m; means of mean column velocity 0.44 m s^{-1}).

Sub-group 3 is best characterised as a bio-run. With a mixture of smooth and flickering flow, it has some elements of a bio-riffle, but on average currents are too slow (mean column: range 0.06-0.26 m s^{-1}, mean 0.13 m s^{-1}), and depths rather high (range 0.7-0.71 m; mean 0.23 m). The dominance of cobbles, however, suggested a bio-riffle, and the sub-group is possibly a mixture, but one that could not be further logically separated.

Sub-group 1 consists of four samples from quiet waters in Langrivier. It is not clear if this represents boulder or cobble pools, as the samples are equally divided. As this is a high-gradient tributary, the sub-group is designated bio-pool (boulder), for the sake of consistency. Depths range from 0.09 to 0.41 m, and mean-column velocities 0.00-0.14 m s^{-1}.

Subgroups 5, 6 and 7 were recognised in the Disa group of samples. This very narrow stream (~ 2 m wide) was confined between heavily mossed and vegetated banks, and gave the impression of having a relatively low gradient. There was little development of a typical step-pool channel, and the overall impression was rather of water quietly trickling over a poorly sorted substratum. The subgroups have been named after biotope types already recognised earlier, although their character is far less distinct (Table 11.4). Sub-group 5 represented bio-rapids, with two samples from cascades over boulders. Sub-group 6 represented bio-runs, with six samples from boulders, small cobble and sand. Flow types were characteristic of runs (1

RS, 3 SBT, 1 FRF, 1NF), and current speed higher than in pools. Sub-group 7 consisted of four samples representing bio-pools. Current speeds were mostly lower than in the bio-runs, and the flow types typical of pools (1 RS, 3 BPF).

Subgroups 8 and 9 were distinguished in the Newlands samples. This high-gradient stream had a wider active channel and an open canopy. Its bed was dominated by large clasts. Most of its samples were in a fast-flow group (2 CAS, 1 FF, 1 USW, 2 FRF, 2 RS, 1 SBT), in shallow waters (0.02-0.17 m). Mean-column velocities ranged 0.00-1.35 m s^{-1}, with a mean of 0.37 m s^{-1}. Members of the group could not logically be allocated to a rapid or run grouping. The three samples in sub-group 9 represented a bio-pool (1 BPF, 1 NF, 1 TR (trickle)).

In summary, the alluvial mountain sites reflected a pattern of invertebrate distributions that again was dominated by catchment signatures and distinction between fast and slow-flow areas. The most obvious difference between the alluvial mountain and alluvial foothill sites was the presence of boulder biotopes in the mountain group and their much greater rarity in the foothill group. Comparing the foothill group with the replicate samples from the (mountain) Eerste site (Tables 11.2 and 11.3), and discounting the outliers already mentioned, 20% of the mountain samples were from biologically recognised boulder pools and 16% from boulder rapids, 24% from cobble riffles, 12% from mixed boulder-cobble runs, 4% from cobble pools and 4% from bedrock runs. In the foothill analysis, 14% of samples were from boulder rapids, none from boulder pools, 43% from cobble riffles, 25% from cobble runs and 18% from cobble pools. Within each of these analyses, catchment, and to some extent river, identities were clearly maintained.

11.3.3 Bedrock rivers

Thirty-six samples from three rivers were included in this analysis. These were the only fully bedrock rivers mapped in the project. In alluvial channels, flow shifts and sorts the bed particles, directly influencing the nature of hydraulic habitat, but in bedrock channels the shape is fixed over all but the longest time spans. Thus, the repetitive patterns of, for instance, step-pool, or riffle-run channels will not occur, with unknown implications for the occurrence of hydraulic biotopes.

The similarity analyses again showed an over-riding catchment influence (Figure 11.5a and b), with three groups each containing the 12 samples from one river. Within each river group, the same kinds of sub-groups as distinguished earlier could be detected.

Sub-groups 3, 4 and 9 represented bio-rapids (bedrock) from the Jan Dissels, Elandspad and Dwars respectively. Although the samples came from a range of depths (0.05-0.46 m), velocities were consistently quite high (means of mean-column velocities: 0.36, 0.41 and 0.29 m s^{-1}). The characteristic flow type was moderate to fast and often turbulent (1 FF; 3 CAS; 2 BSW; 2 USW; 5 RS; 1 SBT), and all but one sample was from bedrock.

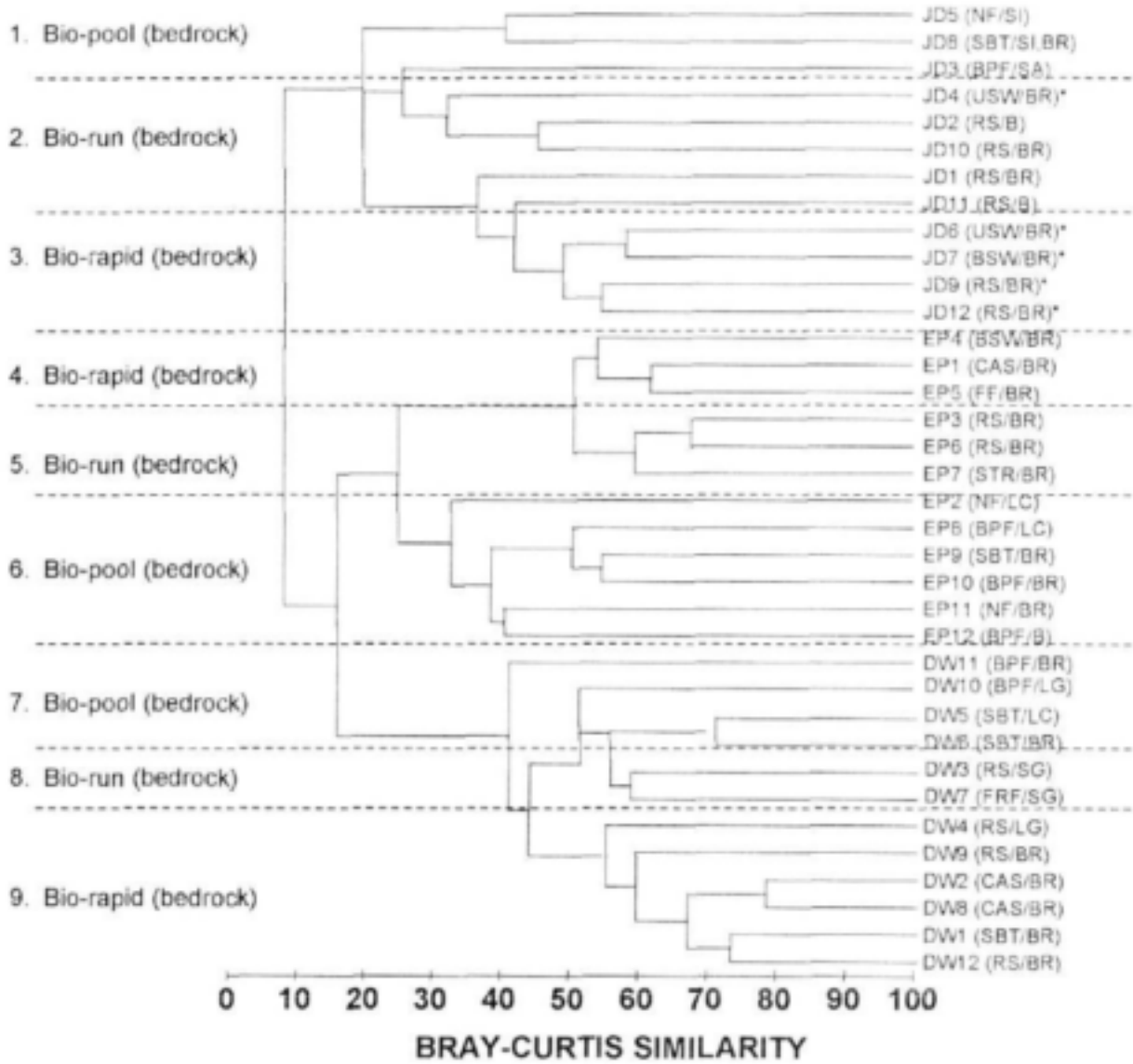


Figure 11.5a Identification of similar invertebrate samples from three bedrock sites. Dendrogram from cluster analysis. Samples are coded by river and invertebrate sample number: JD = Jan Dissels; EP = Elandspad; DW = Dwars. Substrata and flow categories as per Tables 2.3 and 2.4. Sub-groups 2 and 3 are interspersed; members of sub-group 3 are denoted with an *.

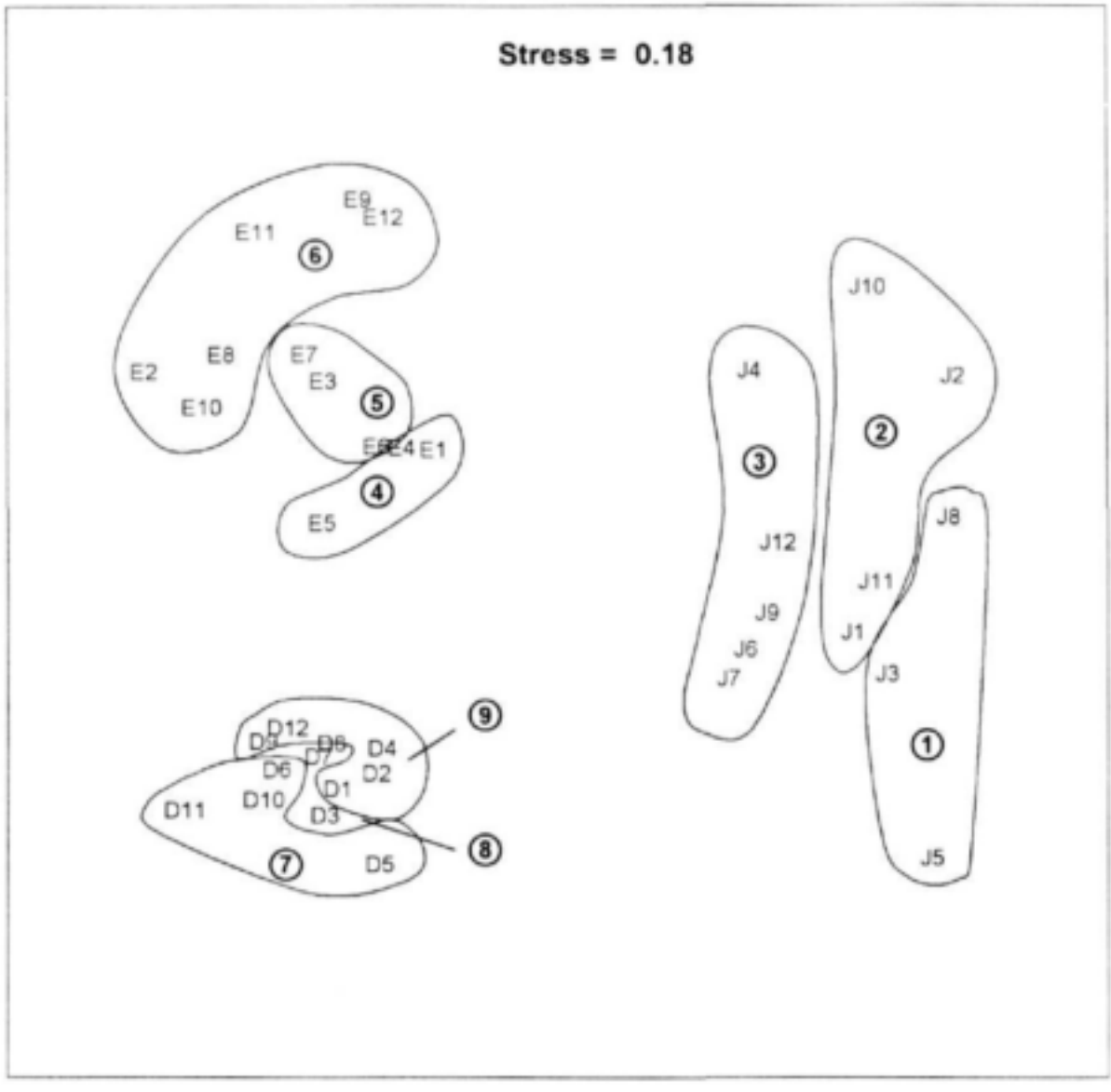


Figure 11.5b Identification of similar invertebrate samples from three bedrock sites. MDS ordination plot. Samples are coded by river and invertebrate sample number: E = Elandspad; J = Jan Dissels; D = Dwars.

Sub-groups 2, 5 and 8 represented bio-runs (bedrock). Water depths tended to be greater than in bio-rapids (0.16-0.65 m), and velocities lower (means of mean-column velocities: 0.11, 0.16 and 0.14 m s^{-1}). Flow types indicated a slower less turbulent flow (7 RS; 1 STR; 1 FRF), and there was some appearance of settled alluvial material on the bedrock base (5 bedrock; 2 boulder; 2 small gravel).

Sub-groups 1, 6 and 7 represented bio-pools (bedrock). Water depths were considerably deeper than in bio-rapids or bio-runs (0.25-1.17 m), and velocities very low (mean of mean-column velocities 0.01, 0.01 and 0.05 m s^{-1}). Flow types reflected this (4 SBT; 6 BPF; 3 NF). The substratum was a mixture of bedrock and settled out alluvial material, some of it quite fine (6 bedrock; 1 boulder; 3 large cobble; 1 large gravel; 1 sand; 1 silt).

On the MDS plot (Figure 11.5b), the three sites were strongly separated, and arranged in a circle, with the bio-rapids clustered most closely within any one group and closest to each other toward the middle of the circle. Bio-pools were most scattered and furthest from other rivers' bio-pools on the outside of the circle. This suggests that:

- across similar rivers, the fauna of bedrock bio-rapids are more similar than are the fauna of bedrock bio-pools, with bedrock bio-runs intermediate;
- bedrock bio-rapids are more homogeneous than bedrock bio-pools in terms of physical habitat and so the same species are more consistently sampled.

Table 11.5 Hydraulic characteristics of the nine groups of samples from bedrock sites, as recognised in Figure 11.5. Sub-groups are recognised as biologically-derived hydraulic biotopes. Depth (m); Mean-column (0.6) velocity (m s^{-1}) and near-bed (NB) velocity (m s^{-1}).

Sub-group	Hydraulic biotope	Sample Code	Flow/Substrata	Depth	0.6	NB	Froude No.
1	Bio-pool (bedrock)	JD5	NF/SI	0.25	0.00	0.00	0.000
		JD8	SBT/SI,BR	0.29	0.02	0.02	0.010
		JD3	BPF/SA	0.89	0.00	0.01	0.000
2	Bio-run (bedrock)	JD2	RS/B	0.65	0.04	0.00	0.015
		JD10	RS/BR	0.65	0.24	0.05	0.098
		JD1	RS/BR	0.32	0.08	0.01	0.046
		JD11	RS/B	0.31	0.09	0.04	0.063
3	Bio-rapid (bedrock)	JD4	USW/BR	0.44	0.57	0.25	0.294
		JD6	USW/BR	0.13	0.25	0.16	0.282
		JD7	BSW/BR	0.13	1.15	0.65	1.020
		JD9	RS/BR	0.16	0.46	0.30	0.389
		JD12	RS/BR	0.12	0.70	0.31	0.633
4	Bio-rapid (bedrock)	EP4	BSW/BR	0.21	0.44	0.09	0.374
		EP1	CAS/BR	0.10	0.47	0.39	0.471
		EP5	FF/BR	0.05	0.75	0.75	1.213
5	Bio-run (bedrock)	EP3	RS/BR	0.49	0.34	0.09	0.161
		EP6	RS/BR	0.27	0.05	0.02	0.034
		EP7	STR/BR	0.31	0.08	0.01	0.055
6	Bio-pool (bedrock)	EP2	NF/LC	0.41	0.00	0.00	0.000
		EP8	BPF/LC	0.62	0.05	0.04	0.019
		EP9	SBT/BR	0.59	0.01	0.00	0.002

Sub-group	Hydraulic biotope	Sample Code	Flow/Substrata	Depth	0.6	NB	Froude No.
6	Bio-pool (bedrock)	EP10	BPF/BR	0.33	0.00	0.01	0.000
		EP11	NF/BR	0.39	0.00	0.00	0.000
		EP12	BPF/BR	0.95	0.00	0.00	0.000
7	Bio-pool (bedrock)	DW11	BPF/BR	0.33	0.03	0.00	0.018
		DW5	SBT/LC	0.84	0.15	0.02	0.052
		DW6	SBT/BR	1.17	0.02	0.03	0.005
		DW10	BPF/LG	0.51	0.01	0.00	0.003
8	Bio-run (bedrock)	DW3	RS/SG	0.16	0.16	0.07	0.125
		DW7	FRF/SG	0.20	0.12	0.04	0.105
9	Bio-rapid (bedrock)	DW4	RS/LG	0.19	0.92	0.43	0.696
		DW9	CAS/BR	0.46	0.17	0.04	0.087
		DW2	CAS/BR	0.10	0.60	0.33	0.610
		DW8	CAS/BR	0.18	1.10	0.70	0.894
		DW1	SBT/BR	0.18	0.20	0.04	0.157
		DW12	RS/BR	0.42	0.17	0.20	0.082

//Table 11.5 continued

11.3.4 Mixed alluvial-bedrock rivers

Four of the sites in least-disturbed rivers had beds consisting of a mixture of bedrock and alluvial material. The upstream half of Bakkerskloof, from the Berg catchment, was mixed boulder, cobble and gravel, whilst the downstream half was bedrock. Its flow types were typical of many bedrock streams, being dominated by pool-like areas interspersed with cascades as water dropped from one bedrock pool to the next. Zachariashoek, also in the Berg catchment, had alternating bedrock and alluvial sections through the site, and its pattern of flow was less pool-like but still with a considerable quantity of quiet water. There were also two Breede sites in this category: Steenbok, which was continuous bedrock along its left bank and most of the bed, and boulders along the right bank; and Wolwekloof, with patches of bedrock at the upstream and downstream extremes of the site. Both had similar flow patterns to Zachariashoek, and all four were characterised by more pool-like patches of water than alluvial mountain sites with similar or lower gradients.

Five main sub-groups of similar samples were recognised among the 48 from these four sites (Figure 11.6), with a small group of uncertain identity but named here for expediency "bio-stream". There was one outlier (ZA9) which is not considered further here. The main split was between fast-flow and slow-flow sites, with all but one of the slow set being from the Berg sites. The fast group then divided into one sub-group from the Berg catchment, two from the Breede catchment, and the small bio-stream cluster (Table 11.6).

Sub-group 2 represented bio-pools (cobble) from the Berg tributaries, with fairly shallow water depths (0.03-0.45 m) and low velocities (mean of mean-column velocities 0.03 m s^{-1}). Flow types were mostly slow (1 USW; 3 RS; 1 SBT; 2 BPF; 2 NF; 1 TR), and the substratum dominated by cobble (2 boulder; 4 large cobble; 2 large gravel; 1 sand, 1 silt).

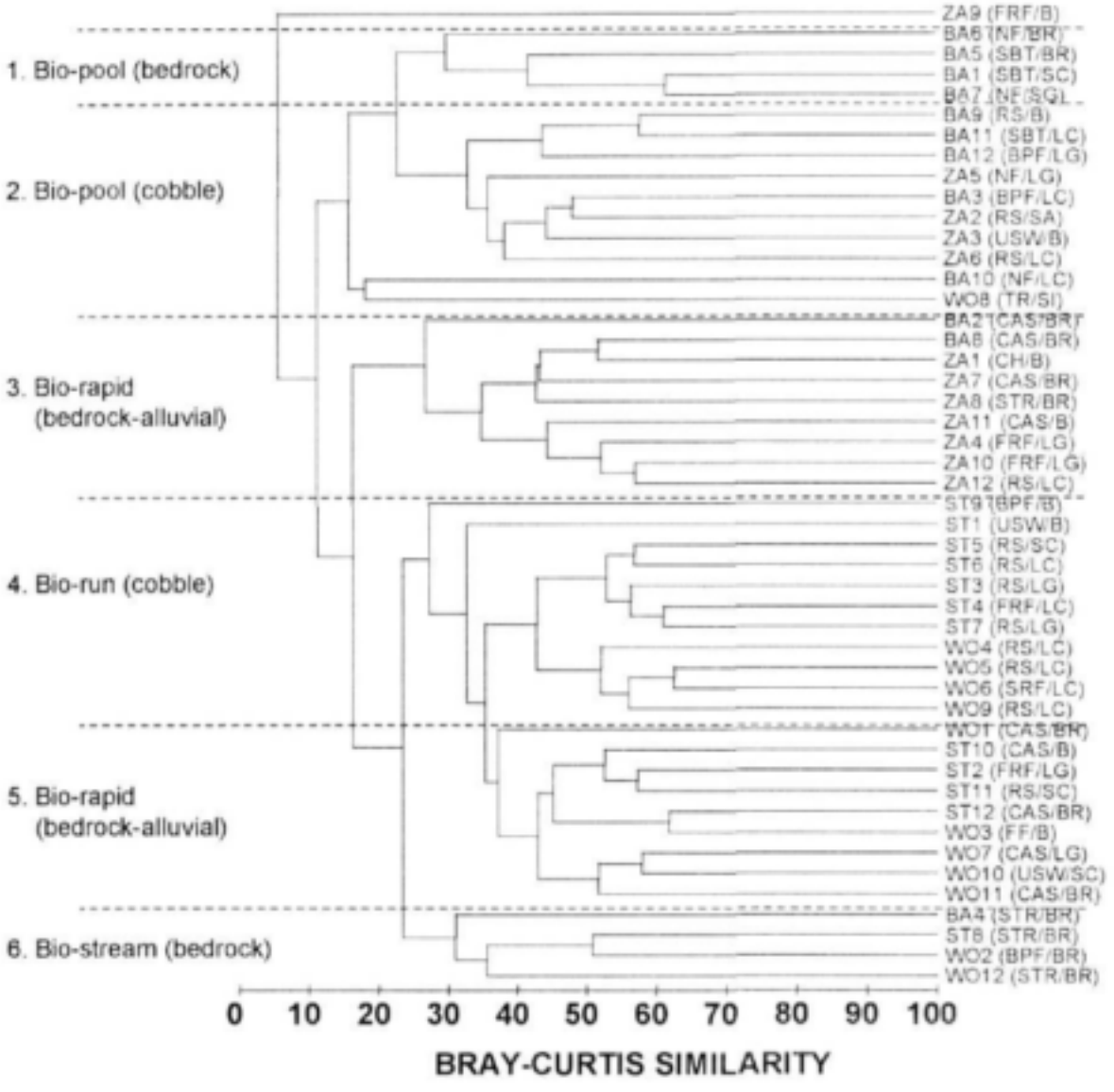


Figure 11.6a Identification of similar invertebrate samples from four mixed alluvial-bedrock sites. Dendrogram from cluster analysis. Samples are coded by river and invertebrate sample number. *Berg group*: ZA = Zachariashoek; BA = Bakkerskloof. *Breede group*: WO = Wolvekloof; ST = Steenbok. Substrata and flow categories as per Tables 2.3 and 2.4.

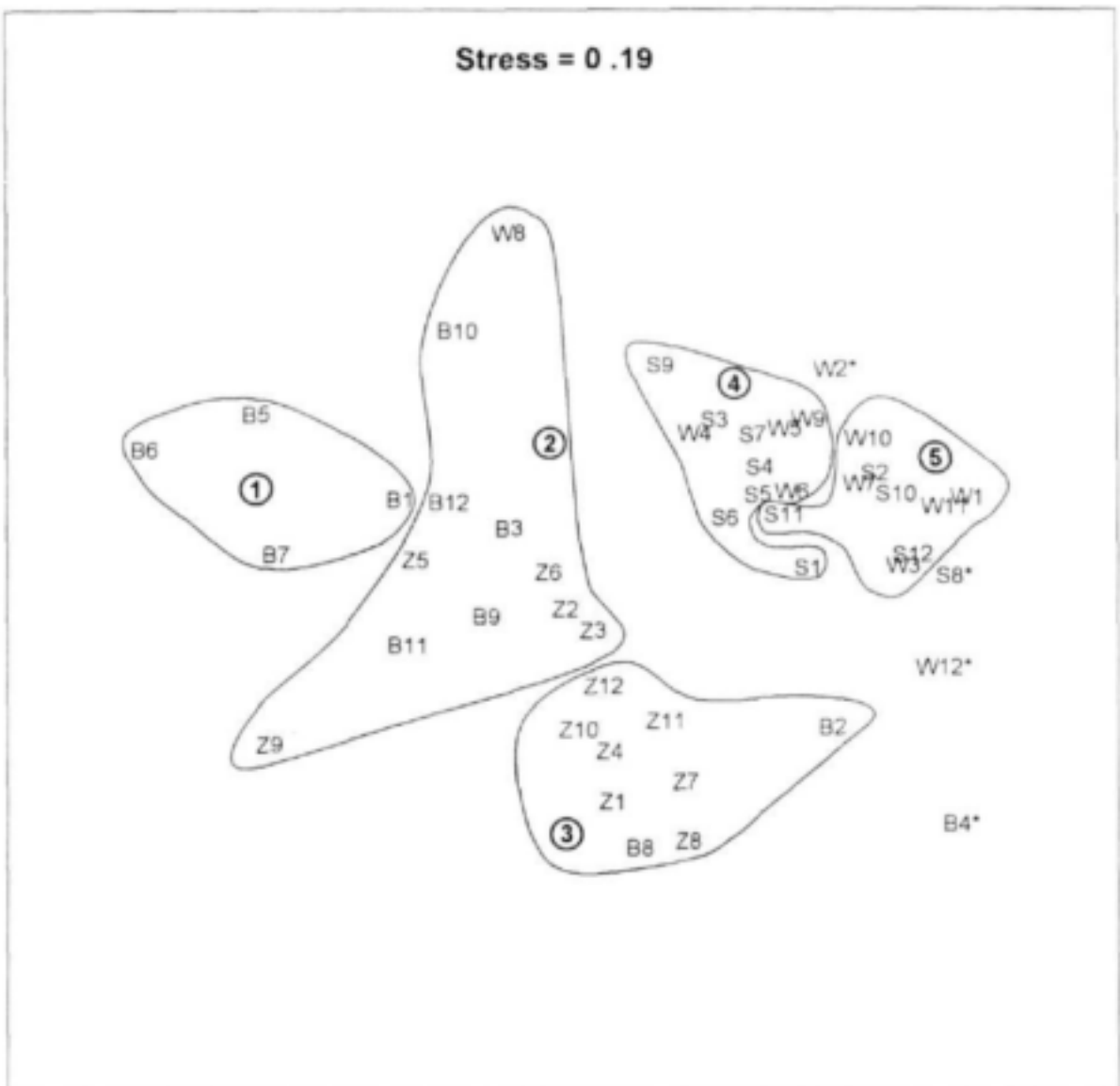


Figure 11.6b Identification of similar invertebrate samples from four mixed alluvial-bedrock sites. MDS ordination plot. Samples are coded by river and invertebrate sample number. *Berg group*: B = Berg; Z = Zachariashoek. *Breede group*: S = Steenbok; W = Wolvekloof. Sub-group 6 is denoted with an *.

Sub-group 1, from bio-pools (bedrock), consisted of four samples from quiet bedrock areas, two of which had small cobble or gravel on the bedrock. The hydraulic statistics of the sub-group were similar to those of sub-group 2.

Sub-group 3 represented bio-rapids (bedrock, boulder) from the Berg tributaries, with turbulent water (4 CAS; 1 CH; 1 STR; 2 FRF; 1 RS) over mostly bedrock (4 bedrock; 2 boulder; 1 large cobble; 2 large gravel). Water depths were shallow (mean of 0.07 m) and mean-column velocities high (mean of 0.33 m s^{-1}). Bio-rapid 5, from the Breede tributaries, had a similar composition of flow types (5 CAS; 1 FF; 1 USW; 1 FRF; 1 RS) and substrata (3 bedrock; 2 boulder; 2 small cobble, 2 large gravel). Its depths were also similar (mean of 0.06 m) and velocities somewhat higher (mean of 0.57 m s^{-1}).

Sub-group 4 represented bio-runs (cobble). All samples came from the Breede tributaries, from medium speed, smooth flowing waters (1 USW; 7 RS; 1 FRF; 1 SRF; 1 BPF). The underlying substratum was mainly cobble (2 boulder; 6 large cobble; 1 small cobble; 2 large gravel).

Sub-group 6 was a set of four samples from three sites. All four were from bedrock, and three from the flow types described as "stream", which is defined in Table 2.3 as "water flowing rapidly in a smooth sheet of water; similar to a chute but not forced between two large bed elements". It was usually found as a very shallow, smooth sheet of water flowing fast over large, hard substrata such as very large boulders or bedrock. The hydraulic statistics attached to these four samples did not reveal any common characteristics other than low water depths.

Table 11.6 Hydraulic characteristics of the nine groups of samples from mixed alluvial-bedrock sites, as recognised in Figure 11.6. Sub-groups are recognised as biologically-derived hydraulic biotopes. Depth (m); Mean-column (0.6) and near-bed (NB) velocity (m s^{-1}).

Sub-group	Hydraulic biotope	Sample Code	Flow/Substrata	Depth	0.6	NB	Froude No.
1	Bio-pool (bedrock)	BA6	NF/BR	0.16	0.00	0.00	0.000
		BA5	SBT/BR	0.16	0.02	0.01	0.012
		BA1	SBT/SC	0.69	0.01	0.00	0.003
		BA7	NF/SG	0.29	0.00	0.00	0.000
2	Bio-pool (cobble)	BA9	RS/B	0.03	0.12	0.12	0.248
		BA11	SBT/LC	0.12	0.03	0.02	0.023
		BA12	BPF/LG	0.23	0.01	0.01	0.009
		ZA5	NF/LG	0.14	0.00	0.00	0.000
		BA3	BPF/LC	0.30	0.01	0.00	0.009
		ZA2	RS/SA	0.11	0.08	0.04	0.075
		ZA3	USW/B	0.18	0.02	0.02	0.020
		ZA6	RS/LC	0.24	0.02	0.01	0.018
		BA10	NF/LC	0.15	0.00	0.00	0.000
		WO8	TR/SI	0.03	0.00	0.00	0.006
3	Bio-rapid (bedrock-alluvial)	BA2	CAS/BR	0.04	0.36	0.36	0.699
		BA8	CAS/BR	0.12	0.01	0.14	0.311
		ZA1	CH/B	0.05	0.44	0.44	0.679

Sub-group	Hydraulic biotope	Sample Code	Flow/Substrata	Depth	0.6	NB	Froude No.
3	Bio-rapid (bedrock-alluvial)	ZA7	CAS/BR	0.10	0.33	0.49	0.619
		ZA8	STR/BR	0.04	0.97	0.97	1.555
		ZA11	CAS/B	0.07	0.18	0.29	0.410
		ZA4	FRF/LG	0.05	0.37	0.41	0.655
		ZA10	FRF/LG	0.04	0.20	0.23	0.427
		ZA12	RS/LC	0.14	0.09	0.06	0.081
4	Bio-run (cobble)	ST9	BPF/B	0.42	0.01	0.00	0.004
		ST1	USW/B	0.12	0.28	0.27	0.333
		ST5	RS/SC	0.08	0.13	0.13	0.133
		ST6	RS/LC	0.13	0.06	0.04	0.061
		ST3	RS/LG	0.16	0.06	0.04	0.048
		ST4	FRF/LC	0.06	0.09	0.18	0.282
		ST7	RS/LG	0.08	0.23	0.17	0.239
		WO4	RS/LC	0.23	0.11	0.08	0.072
		WO5	RS/LC	0.21	0.13	0.17	0.086
		WO6	SRF/LC	0.09	0.19	0.17	0.201
		WO9	RS/LC	0.15	0.29	0.22	0.254
5	Bio-rapid (bedrock-alluvial)	WO1	CAS/BR	0.04	0.96	0.96	1.471
		ST10	CAS/B	0.05	0.46	0.46	0.671
		ST2	FRF/LG	0.02	0.30	0.30	0.763
		ST11	RS/SC	0.11	0.35	0.38	0.336
		ST12	CAS/BR	0.09	1.18	1.53	2.006
		WO3	FF/B	0.04	0.57	0.57	0.910
		WO7	CAS/LG	0.04	0.24	0.24	0.411
		WO10	USW/SC	0.08	0.49	0.52	0.533
		WO11	CAS/BR	0.04	0.34	0.34	0.519
6	Bio-stream (bedrock)	BA4	STR/BR	0.02	0.64	0.64	1.438
		ST8	STR/BR	0.03	0.18	0.18	0.360
		WO2	BPF/BR	0.13	0.07	0.06	0.062
		WO12	STR/BR	0.01	0.44	0.44	1.405

//Table 11.6 continued

11.4 Summary

Apart from the three questionable sub-groups, 38 sub-groups of samples were recognised. Twelve were bio-pools, 11 bio-rapids, five bio-riffles and ten bio-runs. These four main groups had quite different hydraulic characteristics (Table 11.7). The following discussion uses the mean values from each invertebrate sampling point.

Bio-pools ranged in depth from very shallow to more than 1 m, but with very low mean-column and near-bed velocities (0.00-0.10 m s^{-1}). Froude numbers were mostly <0.070. The full range of substrata occurred, with boulders, large cobble and small cobble each contributing on average about 22% and a higher proportion of sand and silt than in any other hydraulic biotope (Table 11.8). The most common flow types were BPF and SBT (Table 11.8).

Table 11.7a **Summary statistics for each sub-group of samples recognised in Tables 11.2-11.6: ranges, means and standard deviations of water depth, mean-column velocity and near-bed velocity.** Up to six individual sets of depth and velocity measurements were made within the area where each invertebrate sample was collected. The means of these are the values given in Tables 11.2-11.6. The values in this summary table are the ranges, means (Ave) and standard deviations (SD) of these means. Depth (m); mean-column (0.6) and near-bed (NB) velocity (m s^{-1}).

Hydraulic Biotope	Sub-group	Analysis Group	Ref. Figure	Range of Depth	Ave Depth	SD Depth	Range of NB	Ave NB	SD NB	Range of 0.6	Ave 0.6	SD 0.6
Bio-pool	2	Foothill	11.2	0.04 – 0.40	0.19	0.18	0.01 – 0.24	0.07	0.11	0.01 – 0.24	0.10	0.10
Bio-pool	3	Foothill	11.2	0.08 – 0.45	0.25	0.15	0.00 – 0.02	0.01	0.01	0.00 – 0.07	0.01	0.03
Bio-pool (bedrock)	1	Alluvial-Bedrock	11.6	0.16 – 0.69	0.33	0.25	0.00 – 0.01	0.00	0.01	0.00 – 0.02	0.01	0.01
Bio-pool (bedrock)	1	Bedrock	11.5	0.25 – 0.89	0.50	0.34	0.00 – 0.02	0.01	0.01	0.00 – 0.02	0.01	0.01
Bio-pool (bedrock)	6	Bedrock	11.5	0.33 – 0.95	0.55	0.23	0.00 – 0.04	0.01	0.02	0.00 – 0.05	0.01	0.02
Bio-pool (bedrock)	7	Bedrock	11.5	0.33 – 1.17	0.71	0.37	0.00 – 0.07	0.01	0.02	0.01 – 0.15	0.05	0.07
Bio-pool (boulder)	1	Mountain	11.4	0.09 – 0.41	0.21	0.14	0.00 – 0.10	0.03	0.05	0.00 – 0.14	0.05	0.06
Bio-pool (boulder)	2	Mountain (IS)	11.3	0.07 – 0.33	0.17	0.10	0.00 – 0.14	0.05	0.04	0.00 – 0.67	0.10	0.20
Bio-pool (cobble)	2	Alluvial-Bedrock	11.6	0.03 – 0.45	0.19	0.13	0.00 – 0.12	0.02	0.04	0.00 – 0.12	0.03	0.04
Bio-pool (cobble)	5	Mountain (IS)	11.3	0.08 – 0.56	0.20	0.14	0.00 – 0.18	0.04	0.05	0.00 – 0.14	0.02	0.04
Bio-pool (Disa)	6	Mountain	11.4	0.03 – 0.18	0.08	0.06	0.00 – 0.19	0.08	0.06	0.00 – 0.19	0.08	0.07
Bio-pool (Newlands)	9	Mountain	11.4	0.03 – 0.19	0.12	0.08	0.00 – 0.05	0.03	0.03	0.00 – 0.09	0.05	0.05
Bio-rapid	7	Foothill	11.2	0.05 – 0.52	0.28	0.24	0.11 – 0.45	0.27	0.17	0.34 – 0.60	0.46	0.13
Bio-rapid	10	Foothill	11.2	0.06 – 0.58	0.25	0.22	0.05 – 0.94	0.37	0.40	0.11 – 0.87	0.42	0.36
Bio-rapid	2	Mountain	11.4	0.07 – 0.45	0.22	0.12	0.00 – 0.98	0.40	0.32	0.08 – 0.99	0.44	0.30
Bio-rapid	4	Mountain	11.4	0.05 – 0.71	0.21	0.15	0.02 – 0.97	0.36	0.30	0.08 – 1.06	0.45	0.33
Bio-rapid (bedrock)	3	Bedrock	11.5	0.12 – 0.16	0.14	0.02	0.16 – 0.65	0.36	0.21	0.25 – 1.15	0.67	0.40
Bio-rapid (bedrock)	4	Bedrock	11.5	0.05 – 0.21	0.12	0.08	0.09 – 0.75	0.41	0.33	0.44 – 0.75	0.58	0.16
Bio-rapid (bedrock)	9	Bedrock	11.5	0.10 – 0.46	0.26	0.15	0.04 – 0.70	0.29	0.25	0.17 – 1.10	0.54	0.42
Bio-rapid (bedrock-alluvial)	3	Alluvial-Bedrock	11.6	0.04 – 0.14	0.07	0.04	0.06 – 0.97	0.38	0.26	0.01 – 0.97	0.33	0.28
Bio-rapid (bedrock-alluvial)	5	Alluvial-Bedrock	11.6	0.02 – 0.11	0.06	0.03	0.24 – 1.53	0.56	0.43	0.24 – 1.18	0.57	0.32
Bio-rapid (boulder)	1	Mountain (IS)	11.3	0.01 – 0.16	0.07	0.06	0.18 – 1.25	0.70	0.40	0.02 – 1.25	0.65	0.40
Bio-rapid (Disa)	5	Mountain	11.4	0.04 – 0.06	0.05	0.01	0.20 – 0.31	0.26	0.08	0.20 – 0.46	0.33	0.18
Bio-riffle	4	Foothill	11.2	0.15 – 0.20	0.17	0.02	0.14 – 0.35	0.26	0.08	0.26 – 0.47	0.35	0.08
Bio-riffle	6	Foothill	11.2	0.04 – 0.16	0.09	0.04	0.09 – 0.55	0.28	0.18	0.08 – 0.56	0.31	0.22
Bio-riffle	8	Foothill	11.2	0.04 – 0.15	0.08	0.04	0.09 – 0.44	0.24	0.13	0.06 – 0.52	0.25	0.16
Bio-riffle	11	Foothill	11.2	0.10 – 0.32	0.18	0.09	0.17 – 0.34	0.24	0.06	0.31 – 0.69	0.42	0.16

Hydraulic Biotope	Sub-group	Analysis Group	Ref. Figure	Range of Depth	Ave Depth	SD Depth	Range of NB	Ave NB	SD NB	Range of 0.6	Ave 0.6	SD 0.6
Bio-riffle	3	Mountain (IS)	11.3	0.04 – 0.18	0.08	0.04	0.12 – 0.46	0.28	0.09	0.01 – 0.37	0.25	0.10
Bio-run	5	Foothill	11.2	0.07 – 0.20	0.11	0.05	0.00 – 0.06	0.04	0.02	0.01 – 0.08	0.04	0.03
Bio-run	9	Foothill	11.2	0.11 – 0.94	0.37	0.29	0.00 – 0.25	0.07	0.10	0.00 – 0.30	0.18	0.12
Bio-run	3	Mountain	11.4	0.07 – 0.71	0.23	0.23	0.02 – 0.21	0.08	0.05	0.06 – 0.26	0.13	0.09
Bio-run	4	Mountain (IS)	11.3	0.07 – 0.20	0.13	0.04	0.05 – 0.27	0.19	0.10	0.01 – 0.24	0.15	0.10
Bio-run (bedrock)	2	Bedrock	11.5	0.31 – 0.65	0.48	0.20	0.00 – 0.05	0.03	0.03	0.04 – 0.24	0.11	0.09
Bio-run (bedrock)	5	Bedrock	11.5	0.27 – 0.49	0.36	0.12	0.01 – 0.09	0.04	0.04	0.05 – 0.34	0.16	0.16
Bio-run (bedrock)	8	Bedrock	11.5	0.16 – 0.20	0.18	0.03	0.04 – 0.07	0.06	0.02	0.12 – 0.16	0.14	0.03
Bio-run (bedrock)	6	Mountain (IS)	11.3	0.14 – 0.21	0.18	0.05	0.08 – 0.21	0.15	0.09	0.05 – 0.19	0.12	0.10
Bio-run (cobble)	4	Alluvial-Bedrock	11.6	0.06 – 0.42	0.16	0.10	0.00 – 0.27	0.13	0.08	0.01 – 0.29	0.14	0.09
Bio-run (Disa)	7	Mountain	11.4	0.08 – 0.14	0.11	0.03	0.02 – 0.06	0.04	0.02	0.03 – 0.05	0.04	0.01
Bio-stream (bedrock)	6	Alluvial-Bedrock	11.6	0.01 – 0.13	0.05	0.06	0.06 – 0.64	0.33	0.26	0.07 – 0.64	0.33	0.26
Fast (Newlands)	8	Mountain	11.4	0.02 – 0.17	0.11	0.04	0.05 – 1.35	0.31	0.40	0.00 – 1.35	0.40	0.40
Mixed	1	Foothill	11.2	0.03 – 0.23	0.11	0.09	0.00 – 0.13	0.03	0.07	0.00 – 0.11	0.03	0.06

//Table 11.7a continued

Table 11.7b Summary statistics for each sub-group of samples recognised in Tables 11.2-11.6: percentage composition of substrata. *Substrata categories as per Table 2.4.*

Hydraulic Biotope	Sub-group	Analysis Group	Ref. Figure	BR	B	LC	SC	LG	SG	SA	SILT
Bio-pool	2	Foothill	11.2			25.0	75.0				
Bio-pool	3	Foothill	11.2		16.7	50.0	33.3				
Bio-pool (bedrock)	1	Alluvial-Bedrock	11.6	50.0			25.0		25.0		
Bio-pool (bedrock)	1	Bedrock	11.5	33.3						33.3	33.3
Bio-pool (bedrock)	6	Bedrock	11.5	50.0	16.7	33.3					
Bio-pool (bedrock)	7	Bedrock	11.5	50.0		25.0		25.0			
Bio-pool (boulder)	1	Mountain	11.4		50.0	25.0	25.0				
Bio-pool (boulder)	2	Mountain (IS)	11.3	16.7	66.6			16.7			
Bio-pool (cobble)	2	Alluvial-Bedrock	11.6		20.0	40.0		20.0		10.0	10.0
Bio-pool (cobble)	5	Mountain (IS)	11.3		7.7	53.8		38.5			
Bio-pool (Disa)	6	Mountain	11.4		50.0		33.3			16.7	
Bio-pool (Newlands)	9	Mountain	11.4		33.3		66.7				
Bio-rapid	7	Foothill	11.2		100.0						
Bio-rapid	10	Foothill	11.2		80.0	20.0					
Bio-rapid	2	Mountain	11.4		71.4	28.6					
Bio-rapid	4	Mountain	11.4	5.9	64.6	23.6	5.9				
Bio-rapid (bedrock)	3	Bedrock	11.5	100.0							
Bio-rapid (bedrock)	4	Bedrock	11.5	100.0							
Bio-rapid (bedrock)	9	Bedrock	11.5	83.3				16.7			
Bio-rapid (bedrock-alluvial)	3	Alluvial-Bedrock	11.6	44.4	22.2	11.1		22.2			
Bio-rapid (bedrock-alluvial)	5	Alluvial-Bedrock	11.6	33.3	22.2		22.2	22.2			
Bio-rapid (boulder)	1	Mountain (IS)	11.3		100.0						
Bio-rapid (Disa)	5	Mountain	11.4		50.0	50.0					
Bio-riffle	4	Foothill	11.2		40.0	40.0		20.0			
Bio-riffle	6	Foothill	11.2		33.3	33.3	16.7	16.7			
Bio-riffle	8	Foothill	11.2		12.5	50.0	12.5	25.0			
Bio-riffle	11	Foothill	11.2		20.0	60.0	20.0				
Bio-riffle	3	Mountain (IS)	11.3		33.3	66.7					
Bio-run	5	Foothill	11.2			40.0		40.0		20.0	
Bio-run	9	Foothill	11.2		22.2	66.6	11.1				
Bio-run	3	Mountain	11.4		14.3	71.4		14.3			
Bio-run	4	Mountain (IS)	11.3		50.0	50.0					
Bio-run (bedrock)	2	Bedrock	11.5	50.0	50.0						
Bio-run (bedrock)	5	Bedrock	11.5	100.0							
Bio-run (bedrock)	8	Bedrock	11.5						100.0		
Bio-run (bedrock)	6	Mountain (IS)	11.3	100.0							
Bio-run (cobble)	4	Alluvial-Bedrock	11.6		18.2	54.5	9.1	18.2			
Bio-run (Disa)	7	Mountain	11.4		25.0		25.0				50.0
Bio-stream (bedrock)	6	Alluvial-Bedrock	11.6								
Fast (Newlands)	8	Mountain	11.4		55.5	33.3	11.1				
Mixed	1	Foothill	11.2		50.0			25.0		25.0	

Table 11.7c Summary statistics for each sub-group of samples recognised in Tables 11.2-11.6: percentage composition of flow types. Flow type categories as per Table 2.3.

Hydraulic Biotope	Sub-group	Analysis Group	Ref. Figure	NF	TR	BPF	SBT	RS	FRF	USW	BSW	CH	CAS	STR	FF
Bio-pool	2	Foothill	11.2			25.0	50.0		25.0						
Bio-pool	3	Foothill	11.2			50.0	33.3	16.7							
Bio-pool (bedrock)	1	Alluvial-Bedrock	11.6	50.0			50.0								
Bio-pool (bedrock)	1	Bedrock	11.5	33.3		33.3	33.3								
Bio-pool (bedrock)	6	Bedrock	11.5	33.3		50.0	16.7								
Bio-pool (bedrock)	7	Bedrock	11.5			33.3	66.7								
Bio-pool (boulder)	1	Mountain	11.4	25.0		25.0	25.0	25.0							
Bio-pool (boulder)	2	Mountain (IS)	11.3			16.7	50.0	33.3							
Bio-pool (cobble)	2	Alluvial-Bedrock	11.6	20.0	10.0	20.0	10.0	30.0		10.0					
Bio-pool (cobble)	5	Mountain (IS)	11.3			46.2	38.4	15.4							
Bio-pool (Disa)	6	Mountain	11.4			75.0		25.0							
Bio-pool (Newlands)	9	Mountain	11.4	33.3	33.3	33.3									
Bio-rapid	7	Foothill	11.2					33.3				33.3	33.3		
Bio-rapid	10	Foothill	11.2				20.0	20.0			20.0		20.0	20.0	
Bio-rapid	2	Mountain	11.4			14.3		14.3	14.3	28.6	14.3				14.3
Bio-rapid	4	Mountain	11.4					23.6	5.9	17.7	17.7		29.5		5.9
Bio-rapid (bedrock)	3	Bedrock	11.5					40.0		40.0	20.0				
Bio-rapid (bedrock)	4	Bedrock	11.5								33.3		33.3		33.3
Bio-rapid (bedrock)	9	Bedrock	11.5				16.7	50.0					33.3		
Bio-rapid (bedrock-alluvial)	3	Alluvial-Bedrock	11.6					11.1	22.2			11.1	44.4	11.1	
Bio-rapid (bedrock-alluvial)	5	Alluvial-Bedrock	11.6					11.1	11.1	11.1			55.5		11.1
Bio-rapid (boulder)	1	Mountain (IS)	11.3								25.0	37.5	37.5		
Bio-rapid (Disa)	5	Mountain	11.4										100.0		
Bio-riffle	4	Foothill	11.2					40.0		40.0			20.0		
Bio-riffle	6	Foothill	11.2				16.7	16.7	33.3				33.3		
Bio-riffle	8	Foothill	11.2					12.5	62.5		25.0				
Bio-riffle	11	Foothill	11.2					20.0	20.0	40.0	20.0				
Bio-riffle	3	Mountain (IS)	11.3						33.3	25.0	16.6		25.0		
Bio-run	5	Foothill	11.2				60.0	40.0							
Bio-run	9	Foothill	11.2	11.1		11.1	33.3	44.4							
Bio-run	3	Mountain	11.4				14.2	28.6	57.2						
Bio-run	4	Mountain (IS)	11.3					33.3	33.3	33.3					
Bio-run (bedrock)	2	Bedrock	11.5					100.0							

Hydraulic Biotope	Sub-group	Analysis Group	Ref. Figure	NF	TR	BPF	SBT	RS	FRF	USW	BSW	CH	CAS	STR	FF
Bio-run (bedrock)	5	Bedrock	11.5					66.7						33.3	
Bio-run (bedrock)	8	Bedrock	11.5					50.0	50.0						
Bio-run (bedrock)	6	Mountain (IS)	11.3				100.0								
Bio-run (cobble)	4	Alluvial-Bedrock	11.6			9.1		63.6	18.2	9.1					
Bio-run (Disa)	7	Mountain	11.4			75.0		25.0							
Bio-stream (bedrock)	6	Alluvial-Bedrock	11.6			25.0								75.0	
Fast (Newlands)	8	Mountain	11.4				11.1	22.2	22.2	11.1			22.2		11.1
Mixed	1	Foothill	11.2	50.0				25.0	25.0						

//Table 11.7c continued

Table 11.7d Summary statistics for each sub-group of samples recognised in Tables 11.2-11.6: range, mean (Ave) and standard deviations (SD) of Froude numbers.

Hydraulic Biotope	Sub-group	Analysis Group	Ref. Figure	Range of Froude	Ave Froude	SD Froude
Bio-pool	2	Foothill	11.2	0.000 - 0.543	0.116	0.162
Bio-pool	3	Foothill	11.2	0.000 - 0.043	0.009	0.015
Bio-pool (bedrock)	1	Alluvial-Bedrock	11.6	0.000 - 0.023	0.003	0.006
Bio-pool (bedrock)	1	Bedrock	11.5	0.000 - 0.042	0.005	0.013
Bio-pool (bedrock)	6	Bedrock	11.5	0.000 - 0.038	0.003	0.009
Bio-pool (bedrock)	7	Bedrock	11.5	0.000 - 0.066	0.021	0.024
Bio-pool (boulder)	1	Mountain	11.4	0.000 - 0.222	0.042	0.068
Bio-pool (boulder)	2	Mountain (IS)	11.3	0.000 - 0.243	0.039	0.046
Bio-pool (cobble)	2	Alluvial-Bedrock	11.6	0.000 - 0.790	0.043	0.118
Bio-pool (cobble)	5	Mountain (IS)	11.3	0.000 - 0.171	0.030	0.040
Bio-pool (Disa)	6	Mountain	11.4	0.000 - 0.535	0.114	0.121
Bio-pool (Newlands)	9	Mountain	11.4	0.000 - 0.159	0.065	0.064
Bio-rapid	7	Foothill	11.2	0.072 - 1.356	0.359	0.327
Bio-rapid	10	Foothill	11.2	0.000 - 2.299	0.532	0.633
Bio-rapid	2	Mountain	11.4	0.005 - 1.423	0.392	0.364
Bio-rapid	4	Mountain	11.4	0.000 - 4.539	0.514	0.637
Bio-rapid (bedrock)	3	Bedrock	11.5	0.035 - 1.417	0.532	0.350
Bio-rapid (bedrock)	4	Bedrock	11.5	0.028 - 1.806	0.686	0.513
Bio-rapid (bedrock)	9	Bedrock	11.5	0.016 - 1.357	0.426	0.420
Bio-rapid (bedrock-alluvial)	3	Alluvial-Bedrock	11.6	0.000 - 2.698	0.583	0.593
Bio-rapid (bedrock-alluvial)	5	Alluvial-Bedrock	11.6	0.000 - 3.324	0.860	0.678
Bio-rapid (boulder)	1	Mountain (IS)	11.3	0.053 - 3.992	1.019	0.894
Bio-rapid (Disa)	5	Mountain	11.4	0.183 - 0.527	0.371	0.146
Bio-riffle	4	Foothill	11.2	0.007 - 0.830	0.339	0.217
Bio-riffle	6	Foothill	11.2	0.000 - 1.118	0.346	0.277
Bio-riffle	8	Foothill	11.2	0.000 - 1.485	0.369	0.360
Bio-riffle	11	Foothill	11.2	0.058 - 1.173	0.332	0.278
Bio-riffle	3	Mountain (IS)	11.3	0.000 - 0.835	0.344	0.215
Bio-run	5	Foothill	11.2	0.000 - 0.157	0.043	0.049
Bio-run	9	Foothill	11.2	0.000 - 0.350	0.073	0.084
Bio-run	3	Mountain	11.4	0.000 - 0.362	0.095	0.092
Bio-run	4	Mountain (IS)	11.3	0.000 - 0.643	0.193	0.179
Bio-run (bedrock)	2	Bedrock	11.5	0.000 - 0.221	0.060	0.053
Bio-run (bedrock)	5	Bedrock	11.5	0.000 - 0.243	0.081	0.080
Bio-run (bedrock)	8	Bedrock	11.5	0.028 - 0.224	0.115	0.065
Bio-run (bedrock)	6	Mountain (IS)	11.3	0.042 - 0.313	0.125	0.094
Bio-run (cobble)	4	Alluvial-Bedrock	11.6	0.000 - 0.766	0.161	0.155
Bio-run (Disa)	7	Mountain	11.4	0.026 - 0.271	0.051	0.059
Bio-stream (bedrock)	6	Alluvial-Bedrock	11.6	0.000 - 2.213	0.673	0.722
Fast (Newlands)	8	Mountain	11.4	0.000 - 3.576	0.467	0.831
Mixed	1	Foothill	11.2	0.000 - 0.479	0.068	0.135

Table 11.8a Means of percentages of flow types per hydraulic biotope. Flow categories as per Table 2.3.

Biotope	NF	TR	BPF	SBT	RS	FRF	USW	BSW	CH	CAS	STR	FF
Bio-pool	16.2	3.6	34.0	31.1	12.1	2.1	1.0	-	-	-	-	-
Bio-run	1.1	-	9.5	20.8	45.2	15.9	4.2	-	-	-	3.3	-
Bio-riffle	-	-	-	3.3	17.8	29.8	21.0	12.3	-	15.7	-	-
Bio-rapid	-	-	1.3	3.3	18.5	4.9	8.9	11.8	7.5	35.2	2.8	5.9

Table 11.8b Means of percentages of substrata per hydraulic biotope (alluvial and mixed channel type groups only). Substrata categories as per Table 2.4.

Biotope	BR	B	LC	SC	LG	SG	SA	SI
Bio-pool	12.0	25.6	21.6	24.1	11.5	2.2	2.2	1.0
Bio-run	16.7	18.6	38.6	6.0	9.0	-	3.3	8.3
Bio-riffle	-	27.8	50.0	9.8	12.3	-	-	-
Bio-rapid	1.0	77.7	20.4	1.0	-	-	-	-

Table 11.8c Means of percentages of substrata per hydraulic biotope (bedrock channel type only). Substrata categories as per Table 2.4.

Biotope	BR	B	LC	SC	LG	SG	SA	SI
Bio-pool	44.4	5.6	19.4	-	8.3	-	11.1	11.1
Bio-run	50.0	16.7	-	-	-	33.3	-	-
Bio-riffle	-	-	-	-	-	-	-	-
Bio-rapid	94.4	-	-	-	5.6	-	-	-

Bio-runs were somewhat shallower but many were still more than 0.50 m deep. Mean-column velocities were higher than in pools, between 0.05 and 0.19 m s^{-1}, and Froude numbers mostly between 0.070 and 0.200. The full range of substrata occurred, with a predominance of bedrock, boulders and large cobble. The most common flow types were RS, then SBT.

Bio-riffles were consistently very shallow (all but one sample < 0.30 m), with consistently higher current speeds than bio-runs (0.27-0.39 m s^{-1}). Froude numbers were within the small range 0.332 and 0.425. Four substratum categories occurred: boulder, large and small cobble and large gravel. Large cobble was most abundant. The most common flow types were FRF, then USW, then RS and CAS.

Bio-rapids had a wider range of depths than riffles, from very shallow to 0.70 m. This reflects the different hydraulic areas over and between large bed elements. Current speeds were the highest recorded, ranging between 0.38 and 0.64 m s^{-1}. Froude numbers were also the highest recorded (0.371-0.900). No substrata smaller than large cobble were recorded, and boulders were most common, followed by bedrock. This hydraulic biotope had the widest range of flow types, ranging from BPF to FF. CAS was the dominant form, followed by RS and BSW.

It is emphasised that the above hydraulic measurements are means of all the samples in one sub-group, and that these in turn are means of two to six measurements taken at the point of invertebrate collection. Individual measurements covered a wider range than the above. The ranges for the sub-groups are shown in Table 11.2-11.6, and the ranges for any one sample in the database. Nevertheless, the summary values above do present a remarkably consistent picture, considering the complexity of flow in these streams. Indeed single measurements may provide a misleading picture of local hydraulics, simply because they may have been made in or out of hydraulic cover, and on or beside a large bed element. In such a situation, mean values from several readings would be far better indicators of hydraulic biotopes, than would a single reading or a range.

These analyses indicate that within Western Cape mountain and foothill rivers, there are four main areas with different species assemblages. Further down stream, additional types of hydraulic biotopes, such as marginal vegetation, also become available. The areas identified are broader than expected, larger than the hydraulic biotopes we had envisaged, but in most cases probably still smaller than morphological units. They appear to represent the hydraulic conditions experienced by broad assemblages of species rather than the more specific conditions experienced by individual species. The hydraulic biotiopes are probably an appropriate level for use in river surveys, biomonitoring and similar activities, where it can guide the choice of sampling points within a site. Their distribution within morphological units is addressed in Chapter 12, their distribution within different reach types in Chapter 13 and their relationship with discharge in Chapter 14.

It is clear from the above that hydraulic biotopes do not adequately describe the exact conditions in which a species may be found. The very small chironomid *Aphrotenia*, for example, occurs in quiet waters, as are described above for bio-pools. Its actual habitat within that bio-pool, however, is small gravel in very quiet edge waters in hydraulic cover such as that provided by a boulder. We suggest that this level of detail be called the *hydraulic habitat* of the species. Encompassing descriptions of a specific combination of flow type and substratum and other details of where the species is found, the hydraulic habitat is an appropriate unit for the study of species as opposed to one of species assemblages. The hydraulic habitat would be derived from many measurements of where a specific species occurs, and developed as a profile of its required physical habitat. This process is described in Chapter 17.

12. MORPHOLOGICAL UNITS

12.1 Recap

The third aim listed for this project (Section 3.4) was to assess the biological significance of geomorphologically derived morphological units (MUs). MUs were mapped for each study site (for example, Figures 7.4c, 7.5c and 7.6c), so that every invertebrate sample could be linked to one. Thus, the twelve samples from each least-disturbed river, and the 52 replicate samples from the Eerste, were again available for the analyses. It should be noted, however, that because the MUs were not mapped until the second year of the study, that is until after the invertebrate samples had been collected, biological sampling could not be designed specifically to test MUs.

It was thought that each study site could differ in its combination of MUs, and thus could either be supporting different combinations of species or the same species assemblages but in different proportions. Either way, samples collected for instance for biomonitoring purposes, could produce different results simply because of the areas within the site that were sampled. Bio-riffles, and bio-rapids on boulder, cobble or bedrock, all have the appearance of turbulent, fast-flowing water over rock, and could be sampled together in one comprehensive biomonitoring sweep. In Chapter 11, however, they have been shown to have distinct species assemblages. In this chapter, we report on initial analyses designed to investigate the nature of within-site physical differences, and how these might be affecting animal distributions.

12.2 Physically similar sites

The number, type and area of coverage of each MU were outputted from the digitised GIS maps. The number and type of each MU within each site was used to run the CLUSTER module of PRIMER, just as invertebrates were used in Chapters 10 and 11, to determine which sites were similar in terms of MUs. Four main groups (Figures 12.1 and 12.2) were recognised. Group 1 consisted of six mountain sites. Altitudes ranged 100-350 m, and slopes were very similar (0.060-0.100) (Table 12.1). Group 2 consisted of four transitional/upper foothill sites, with an altitude range of 380-700 m and similar slopes (0.013-0.030). Group 3 consisted of the bedrock streams, although one mixed alluvial/bedrock site (Bakkerskloof) was included. There were wide ranges of altitude (80-860 m) and slope (0.005-0.100). Group 4 consisted of two sub-groups. Sub-group 4a included the two lower foothill sites at relatively low altitudes (260, 430 m), and relatively low slopes (0.002, 0.010). Sub-group 4b consisted of what we have previously identified (Chapter 11) as a mixed bedrock-alluvial site (Steenbok) and a transitional mountain/foothill site (Du Toits). These two are recognised as outliers, probably due to Steenbok having some unusual MUs (bedrock pavement, slump) and Du Toits consisting almost entirely of the one MU, Plane-bed.

In summary, substratum, via MUs, remained a good distinguisher of different kinds of sites at the second (bedrock v alluvial) and third (mountain v foothill) levels of distinction, with slope also providing a tight, consistent pattern within the alluvial groups (1, 2 and 4a). Altitude was a less useful guide.

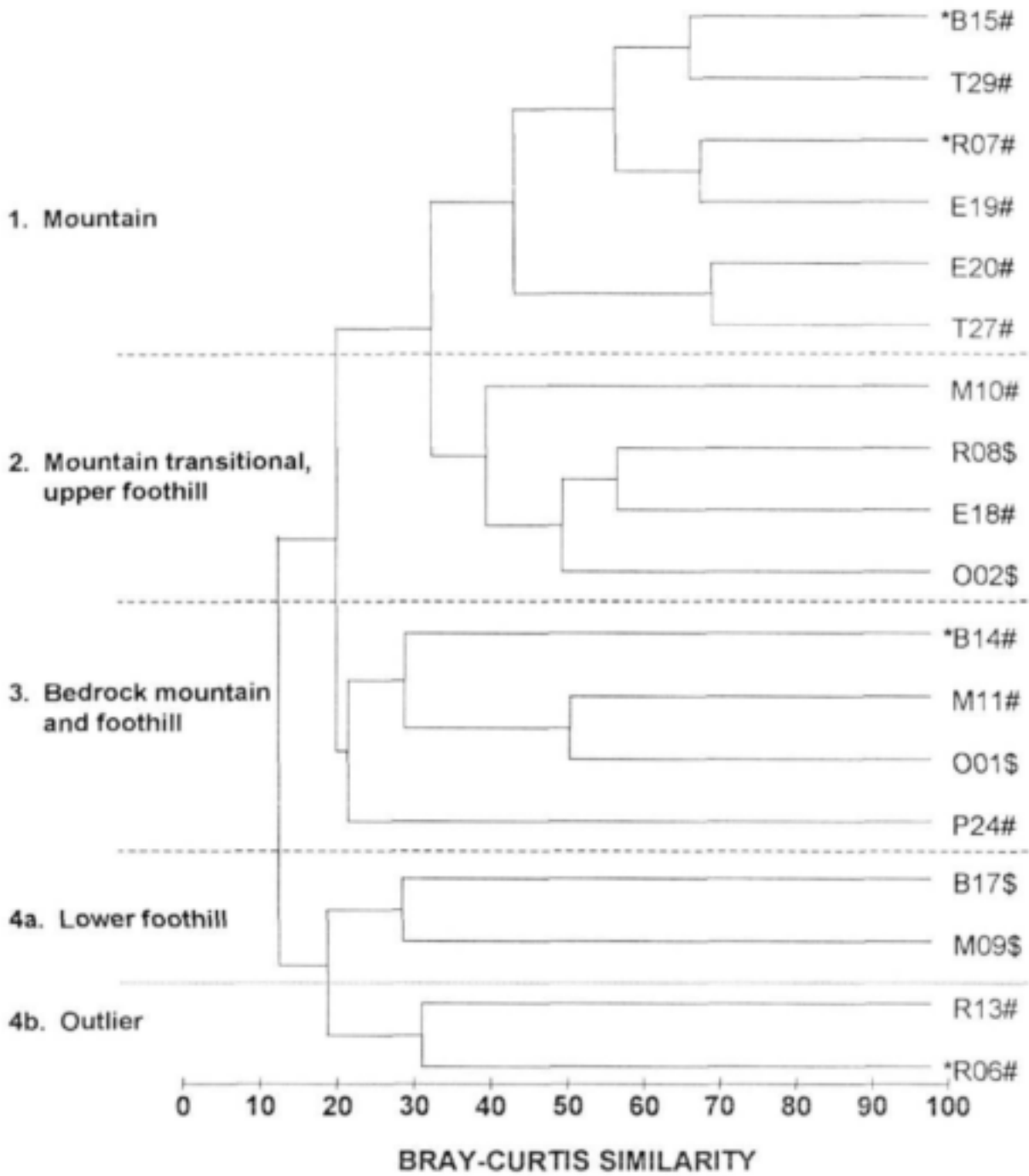


Figure 12.1 **Dendrogram of the similarity of 18 least-disturbed sites, based on the number and types of MUs mapped at the sites.** . # = pre-identified as biological mountain zone and $ as a biological foothill zone. * denote mixed alluvial-bedrock streams.

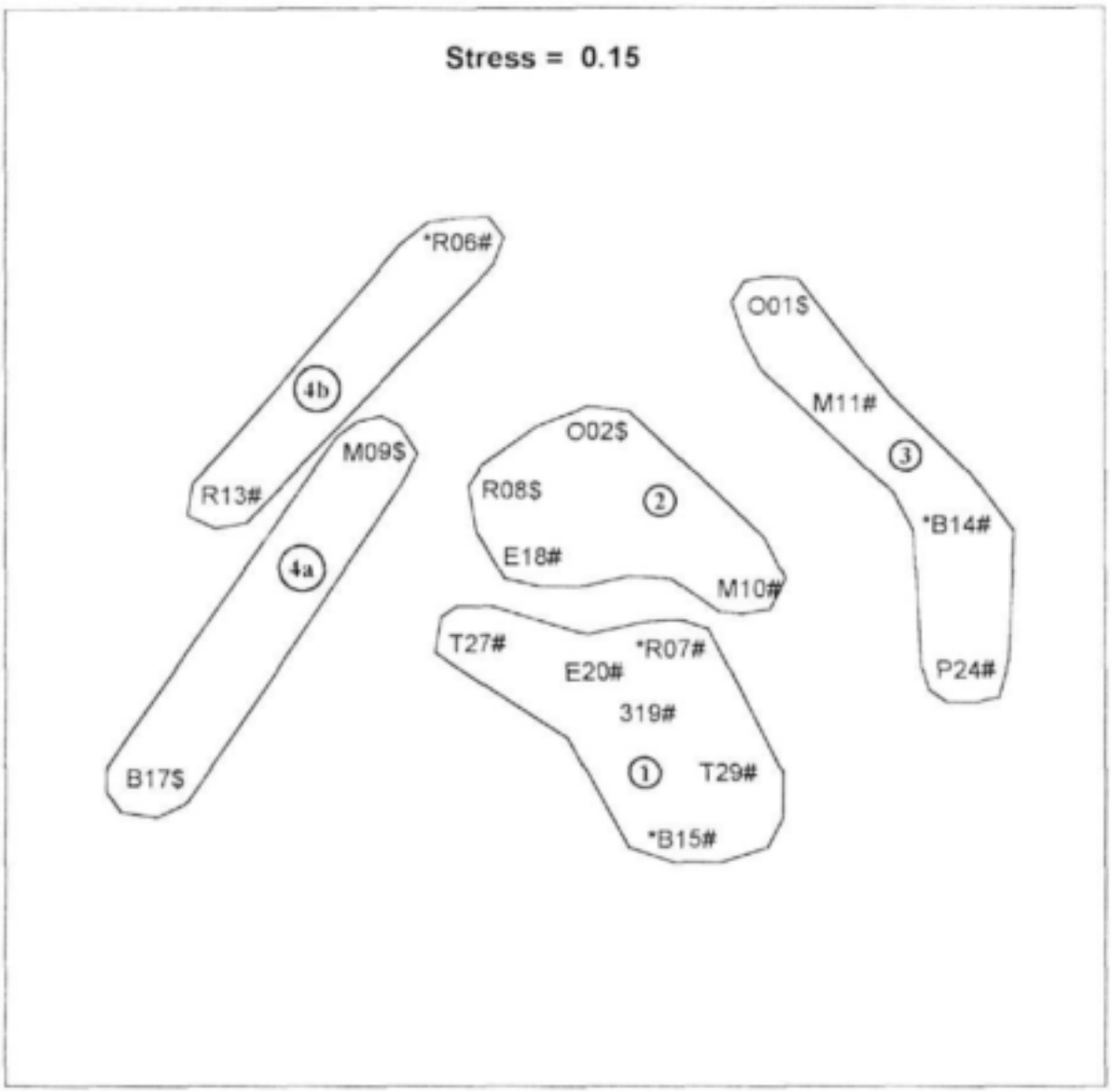


Figure 12.2 Two-dimensional MDS configuration of the 18 least-disturbed sites, based on the number and types of MUs mapped at the sites. Group 1 = mountain zone; Group 2 = mountain-upper foothill zone; Group 3 = bedrock sites in mountain and foothill zones; Group 4a = lower foothill zone; Group 4b = outliers. # = pre-identified as biological mountain zone and $ as a biological foothill zone. * denotes mixed alluvial-bedrock streams.

Table 12.1 Summary of altitude and map slope data for the groups recognised in Figures 12.1 and 12.2. # pre-identified as in a biological mountain zone and $ as in a biological foothill zone. * mixed alluvial-bedrock streams.

Group	River	Code	Zone	Altitude (m asl)	Map Slope
1	Zachariashoek*	B15#	Mountain	310	0.100
	Disa	T29#		100	0.080
	Wolvekloof*	R07#		350	0.100
	Langrivier	E19#		350	0.080
	Swartboskloof	E20#		340	0.080
	Newlands	T27#		180	0.060
2	Elands	M10#	Mountain transitional to upper foothill	460	0.020
	Wit	R08$		700	0.013
	Eerste	E18#		380	0.030
	Rondegat	O02$		470	0.026
3	Bakkerskloof*	B14#	Bedrock mountain and foothill	320	0.100
	Elandspad	M11#		860	0.200
	Jan Dissels	O01$		190	0.005
	Dwars	P24#		80	0.040
4a	Berg	B17$	Lower foothill	260	0.002
	Molenaars	M09$		430	0.010
4b	Du Toits	R13$	Outlier	400	0.020
	Steenbok*	R06#		290	0.060

The four categories of sites recognised in Figures 12.1 and 12.2 (i.e. excluding the outlier group) have different percentages of each MU (Table 12.2), with a pattern emerging of characteristic MUs. Alluvial mountain sites are dominated by step and pool MUs, with a minor presence of many other MUs, of which the most common are lateral bars and plane-bed. Lower down, alluvial mountain/upper-foothill sites also have a high number of pools, fewer steps than the mountain sites, but more lateral bar and plane-bed MUs. Further downstream, alluvial lower foothills are dominated by runs, with a range of less-abundant MUs, including pools, plane-bed, rapids, riffles and several kinds of bars. The familiar downstream transformation of channel morphology is shown, from step-pool in the upper reaches, through the confused pattern of change characterised by plane-bed in the upper foothills, to the classic riffle-run configuration of the lower foothills. It should be noted, however, that even in the riffle-run zone, riffles are far less common than runs.

Rapids and pools (Table 12.2) dominate bedrock mountain and foothill sites. It was expected that the same clustering of sites would emerge when the number of each MU was replaced by percentage area, but this did not emerge (Figure 12.3).

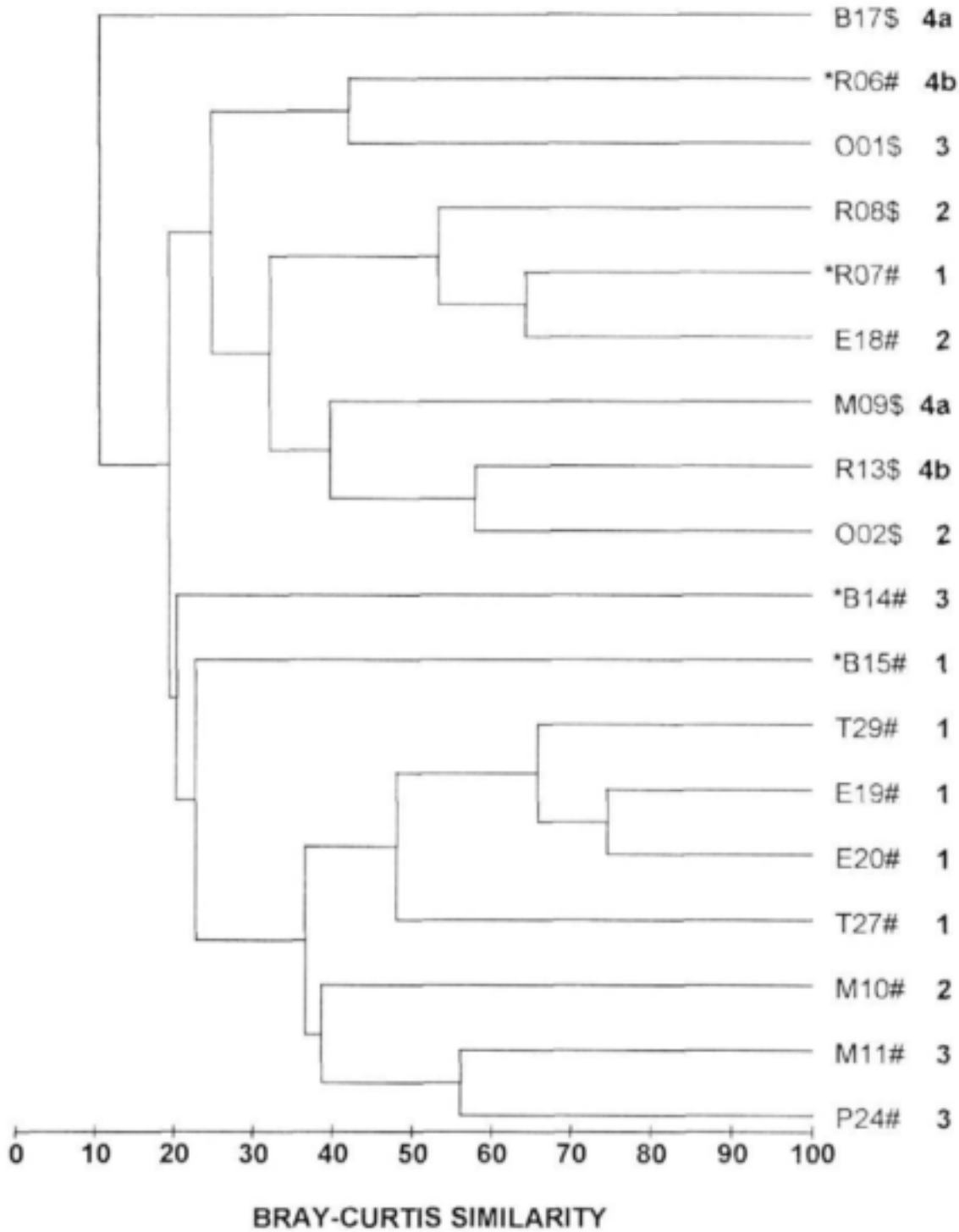


Figure 12.3 Dendrogram of the similarity of 18 least-disturbed sites, based on the area of each type of MU mapped at the sites. # = pre-identified as biological mountain zone and $ as a biological foothill zone. * denotes mixed alluvial-bedrock streams. Numbers in bold to the right of each site code indicate the group number of each river site in Table 12.1: 1 = mountain zone (alluvial); 2 = mountain-upper foothill zone (alluvial); 3 = mountain and foothill zones (bedrock); 4a = lower foothill zone (alluvial); 4b = outliers (alluvial).

Table 12.2 Percentage of MUs (by number) found within the sites in each classified stream zone, with the groups based on Figure 12.1 MUs are defined in Table 6.3.

Morphological Unit	Alluvial Mountain	Alluvial Mountain Transitional to Upper Foothill	Bedrock Mountain and Foothill	Alluvial Lower Foothill
Step	36.0	8.6	3.5	0.0
Pool	30.2	22.9	15.8	7.7
Lateral Bar	8.1	17.1	0.0	7.7
Plane Bed	7.0	17.1	0.0	7.7
Rapid	3.5	2.9	24.6	7.7
Riffle	3.5	0.0	0.0	7.7
Run	1.2	0.0	0.0	30.8
Bedrock Pool	1.2	2.9	1.8	0.0
Bedrock Rapid	1.2	0.0	0.0	0.0
Boulder Bank	1.2	0.0	0.0	0.0
Boulder Bar	1.2	0.0	0.0	0.0
Boulder Rapid	1.2	2.9	0.0	0.0
Lee Bar	1.2	5.7	5.3	0.0
Mid-Channel Bar	1.2	2.9	0.0	7.7
Proto Step	1.2	0.0	1.8	0.0
Sandy Lee Bar	1.2	0.0	0.0	0.0
Backwater	0.0	5.7	3.5	0.0
Bar	0.0	0.0	1.8	0.0
Bedrock Core Bar	0.0	0.0	1.8	0.0
Bedrock Pavement	0.0	0.0	5.3	0.0
Bedrock Step	0.0	0.0	7.0	0.0
Canal	0.0	0.0	8.8	0.0
Cataract	0.0	0.0	1.8	0.0
Flood Bench	0.0	2.9	0.0	0.0
Flood Channel	0.0	0.0	1.8	0.0
Island	0.0	0.0	1.8	7.7
Lateral Channel	0.0	5.7	0.0	0.0
Lateral Channel /Plane Bed	0.0	0.0	0.0	7.7
Mid-Channel Bar Remnant	0.0	0.0	0.0	7.7
Plunge Pool	0.0	0.0	8.8	0.0
Sculptured Bedrock	0.0	0.0	1.8	0.0
Secondary Channel	0.0	2.9	1.8	0.0
Waterfall	0.0	0.0	1.8	0.0

12.3 The distribution of hydraulic biotopes among MUs

Each invertebrate sample, with the exception of a few outliers, had been allocated to a hydraulic biotope (bio-rapid, bio-riffle, bio-run or bio-pool) (Chapter 11). These samples and thus their hydraulic biotopes were now allocated to MUs. In order to preserve the pattern emerging in Chapter 11, separate analyses were done for alluvial foothill, alluvial mountain, bedrock, and mixed alluvial-bedrock sites (Table 11.1),

and for the replicate-sampling site on the Eerste. The breakdown by individual rivers is given in Appendix 12.1.

12.3.1 Alluvial foothill sites

All four hydraulic biotopes were recorded in the alluvial foothill sites (Figure 11.2a), with bio-rapids being least represented. Twenty-two of the 60 samples occurred in Plane-bed MUs (Table 12.3), with eight in run MUs, six in riffle MUs, six in pool MUs, five in rapid MUs, and four or less in secondary channels, lee bars, flood channels, steps, middle-channel bars and lateral bars. These proportions cannot automatically be accepted as representative of the proportion of MUs in alluvial foothills, as no attempt was made to randomly sample. The four outlier samples recognised in Chapter 11 were not allocated to a MU. There was little consistency in the distribution of hydraulic biotopes within a MU. Invertebrates in the 22 Plane-bed samples were from bio-runs (6), bio-riffles (10), bio-rapids (3), and bio-pools (3). Run MUs yielded five bio-pool samples, two bio-riffle samples and only one sample from a bio-run. Only the riffle and rapid MUs yielded mainly invertebrates from a similar hydraulic biotope: five of the six samples from riffle MUs were bio-riffle assemblages; and four of the five samples from rapid MUs were bio-rapid assemblages.

Table 12.3 Alluvial foothill sites: allocation of invertebrate samples, identified by hydraulic biotope, within MUs. Each of the entries in the body of the table represents one invertebrate sample. Each sample is designated by the hydraulic biotope from which it was taken: Ri = bio-riffle; Ru = bio-run; Ra = bio-rapid; Po = bio-pool.

River	Sandy lee bar	Secondary channel	Flood channel	Pool	Riffle	Plane bed	Rapid	Step	Run	Mid-channel bar	Lateral bar	Outlier
Berg					5 Ri 1 Po				5 Po			1
Molenaars				1 Ru		1 Ri 2 Ru 1 Ra			2 Ri	1 Ru 3 Ri		1
Rondegat		1 Po		1 Ri		3 Po 3 Ri 2 Ra					1 Ri	1
Du Toits						6 Ri 4 Ru			1 Ru			1
Elands	1 Ru		1 Ru	3 Ru 1 Ra			4 Ra 1 Ri	1 Ri				

12.3.2 Alluvial mountain sites

None of the 60 samples collected in the alluvial mountain sites were from bio-riffles (Figure 11.4a), although nine of the Newlands samples were from areas categorised as "fast". Although these areas contained more cobble than expected for bio-rapids, their flow types were characteristic of bio-rapids and in both its proportion of MUs (Figure 12.1) and its slope (Table 12.1), Newlands was identified as a mountain rather than foothill site and so more likely to have rapids than riffles. For the purpose of this analysis, the nine "fast" sites at Newlands have therefore been called bio-rapids. Nineteen of the samples from alluvial

mountain sites were from step MUs, 24 from pool MUs, nine from pool MUs, with three or less from lateral channel, riffle and rapid MUs. There was one outlier (Table 12.4). Again, there was no great consistency in the distribution of hydraulic biotopes among MUs, with bio-run and bio-rapid samples constituting 42% of the samples taken from pool MUs, and Plane-bed MUs supporting a mixture of samples. Bio-pool samples, however, were mostly confined to the Pool MU, and step MUs yielded almost entirely bio-rapid samples.

Table 12.4 Alluvial mountain sites: allocation of invertebrate samples, identified by hydraulic biotope, within MUs. Each of the entries in the body of the table represents one invertebrate sample. Each sample is designated by the hydraulic biotope from which it was taken: Ru = bio-run; Ra = bio=rapid; Po = bio-pool.

River	Lateral channel	Pool	Riffle	Plane bed	Rapid	Step	Lateral bar	Outlier
Eerste	1 Ra 1 Ru	2 Ra 2 Ru		3 Ra 1 Ru			1 Ra	1
Langrivier		3 Po 2 Ru	2 Ra 1 Ru	1 Po	1 Ra	2 Ra		
Swartboskloof		4 Po		4 Ra		4 Ra		
Disa		4 Po 4 Ru				2 Ra 2 Ru		
Newlands		3 Po				9 Ra		

12.3.3 Bedrock mountain and foothill sites

Of the 36 invertebrate samples taken from bedrock sites, none were from riffle MUs as these do not occur in bedrock areas (Table 11.8c) (Figure 11.5a). Eleven of the samples were from bedrock pool MUs (Table 12.5), eight from other pools, nine from rapids, and two or less from canal, step, backwater and cataract MUs. Pool and bedrock pool MUs yielded almost as many samples from faster-flowing hydraulic biotopes as from slow ones (three bio-rapid samples; six bio-run, ten bio-pool), and typical fast-flowing areas such as rapid and cataract MUs also produced a mixture. Too few samples were taken from other MUs to attempt generalisations.

12.3.4 Mixed alluvial-bedrock sites

The 48 invertebrate samples taken from mixed alluvial-bedrock sites, represented bio-pools, bio-rapids, bio-runs, the unusual hydraulic biotope "stream", with one outlier (Figure 11.6a). The distribution of samples among MUs was: eight from rapid MUs, seven from step MUs, twelve from plane-bed MUs, and 13 from various kinds of pool MUs (Table 12.6). One sample was taken from a riffle MU, and there were several samples from unusual MUs such as plunge pools, bedrock pavements and sandy lee bars. The wide range of MUs reflects the diversity of this group of sites: the mountain sites provided rapid, step and pool MUs, and the foothill sites, riffle MUs. Additionally, bedrock sites provided pavement, cataract and plunge pool MUs and alluvial sites plane-bed MUs. Again, there was no consistency in the distribution of hydraulic biotopes among MUs, although bio-pools were the most common hydraulic biotope in pool MUs and bio-rapids in rapid MUs.

Table 12.5 Bedrock mountain and foothill sites: allocation of invertebrate samples, identified by hydraulic biotope, within MUs. Each of the entries in the body of the table represents one invertebrate sample. Each sample is designated by the hydraulic biotope from which it was taken: Ru = bio-run; Ra = bio-rapid; Po (BR) = bedrock bio-pool.

River	Bedrock pool	Canal	Pool	Rapid	Step	Backwater	Cataract
Jan Dissels	3 Ru 1 Po (BR)		1 Po (BR) 1 Ra 1 Ru	3 Ra 1 Ru		1 Po (BR)	
Elandspad			5 Po (BR)	1 Ra 2 Ru			1 Po (BR) 1 Ru 2 Ra
Dwars	2 Ra 2 Ru 3 Po (BR)	1 Ra		1 Po (BR) 1 Ra	2 Ra		

Table 12.6 Bedrock mountain and foothill sites: allocation of invertebrate samples, identified by hydraulic biotope, within MUs. Each of the entries in the body of the table represents one invertebrate sample. Each sample is represented by the hydraulic biotope from which it was taken: Ru = bio-run; Ra = bio-rapid; Po = bio-pool; Po (BR) = bedrock bio-pool. Stream = very fast, shallow, smooth flow over rock.

River	Sandy lee bar	Bedrock pool	Plunge pool	Flood channel	Pool	Riffle	Plane-bed	Rapid	Bedrock pavement	Step	Run	Outlier
Bakkerskloof		3 Po (BR)	1 Po (BR) 1 Po	1 Po	2 Po			1 Ra 1 Stream		1 Ra 1 Po		
Zachariashoek	1 Po				2 Ra 2 Po	1 Ra		1 Po 2 Ra		1 Ra	1 Ra	1
Steenbok		1 Ru					5 Ru 3 Ra		1 Ru 1 Stream		1 Ra	
Wolwekloof		1 Stream					4 Ru	2 Ra 1 Stream		3 Ra 1 Po		

12.3.5 Summary

In summary, Tables 12.3-12.6 suggest that there is a mixture of biological assemblages within any one MU type. The total array of MUs provided a good indication of whether a site is bedrock or alluvial, and mountain or foothill, but individual MU-types provided a poorer indication of the species assemblages they support. Some MUs, however, provided a better indication than others did. Of the 19 samples taken over all the rivers from step MUs, 15 (80%) were designated bio-rapid assemblages. Scoring somewhat poorer,

of the 54 taken from Pool MUs, 30 (56%) were designated bio-pool assemblages. Riffle MUs scored better in alluvial foothills sites (83% of samples were designated bio-riffle assemblages), where riffles are most prolific, than in alluvial mountain sites (0%) where they are small and rare. This suggests a prerequisite of some minimum amount of riffle area or abundance before a distinct riffle assemblage develops. Scoring among the lowest in terms of predictability were plane-bed MUs, where of the 43 samples, ten (23%) were designated bio-riffle, 16 (37%) bio-run, 13 (30%) bio-rapid, four (10%) bio-pool assemblages. This reflects their somewhat unstructured mixture of physical and hydraulic conditions.

12.4 The distribution of hydraulic biotopes within a single MU

The high mix of biological assemblages within any one MU type might be a reflection of having pooled data from the same MU-type in different rivers. Individual MUs might show higher consistency. The 52 samples from the Eerste site were used to investigate this. The locations of the 52 samples were plotted on a map of MUs, with each sample represented by its hydraulic biotope as designated in Figure 11.3a (Figure 12.4).

The site consisted of the following MUs:

- 3 plane-bed;
- 2 pool;
- 1 step;
- 1 lateral channel.

Analysis of the hydraulic biotope linked to each sample (Table 12.7) revealed a range of species assemblages within any one MU. Again, the step MU was the most consistent, yielding only the fast-flow bio-riffle and bio-rapid communities. Similar to the findings from the other sites (Section 12.3.5) sixty-two percent of the samples from pool MUs were of bio-pool assemblages. Plane-beds again were the least consistent, with samples allocated to hydraulic biotopes as follows: 20% bio-riffle; 15% bio-run; 30% bio-rapid; and 35% bio-pool. Two of the three plane-bed MUs had samples representing all four of the main hydraulic biotopes, whilst the third had samples representing three. The data suggest that in any MU there would be considerable spatial variability in the distribution of invertebrate species.

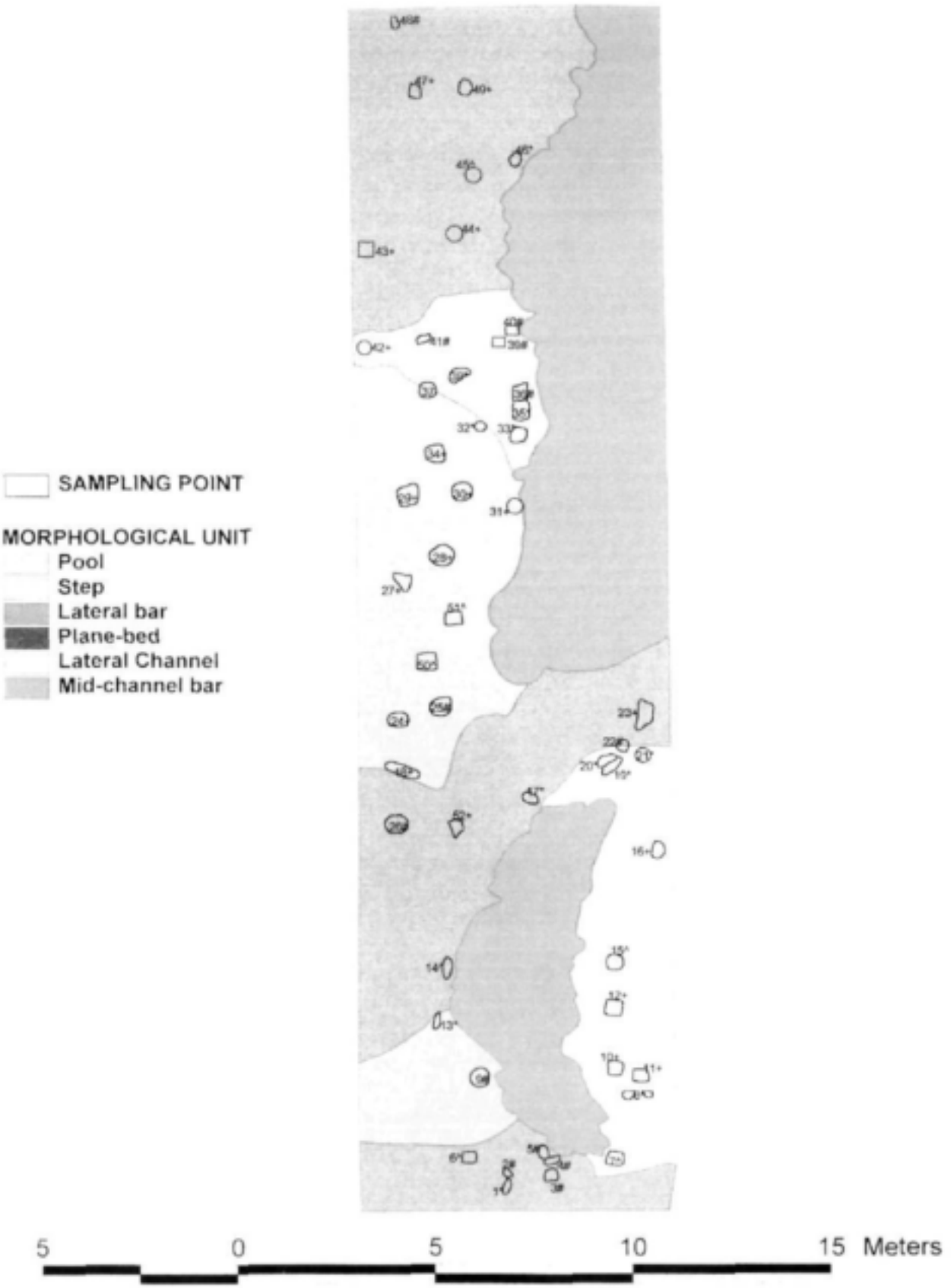


Figure 12.4 **Map of the morphological units of the Eerste River site, with the location of the 52 invertebrate samples collected as part of the intensive survey (Section 11.3.2).** Samples are numbered on the map 1 to 52, with an accompanying symbol to illustrate the major hydraulic biotope which they represent: * = bio-riffle; ^ bio-run; # bio-rapid; + bio-pool.

Table 12.7 The 52 invertebrate samples from the Eerste River site allocated by MU and hydraulic biotope. Each sample is indicated by its code number (Table 11.3). Sample 37 was identified as an outlier in Figure 11.3a, and is not included.

MU	Bio-riffle	Bio-run (cobble, boulder)	Bio-run (bedrock)	Bio-rapid	Bio-pool (cobble)	Bio-pool (boulder)
Plane-bed 1	46	45		48,	42, 43	44, 47, 49
Plane-bed 2	17	14		22, 26	23	52
Plane-bed 3	1, 3	6		2, 4, 5		
Pool 1			50, 51	25	18, 27, 28, 29, 31, 34	24, 30
Pool 2	13			9		
Step	32, 33, 35, 38			36, 39, 40, 41		
Lateral channel	19, 20, 21	7, 8, 15			10, 11, 12, 16	

12.5 Hydraulic biotopes versus MUs as indicators of species assemblages

MUs and hydraulic biotopes each have advantages and disadvantages as indicators of invertebrate assemblages. MU types provide a useful guide to the overall nature of a river reach, and create awareness of the likelihood of finding any one kind of invertebrate assemblage. Bio-rapid assemblages, for instance, would not be found in a site consisting of riffle and pool MUs. At the level of the individual MU, some types such as steps and to a lesser extent pools, may be better guides than others as to what might be present. Even with the better performers, however, there is sufficient diversity in invertebrate assemblages within any one MU to create considerable "noise" in distribution patterns (Table 12.7). Larger animals such as fish may be responding to MUs as single habitats, but invertebrates appear to be distributed within MUs according to a finer-resolution influence.

If MUs cannot be used with any great certainty to locate a specific invertebrate assemblage, then can hydraulic biotopes? The four hydraulic biotopes recognised in Chapter 11 were defined by their different invertebrate assemblages, and so should be good indicators of where those assemblages could be found. Unlike MUs, however, they cannot easily be pinpointed within a stream, as they are areas that have a characteristic spread of flow types and substrata rather than a single one of each (Tables 11.8).

Riffle hydraulic biotopes, for instance, are dominated by FRF and USW flow types and by boulder and large cobble substrata. In the intensive sampling site on the Eerste, 61% of the samples taken from one these two flow types combined with one of these substrata were bio-riffle samples. The picture is more complex than this suggests, however. When all the alluvial foothill and mountain sites were assessed, 90% of the foothill samples (n = 10) with this same combination (FRF or USW flow-types with boulder or large cobble) were of bio-riffle assemblages, but 0% (n = 11) of the mountain samples were. The mountain samples with this combination of flow and substratum contained bio-rapid assemblages. This suggests that bio-riffle assemblages will not occur if environmental conditions other than the flow type and the

substratum are unsuitable. Alternatively, perhaps insufficient riffle habitat occurs in mountain streams for a riffle community to develop.

Similarly, rapid hydraulic biotopes are dominated by the CAS flow type and are the only biotope to have CH and FF flow types. They are also dominated by boulder and bedrock substratum types (Table 11.8). In the intensive sampling site on the Eerste, 86% of the samples with one of these flow types combined with one of the substratum types were bio-rapid samples. When all the alluvial foothill and mountain sites were assessed, 100% (n = 11) of the samples with one of these combinations from mountain sites were of bio-rapid assemblages, as were 60% (n = 5) of the samples from foothill sites. Overall, the likelihood of locating a bio-rapid assemblage, using just the flow type and substratum for guide, is thus quite high.

Bio-runs can occur on any substratum, and RS is their most common flow type. In alluvial foothill sites, 71% of the samples (n = 14) with RS (any substratum) held bio-run assemblages, whilst only 25% of mountain samples (n = 12) held such assemblages; the remainder were almost entirely bio-rapid assemblages. As with bio-riffle fauna, this may reflect the relative rarity of runs in mountain streams.

Bio-pools can also occur on any substratum, and are dominated by BPF and SBT flow types. Only 47% of alluvial foothill samples (n = 17) with these flow types held bio-pool assemblages, with an even lower score of 38% in mountain samples (n = 13). Areas with slow flow types in high-gradient streams are often very small, and it seems possible that the invertebrates may be responding to faster water at the edge or bottom that is not reflected by the flow type.

Both MUs and hydraulic biotopes thus are imperfect guides to specific invertebrate assemblages, although the latter appear to be the better. Undoubtedly there is another finer level of physical resolution that is one of the final determinants of species' distributions. This topic is revisited in Section 12.7 and Chapter 17.

12.6 The influence of discharge

The distribution of flow types changes with changing discharge, and so their proportions within any one MU will also change over time. In order to ascertain how this might affect hydraulic biotopes, that is, the areas within which specific assemblages sit, one site on the Eerste River was sampled on six different occasions within two seasons (summer base flow and winter base flow). This investigation is reported on in Chapter 14.

12.7 Conclusion

The objective of this section of the project was to assess the extent to which faunal distributions are explained by their presence in different MUs. The overall message appears to be that MUs are not particularly good predictors of local species distributions, but can guide on the overall nature of a river reach and thus of the invertebrate assemblages likely to be present. MUs such as 'step' are among the better predictors of invertebrate assemblages and 'plane-bed' is the worst. To actually locate the assemblages, hydraulic biotopes – through their component parts substratum and flow - are better guides than MUs, but have to be used with caution for two reasons.

- The river zone must be pre-identified, as some species assemblages do not occur in all zones. For example, bio-riffle assemblages are rare in mountain streams, even in flow-substrata combinations characteristic of riffles.
- Even if both zone and flow-substrata combinations have been identified, the expected species assemblage will not always be collected. The area of the "habitat" patch (flow and substrata combination) may affect the ability of an appropriate species assemblage to become established, with smaller areas possibly less able to support an appropriate assemblage than bigger areas, because of edge effects. Alternatively, conditions not reflected by the substrata and flow type might be affecting distributions.

The above reasons might explain why there is so much 'noise' in benthic invertebrate samples from rivers – even in what appears to be a fairly uniform area within a site, we may well be sampling a mixture of species assemblages. For biomonitoring and other similar purposes, this 'noise' would probably be reduced if the following were used to guide collection of a sample.

- Use information such as that used in Table 5.1 and 12.1 to identify the biological zone in which the study site is located. This provides an initial indication of the kinds of MUs and hydraulic biotopes likely to be present.
- Map the distribution of MUs within the site, at least mentally, to develop an understanding of where different kinds of species assemblages might be most common.
- Sample in the middle of hydraulic biotopes that cover larger rather than smaller areas.
- Sample plane-bed MUs if a high diversity of possible hydraulic biotopes and species assemblages is desired, as they seem to contain a mixture of most possible hydraulic biotopes. Avoid them, however, if the objective is to collect specific species or species assemblages.

13. REACHES

13.1 Recap

The fourth aim listed for this project (Section 3.5) was to test the biological significance of geomorphologically defined reaches. As the data used thus far in this report were not collected specifically to test reach types, an additional sampling programme was designed specifically to asses reaches, using two sites on one river within the same biological zone but in different reach types (Section 4.6.3).

Different types of reaches have different combinations of morphological units, which define them, and therefore different proportions and types of available hydraulic biotopes (Rowntree and Wadeson 1999). These could in turn manifest as differences in invertebrate assemblages or in the proportions of species within assemblages. If different reach types within the same biological river zone do support different taxa, proportions of taxa, or abundances there could be implications, for instance, for biomonitoring results. In this chapter we report on initial analyses of the physical and biological differences between two adjacent but different reach types. Data from one of four sampling trips is presented (29 and 28 October 1997) for two sites representing the two reach types (Table 14.1). Further analyses of these data will be in D.M. Schael's PhD thesis.

13.2 Methods

Overall sampling methods have been described in Chapter 4 (Sections 4.3-4.5). The methods specific to the reach assessment are reiterated briefly here.

Two 50-m long sites on the Eerste River within the Jonkershoek Nature Reserve in Stellenbosch were chosen for the study. One site (E18#) was also used in the main and intensive study programmes, but extended to 50 m from its original 40 m length to make it the same length as the second site. Study sites were chosen to be 50-m long in order to provide adequate areas for sampling invertebrates (Section 4.5). Substrata were mapped once at each site, prior to the collection of any invertebrate samples, whereas flow types were mapped several times, i.e. on each day when invertebrates were collected. Invertebrates were sampled at both sites on four different occasions for assessing the impact of changing discharge on physical habitat and invertebrate distributions, only one of these data sets is used here. Sampling points were decided upon on site using maps of flow and substratum as discussed in Section 13.3. Invertebrates were collected quantitatively, using a 0.5 x 0.5 x 0.5-m box sampler with a 250 µm mesh on the downstream collecting side and two adjacent sides. A 500-µm mesh was used on the upstream side, so as to allow fast flow into the sampler that would carry the animals disturbed from the bed downstream into the collecting net. Because of the size of the box sampler sample points had to have uniform conditions over at least 0.5 x 0.5-m in area. Each flow/substratum combination also needed to be sufficiently abundant within each study site to allow for three replicate samples of that combination to be sampled. If these criteria were not met within a site, a particular flow and substratum combination could not be used in the study for that site.

After all the sampling points were chosen and delineated on the flow/substratum maps, hydraulic data were collected within each (depth, near bed velocity and mean water column (0.6) velocity). These

measurements were made at four different places within the 0.5 x 0.5-m area. The box sampler was put on the sampling area and a substratum grid was placed over the top of the box sampler in order to record the proportion of each type of substratum present. The bed profile was then measured, using the profiler (described in Section 4.3.5) which was placed inside the box sampler. The substrata were then picked up and scrubbed with a brush and all animals collected into the net. The animals were sorted in the laboratory as described in Section 4.5, with most samples processed in full. Identifications of invertebrates were done to species where possible or to morphological types. Two family groups have not been identified to species for these analyses, the Bactidae (Ephemeroptera) and Simuliidae (Diptera). Specialists aided in the identification of type specimens for the Chironomidae (Diptera), Hemiptera, Leptoceridae and Hydroptilidae (Trichoptera) and Teloganodidae (Ephemeroptera) (see Table 8.1 for specialists). Species/morph type level or closest taxonomic level data (Appendix 13.1) were used for the analysis of similarity between samples.

13.3 Physical comparisons

The two sites chosen for this study were classified as being in the same biological zone, a mountain zone. However, geomorphological assessment of the sites classified them as being in two different geomorphological zones (Table 6.6 and Table 13.1), Eerste site 1 (E18#) being in a mountain stream zone and Eerste site 2 (E21#) in a mountain stream (transitional) zone.

Table 13.1 Geomorphological characteristics of both Eerste river sites. MU = Morphological Unit. The number of each type of MU found in each site is given in parenthesis after each type. Site code as in Table 5.3.

Site (code)	Geomorphological Zone	Reach Type	MU Type (No.)	MU % Area
1	Mountain Stream	Step-pool/	Plane-bed (3)	34
(E18#)		Plane-bed	Step (1)	5
			Pool (2)	19
			Mid-channel bar (1)	9
			Lateral bar (1)	23
			Later channel (1)	10
2	Mountain Stream	Pool-rapid	Boulder rapid (1)	32
(E21#)	(transitional)		Plane-bed (1)	47
			Pool/Plane-bed (1)	21

Classification of Eerste site 1 (E18#), using the morphological units (MUs) in Chapter 12 (Table 12.1) with the other least disturbed sites in the main study, showed that site 1 grouped with the mountain stream/transitional/upper foothill zone sites. Based on that analysis, the two different reaches could be considered to be in the same geomorphological zone.

Site 1 is a hybrid Step-pool/Plane-bed reach; characterised by six different MUs, the dominant one being plane-bed, both in number and area of reach (Table 13.1). Site 2 was classified as a Pool-rapid reach, and consists of three MUs: plane-bed, rapid and pool/plane-bed. The plane-bed MU at site 2 covers the greatest

percentage of the site (Table 13.1) and is in one contiguous area, whereas the three separate plane-bed areas in site 1 cover 5, 14 and 15% of the site respectively.

The dominant substratum by area in both sites is boulder (B) with large cobble (LC) sub-dominant (Figure 13.1, definition and codes as per Table 2.4). The main difference between the substrata of the two sites is the proportion of mixed substrata and smaller bed material (small cobble, large and small gravel, and sand). Mixed substrata categories comprise 22.2% of the total area in site 2 and smaller substrata 9.3% (Figure 13.1). In site 1, mixed substrata comprise only 3.4% of the area and small bed material 6.1%.

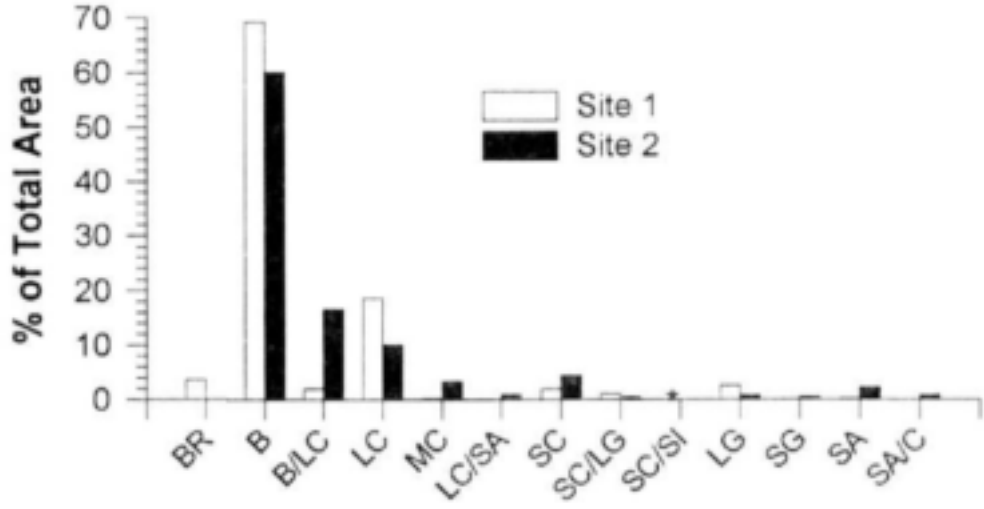


Figure 13.1 Percent cover of each substratum category for each Eerste river site. Substratum codes as per Table 2.4, with exception of "MC" which denotes mixed large and small cobble. The * denotes site 1 = 0.1% which is not visible on this scale; this category was not present in site 2.

Rippled surface (RS) was the dominant flow type during the sampling event reported here, covering 41.6% and 54.2% of the area at sites 1 and 2 respectively, with undular standing waves (USW) sub-dominant (Table 13.2, definitions and codes as per Table 2.3). Thereafter there was a difference between the two sites in the types and proportions of flow recorded (Table 13.2). Site 1 had a greater diversity of flow types, with 13 different types recorded as opposed to nine types in site 2.

The mapped proportions of substrata and flow types guided the choice of flow-substratum combinations for this study. To be consistent between reaches and between sampling times (Chapter 14), a standard set of combinations was decided upon. Even before analysis it was clear that boulder and large cobble dominated each site, and these categories would consistently meet the criteria listed in section 13.2. Flow types that were thought to be present within each reach with areas large enough to be sampled were: BSW, USW, RS, SBT, and BPF and originally FRF. As Table 13.2 shows, these were indeed the dominant flow types, with the exception of FRF, which was not considered further for the study. There remained ten possible flow/substratum combinations for the sampling programme, all of which were used when available in each site (combinations were used as available in a site and were site specific; sampling choices in one site did not dictate the combinations sampled in the other site.)

Table 13.2 Flow type proportions (shown as percent of area covered) for sampling sites 1 and 2 on 29 and 28 October 1997 respectively. The five flow types used in sampling are listed first from fastest flow to slowest, followed by the other flow types recorded at each site but not used in sampling invertebrates, also fastest to slowest.

Flow Type	Site 1	Site 2
Broken Standing Waves	7.2	10.1
Undular Standing Waves	18.3	24.0
Rippled Surface	41.6	54.2
Smooth Boundary Turbulent	8.4	1.6
Barely Perceptible Flow	15.9	6.1
Free Fall	0.1	0.0
Cascade	0.5	0.5
Chute	1.1	1.2
Stream	0.7	0.7
Fast Riffle Flow	4.6	1.6
Slow Riffle Flow	0.3	0.0
Trickle	0.7	0.0
No Flow	0.6	0.0

The distribution of these combinations in site 1 (Figure 13.2) is more evenly divided between the boulder and large cobble substrata than in site 2, which is dominated by boulder. The RS/B and RS/LC combinations cover most of the area at site 1 and RS/B and USW/B at site 2. Figure 13.2 and Table 13.2 also show that there was very little SBT, over either boulder or large cobble, at either site, with the exception of SBT/B at site 1. Barely perceptible flow over large cobble was also not available in large enough proportions or patch sizes to sample at site 2. As a result of the various levels of availability, not all of the flow/substratum combinations were sampled, with 27 samples being collected at site 1 and 21 samples at site 2 (Table 13.3).

Table 13.3 Flow/substratum combinations sampled within each site on 29 and 28 October. Flow and substratum codes as per Tables 2.3 and 2.4. Each flow/substratum combination listed was replicated at three different places within each site.

	Site 1		Site 2	
Flow Type	Substratum		Substratum	
BSW	B	LC	B	LC
USW	B	LC	B	LC
RS	B	LC	B	LC
SBT	B			
BPF	B	LC	B	

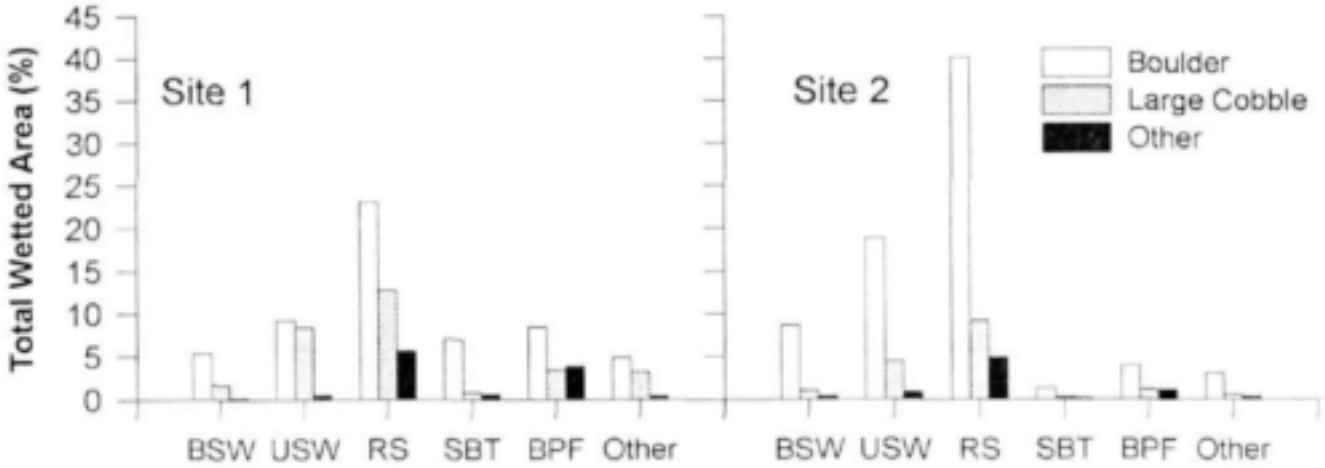


Figure 13.2 Proportions by area of flow type and substrata combinations for both Eerste River sites on 29 and 28 October 1997 (sites 1 and 2 respectively). All flow types (codes as per Table 2.3) and substrata not used for sampling invertebrates were combined into "other".

Water temperature, pH, conductivity, air temperature, and stream discharge were recorded at each site. Water temperature, conductivity and pH readings between sites were similar on average, suggesting that there was not a difference between the two sites (Table 13.4). Discharge between the two sites is different, as site 2 is approximately 1.5 km downstream from site 1 with two tributaries (Jakkels and Lang) entering between the sites.

Table 13.4 Average and standard deviation of values for water chemistry, air temperature, and discharge for each site on 29 and 28 October 1997 (sites 1 and 2 respectively).

Variable	Site 1 Mean ± SD	Site 2 Mean ± SD
Water Temperature (°C)	14.8 ± 3.2	14.8 ± 1.5
Conductivity (mS cm^{-1})	29.0 ± 5.9	26.0 ± 1.2
pH	5.6 ± 0.15	5.9 ± 0.08
Air Temperature (°C)	26.0 ± 8.5	27.0 ± 2.8
Discharge (m^3 s^{-1})	0.065 ± 0.003	0.140 ± 0.063

13.4 Biological comparison of reaches

Invertebrate densities for each replicate sample within each reach were calculated from species counts. Invertebrate densities per sample ranged from 192 – 6,000 animals per m^2 in Eerste site 1 and site 2 respectively (Table 13.5). Overall mean densities between the reaches are slightly different, with site 1 having a lower abundance than site 2.

Table 13.5 **Number of samples (N), minimum, maximum, mean and standard error (SE) of invertebrate densities (# m^{-2}) of samples in each site.**

Sample Statistics	Site 1	Site 2
N	27	21
Minimum sample density	192	204
Maximum sample density	5,328	6,000
Mean sample density	1,755	2,361
SE sample density	306	409

In order to determine if there is a significant statistical difference between animal abundances in the two reaches, the data were first assessed to see if they meet the criteria of normalcy. The distribution of invertebrate density data did not fit the normal distribution assumption (Kolmogorov-Smirnov test, d=0.197, p< 0.01), which is needed for parametric statistical tests. Therefore, all data were 4^{th} root transformed (typical for invertebrate samples, Clark and Warwick, 1994). The distribution of the transformed data was not significantly different from a normal curve (Kolmogorov-Smirnov test, d=0.083, p=n.s.). To assess if there was a significant difference between reaches an analysis of variance (ANOVA) on transformed invertebrate densities was run using Statistica (1999). There was no statistical significant difference between reaches using overall invertebrate densities (p=0.254, Table 13.6).

Table 13.6 **General ANOVA table examining the effect of reach on invertebrate densities.** d.f. = degrees of freedom; MSS = Mean Sums of Squares, F = test statistic and P = significance level.

	d.f.	MSS	F	P
effect	1	3.218	1.3	0.254
error	46	2.413		

Clearly this sort of analysis does not take into account the different species found or the proportion of each species identified within each reach, as it integrates all species into a comparison of single numbers. In order to take these individual species and their densities into account, the full set of data or species lists (densities 4^{th} root transformed), for each reach was then used for agglomerative hierarchical cluster analysis in PRIMER using the CLUSTER module.

The result of the cluster analysis shows that the primary split in the dendrogram (Figure 13.3) is between the faster hydraulic conditions (BSW, USW, and RS) and slower (RS, SBT and BPF) conditions with some overlap of samples with RS (further explanation in section 13.5). As all samples were from the same river, the catchment signature that was evident in Chapter 10 is not apparent. It was thought, however, that the major split would be between reaches, followed by different flow type/substrata combinations or hydraulic biotopes (as defined in Chapter 11) groupings. At first inspection the split is only between hydraulic conditions with no effect of reach type. However on closer examination within the "fast" group there does seem to be some site differentiation with hydraulic biotopes grouping out by site rather than mixing between sites (Figure 13.4). This pattern is not seen as strongly within the "slow" group, perhaps because

of an unbalanced representation of slower flow/substrata combinations in site 2 compared to site 1 (no SBT combinations and only BPF/B sampled in site 2).

At this point, with the data from this one analysis, there is no significant difference between the two studied reaches in terms of overall invertebrate density. A species-level multivariate analysis also showed that there was not a strong difference between the reaches and that the hydraulic condition (fast or slow flow) was the primary split of groups. However, within the two major groups there were subtle sub-groupings that seemed to reflect the two different sites. Sub-groupings by hydraulic biotope and reaches are discussed in Section 13.5.

13.5 Hydraulic Biotopes

Examining the dendrogram outputted by the cluster analysis beyond the initial split of the two main groups of "fast" and "slow" groups, sub-groups of invertebrate samples delineating different hydraulic biotopes can be identified (Figure 13.4). The MDS plot (Figure 13.5) further shows the split between "fast" and "slow" groups of samples as well as specific sub-groupings. Eighteen such sub-groups were identified: five from pools, four from runs, three from riffles, four from rapids and two undefined. Most of these sub-groups were site specific, but four groups were indeterminable (50/50 split) and two groups had the majority of their samples from one site. Table 13.7 gives information on each hydraulic biotope derived from Figure 13.4.

As discussed in Section 13.4, some samples observed as RS on boulder and large cobble fell within the "Fast" and some within the "Slow" hydraulic groupings. Hydraulically the samples that group with the "Fast" category are more closely related to USW sample than to samples in the "Slow" group, with animals reflecting this. Rippled surface as shown in Chapter 11, is one of the more hydraulically variable flow types, and does tend to bridge the two major hydraulic groupings.

Tables 13.8 and 13.9 are summaries of the hydraulic data for each hydraulic biotope, giving the range, mean and standard deviations for the parameters recorded at each sampling area within a biotope type and the average percentage of substrata present. These hydraulic ranges and means fall well within those seen in Chapter 11, and most importantly demonstrate that most sub-groups contained samples from one site. Although there were sub-groups containing samples from both sites, these were not the norm. There is a basic affiliation with site and hydraulic biotope.

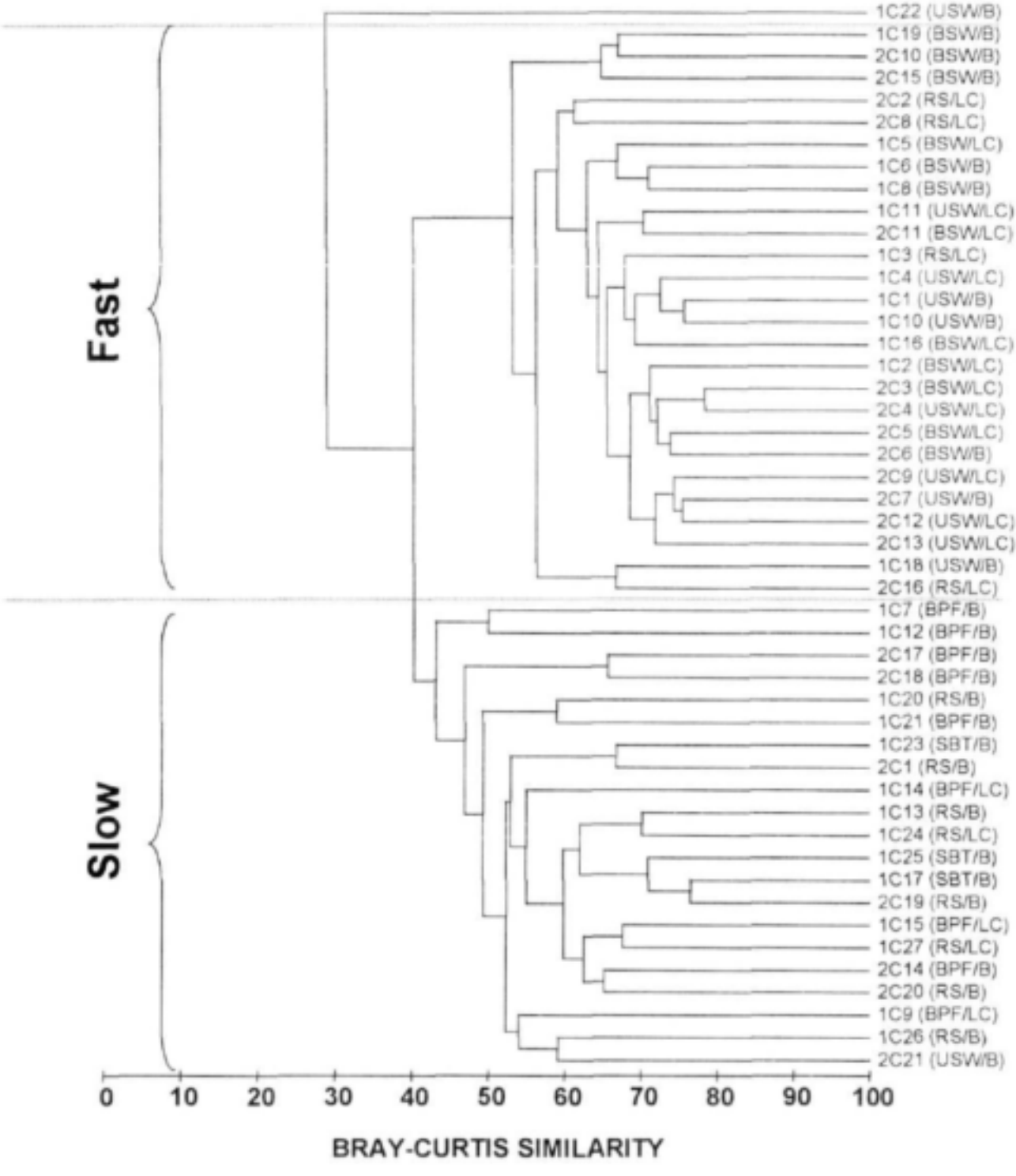


Figure 13.3 **Species-level dendrogram for individual samples at the two sites in different reach types on the Eerste River. Lines represent the split between the two major groupings of flow conditions, with the outlier at the top.** 1 = Eerste site 1, 2 = Eerste site 2, C = sampling period (Table 14.1), 29 October (site 1) and 28 October (site 2) 1997. Number after the data code is the sample number. Flow and substrata combinations appear in parentheses after each sampling point, categories as per Tables 2.3 and 2.4.

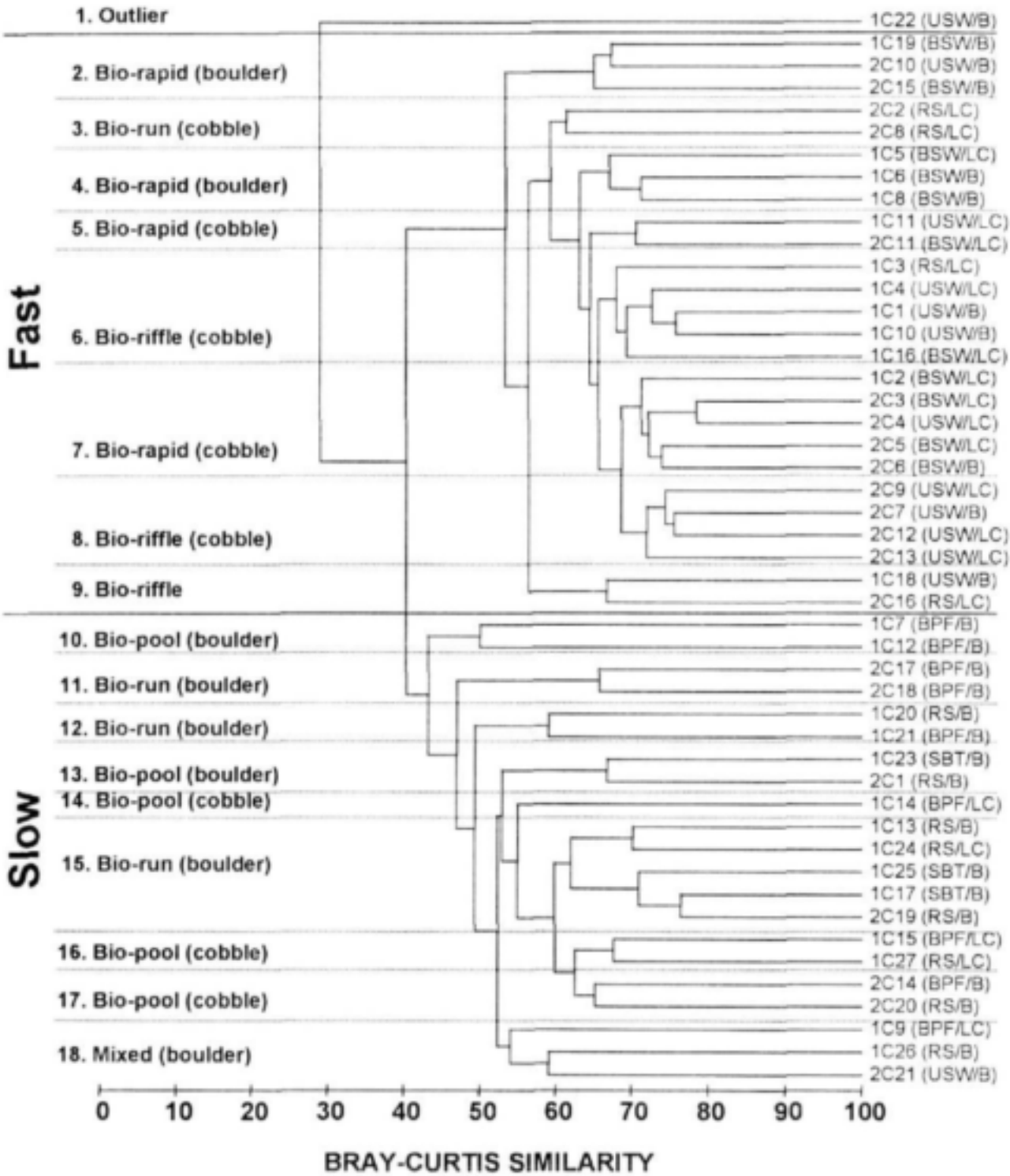


Figure 13.4 **Species-level dendrogram (same as Figure 13.3) for individual samples at the two sites in different reach types on the Eerste River, demarcating different hydraulic biotopes.** Codes as described for Figure 13.3.

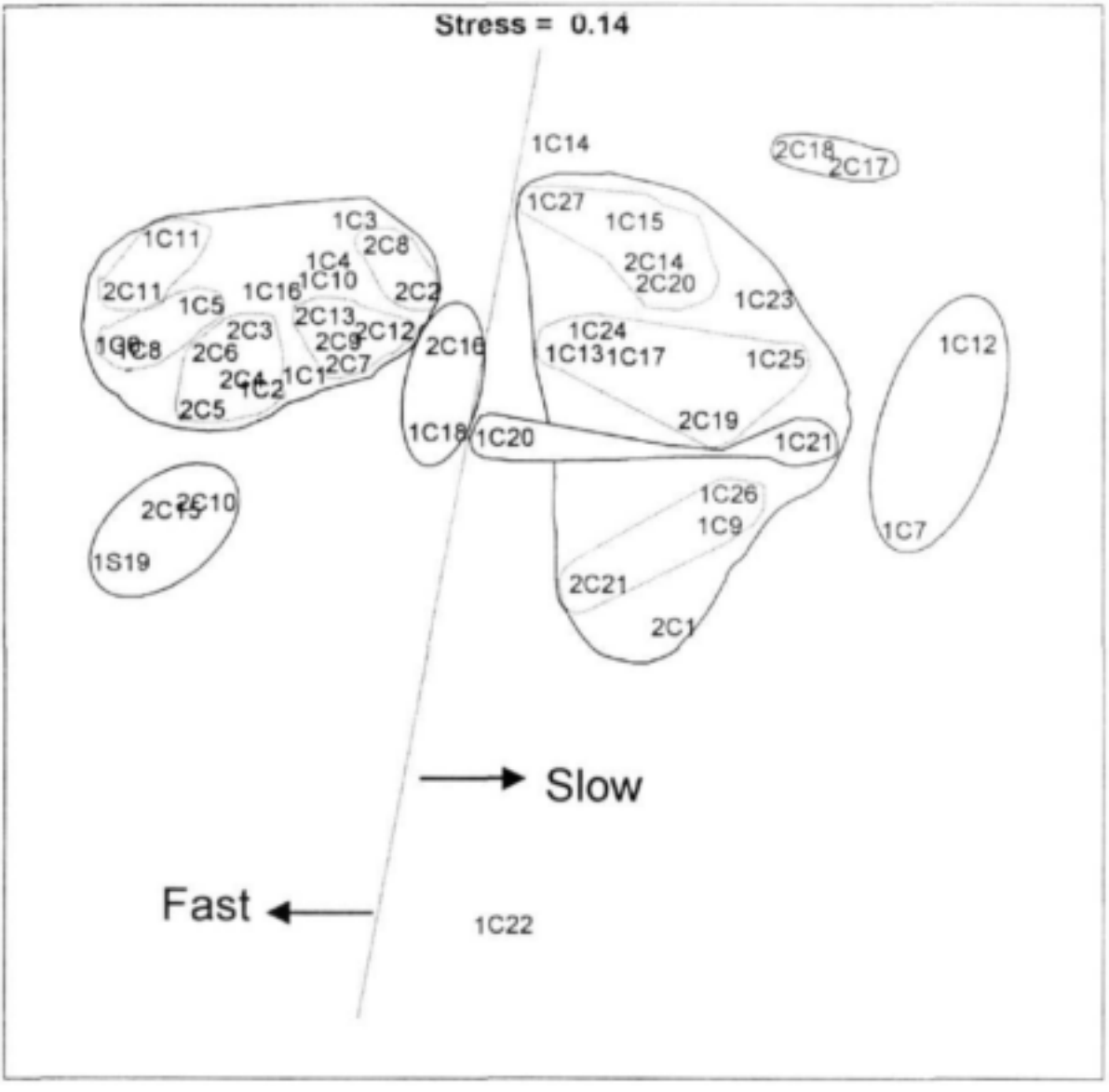


Figure 13.5 MDS plot of invertebrate samples from two sites in different reach types on the Eerste River. Codes as described for Figure 13.3. Solid circles demarcate major groupings and dotted circles smaller sub-groups. The dotted line shows the split into two planes between the hydraulically fast and slow samples.

Table 13.7 **Hydraulic characteristics of the 18 groups of samples from both sites on the Eerste River, as recognised in Figure 13.5.** The sub-groups are recognised as biologically derived hydraulic biotopes. Site number, sampling code (S.C.) and flow types sampled are also given. Statistics are: mean and standard deviations (SD) of the four readings taken within each sampling area, of Depth (m); near-bed (*NB*) and *Mean-column (0.6) velocity (m s^{-1}) and Froude number.*

Sub-group	Hydraulic Biotope	Site	S.C.	Flow Type	Depth		NB		0.6		Froude	
					Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	Outlier	1	22	USW	0.31	0.10	0.12	0.11	0.26	0.02	0.155	0.022
2	Bio-Rapid (boulder)	1	19	BSW	0.20	0.10	0.55	0.20	0.48	0.09	0.369	0.094
		2	10	BSW	0.20	0.04	0.77	0.26	0.52	0.15	0.382	0.133
		2	15	BSW	0.15	0.02	0.26	0.16	0.34	0.07	0.291	0.075
3	Bio-Run (cobble)	2	2	RS	0.43	0.05	0.14	0.09	0.22	0.08	0.107	0.038
		2	8	RS	0.16	0.03	0.05	0.03	0.08	0.04	0.059	0.033
4	Bio-Rapid (boulder)	1	5	BSW	0.17	0.05	0.35	0.47	0.49	0.38	0.424	0.409
		1	6	BSW	0.10	0.04	0.36	0.16	0.46	0.13	0.464	0.093
		1	8	BSW	0.07	0.01	0.99	0.38	1.01	0.36	1.246	0.527
5	Bio-Rapid (cobble)	1	11	USW	0.21	0.04	0.17	0.11	0.32	0.10	0.226	0.080
		2	11	BSW	0.15	0.04	0.17	0.15	0.32	0.20	0.274	0.182
6	Bio-Riffle (cobble)	1	3	RS	0.20	0.04	0.05	0.06	0.10	0.06	0.074	0.052
		1	4	USW	0.25	0.01	0.42	0.11	0.49	0.10	0.312	0.068
		1	1	USW	0.08	0.02	0.20	0.19	0.22	0.18	0.262	0.215
		1	10	USW	0.09	0.03	0.30	0.11	0.31	0.10	0.359	0.154
		1	16	BSW	0.11	0.04	0.35	0.14	0.44	0.11	0.442	0.136
7	Bio-Rapid (cobble)	1	2	BSW	0.16	0.06	0.24	0.16	0.24	0.20	0.203	0.185
		2	3	BSW	0.35	0.05	0.49	0.22	0.87	0.07	0.472	0.025
		2	4	USW	0.23	0.06	0.19	0.37	0.59	0.26	0.416	0.232
		2	5	BSW	0.09	0.04	0.28	0.10	0.43	0.14	0.475	0.114
		2	6	BSW	0.24	0.04	0.38	0.25	0.36	0.26	0.244	0.186
8	Bio-Riffle (cobble)	2	9	USW	0.20	0.01	0.18	0.04	0.30	0.02	0.213	0.014
		2	7	USW	0.17	0.04	0.09	0.11	0.16	0.12	0.132	0.104
		2	12	USW	0.30	0.04	0.23	0.05	0.28	0.03	0.163	0.019
		2	13	USW	0.30	0.04	0.07	0.04	0.16	0.06	0.095	0.031
9	Bio-Riffle (cobble)	1	18	USW	0.17	0.09	0.12	0.11	0.15	0.10	0.143	0.116
		2	16	RS	0.29	0.04	0.24	0.03	0.30	0.02	0.182	0.012
10	Bio-Pool (boulder)	1	7	BPF	0.15	0.03	0.03	0.01	0.05	0.01	0.038	0.006
		1	12	BPF	0.12	0.04	0.01	0.01	0.02	0.01	0.022	0.004
11	Bio-Run (boulder)	2	17	BPF	0.43	0.02	0.13	0.02	0.14	0.02	0.067	0.010
		2	18	BPF	0.42	0.05	0.09	0.01	0.11	0.02	0.053	0.015
12	Bio-Run (boulder)	1	20	RS	0.29	0.02	0.13	0.02	0.21	0.04	0.123	0.022
		1	21	BPF	0.16	0.15	0.03	0.03	0.05	0.03	0.051	0.046
13	Bio-Pool (boulder)	1	23	SBT	0.41	0.03	0.04	0.01	0.06	0.01	0.029	0.005
		2	1	RS	0.28	0.01	0.00	0.01	0.01	0.01	0.005	0.006
14	Bio-Pool (cobble)	1	14	BPF	0.41	0.01	0.02	0.01	0.05	0.01	0.025	0.007
15	Bio-Run (boulder)	1	13	RS	0.34	0.08	0.06	0.06	0.14	0.05	0.082	0.040
		1	24	RS	0.41	0.06	0.06	0.03	0.12	0.01	0.062	0.008
		1	25	SBT	0.43	0.07	0.02	0.00	0.03	0.01	0.014	0.003
		1	17	SBT	0.28	0.07	0.07	0.01	0.09	0.01	0.058	0.013
		2	19	RS	0.20	0.04	0.11	0.03	0.15	0.01	0.105	0.017
16	Bio-Pool (cobble)	1	15	BPF	0.24	0.05	0.03	0.01	0.04	0.01	0.025	0.009
		1	27	RS	0.34	0.02	0.05	0.01	0.14	0.02	0.079	0.012

Sub-group	Hydraulic Biotope	Site	S.C.	Flow Type	Depth		NB		0.6		Froude	
					Mean	SD	Mean	SD	Mean	SD	Mean	SD
17	Bio-Pool (boulder)	2	14	BPF	0.11	0.03	0.01	0.01	0.02	0.01	0.019	0.006
		2	20	RS	0.44	0.05	0.13	0.05	0.18	0.03	0.085	0.018
18	Mixed (boulder)	1	9	BPF	0.22	0.07	0.03	0.00	0.05	0.01	0.033	0.003
		1	26	RS	0.50	0.07	0.07	0.05	0.14	0.05	0.061	0.019
		2	21	USW	0.32	0.06	0.10	0.01	0.16	0.01	0.090	0.013

//Table 13.7 continued

There are some differences between the proportions of hydraulic-biotope types identified within each site. Site 1 had three bio-pools (one boulder and two cobble), two boulder bio-runs, one cobble bio-riffle and one bio-rapid, with a total of seven hydraulic biotopes of four different types. Site 2 also had four different hydraulic biotope types, but in a different configuration. There was one bio-pool (boulder), two bio-runs (one cobble and one boulder), one cobble bio-riffle and two bio-rapids (one cobble and one boulder) for a total of six defined hydraulic biotopes. These differences mirror differences in the distribution of flow types between the sites and demonstrates that there were more "turbulent" hydraulic biotopes (i.e. rapids and riffles) present in the reach characterised as Pool-rapid (site 2) and more "quiet" hydraulic biotope types (i.e. pools and runs) identified in site 1 (Step-pool/Plane-bed reach type).

13.6 Further analyses

As could be seen by the analyses completed to date, comparing the reaches by examining overall density does not show any difference between the two. However, by using a cluster analysis and identifying hydraulic biotopes, it can be shown that different reach types within the same zone have some differences in their invertebrate assemblages.

As these are preliminary analyses, there is more to accomplish with these data. Identifying the species or groups of species that are creating these differences will be done using SIMPER in Primer (Clark and Warwick 1994), as well as an investigation of the different proportions of species within a biotope, and the relationship between sample location and species composition. Additionally, as there are samples from three more sample dates that have not yet been analysed, it will be possible to ascertain if these patterns are repeated through time and changes in discharge (Chapter 14 and PhD thesis of D.M. Schael).

Table 13.8 Summary statistics for each group of samples recognised in Table 13.6: range, mean and standard deviation (SD) of depth and percent composition of substrata. These statistics are listed by hydraulic biotope, sub-group number, site representation and number of samples (N) within each hydraulic biotope. Depth data calculated from the means from Table 13.7. Substratum averages from all contributions within the group. Site designation is based on group composition; none means that both sites were equally represented in the sub-group; and a * denotes that the majority of samples were from that site, but that one sample in the sub-group was from the other site.

				Depth (m)			Substrata (% coverage)				
Hydraulic Biotope	Sub-group	Site	N	Range	Mean	SD	B	LC	SC	LG	SG
Bio-Pool (boulder)	10	1	2	0.12 – 0.15	0.13	0.02	98	2	0	0	0
Bio-Pool (boulder)	13	none	2	0.28 – 0.41	0.34	0.09	66	28	6	0	0
Bio-Pool (cobble)	14	1	1	.	0.41	.	20	40	36	4	0
Bio-Pool (cobble)	16	1	2	0.24 – 0.34	0.29	0.07	20	54	18	6	2
Bio-Pool (boulder)	17	2	2	0.11 – 0.44	0.28	0.24	62	6	24	0	8
Bio-Rapid (boulder)	2	2	3	0.15 – 0.20	0.18	0.03	85	3	9	3	0
Bio-Rapid (boulder)	4	1	3	0.07 – 0.17	0.11	0.05	48	37	9	5	0
Bio-Rapid (cobble)	5	none	2	0.15 – 0.21	0.18	0.05	36	18	24	22	0
Bio-Rapid (cobble)	7	2*	5	0.09 – 0.35	0.21	0.10	36	46	10	6	2
Bio-Riffle (cobble)	6	1	5	0.08 – 0.25	0.14	0.08	16	40	28	10	6
Bio-Riffle (cobble)	8	2	4	0.17 – 0.30	0.24	0.07	26	29	28	15	2
Bio-Riffle (boulder)	9	none	2	0.17 – 0.29	0.23	0.08	52	38	6	4	0
Bio-Run (cobble)	3	2	2	0.16 – 0.43	0.30	0.19	28	40	32	0	0
Bio-Run (boulder)	11	2	2	0.42 – 0.43	0.43	0.01	74	4	8	0	14
Bio-Run (boulder)	12	1	2	0.16 – 0.29	0.23	0.10	76	16	4	4	0
Bio-Run (boulder)	15	1*	5	0.20 – 0.43	0.33	0.09	66	19	11	3	0
Mixed (boulder)	18	none	3	0.22 – 0.50	0.35	0.14	84	3	8	5	0
Outlier	1	1	1	.	0.31	.	80	0	20	0	0

Table 13.9 **Summary statistics for each sub-group of samples recognised in Table 13.7: ranges, means and standard deviations of mean-column (0.6) velocity, near-bed (NB) velocity and froude number. These statistics are listed by hydraulic biotope, sub-group number, site representation and number of samples (N) within each hydraulic biotope.** Four individual sets of velocity measurements were made within the area where each invertebrate sample was collected. The means of these values are given in Table 13.6. The values in this summary table are the ranges, means and standard deviations of these means. Velocity is measured as m s^{-1}, and Froude number is dimensionless. Site designation is based on group composition; none means that both sites were equally represented in the sub-group; and a * denotes that the majority of samples were from that site, but that one sample in the sub-group was from the other site.

				Near Bed Velocity (m s^{-1})			Mean (0.6) Velocity (m s^{-1})			Froude Number		
Hydraulic Biotope	**Sub-group**	**Site**	**N**	**Range**	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**	**Mean**	**SD**
Bio-Pool (boulder)	10	1	2	0.01 – 0.03	0.02	0.01	0.02 – 0.05	0.03	0.02	0.022 – 0.038	0.030	0.012
Bio-Pool (boulder)	13	none	2	0.00 – 0.04	0.02	0.02	0.01 – 0.06	0.03	0.04	0.005 – 0.029	0.017	0.017
Bio-Pool (cobble)	14	1	1	.	0.02	.	.	0.05	.	.	0.025	.
Bio-Pool (cobble)	16	1	2	0.03 – 0.05	0.04	0.01	0.04 – 0.14	0.09	0.07	0.025 – 0.079	0.052	0.038
Bio-Pool (boulder)	17	2	2	0.01 – 0.13	0.07	0.08	0.02 – 0.18	0.10	0.11	0.019 – 0.085	0.052	0.047
Bio-Rapid (boulder)	2	2	3	0.26 – 0.77	0.53	0.25	0.34 – 0.52	0.45	0.09	0.291 – 0.382	0.348	0.049
Bio-Rapid (boulder)	4	1	3	0.35 – 0.99	0.57	0.37	0.46 – 1.01	0.65	0.31	0.424 – 1.246	0.711	0.464
Bio-Rapid (cobble)	5	none	2	0.17 – 0.17	0.17	0.01	0.32 – 0.32	0.32	0.00	0.226 – 0.274	0.250	0.034
Bio-Rapid (cobble)	7	2*	5	0.19 – 0.49	0.32	0.12	0.24 – 0.87	0.50	0.24	0.203 – 0.475	0.362	0.129
Bio-Riffle (cobble)	6	1	5	0.05 – 0.42	0.26	0.14	0.10 – 0.49	0.31	0.16	0.074 – 0.442	0.290	0.138
Bio-Riffle (cobble)	8	2	4	0.07 – 0.23	0.14	0.07	0.16 – 0.30	0.22	0.07	0.095 – 0.213	0.151	0.050
Bio-Riffle (boulder)	9	none	2	0.12 – 0.24	0.18	0.09	0.15 – 0.30	0.22	0.11	0.143 – 0.182	0.162	0.028
Bio-Run (cobble)	3	2	2	0.05 – 0.14	0.10	0.06	0.08 – 0.22	0.15	0.10	0.059 – 0.107	0.083	0.034
Bio-Run (boulder)	11	2	2	0.09 – 0.13	0.11	0.03	0.11 – 0.14	0.12	0.02	0.053 – 0.067	0.060	0.010
Bio-Run (boulder)	12	1	2	0.03 – 0.13	0.08	0.07	0.05 – 0.21	0.13	0.11	0.051 – 0.123	0.087	0.051
Bio-Run (boulder)	15	1*	5	0.02 – 0.11	0.06	0.03	0.03 – 0.15	0.11	0.05	0.014 – 0.105	0.064	0.034
Mixed (boulder)	18	none	3	0.03 – 0.10	0.07	0.04	0.05 – 0.16	0.11	0.06	0.033 – 0.090	0.061	0.028
Outlier	1	1	1	.	0.12	.	.	0.26	.	.	0.155	.

14. THE RELATIONSHIP BETWEEN HYDRAULIC BIOTOPE AND DISCHARGE

14.1 Recap

The final aim of this project (Section 3.7) was to record changes in the distributions of flow types and invertebrates with discharge, and to assess the temporal stability of hydraulic biotopes and their biota.

Hydraulic biotopes are defined by their species assemblage and described by hydraulic conditions (flow type and substrata). Thus, as flow conditions change there will be a point where the biota changes and at that point, by definition, the hydraulic biotope also changes. If we can define and understand those points of change, understanding of hydraulic biotopes will be enhanced through a better understanding of the resilience of patches of different hydraulic character, and the relationship of this to invertebrate distributions.

In this chapter the stability of hydraulic conditions and invertebrate assemblages are tracked over a series of discharges. It was thought that up to a point, the discharge and resulting hydraulic changes would not be reflected in changes in the distribution of invertebrate species. However, discharge should eventually increase (or decrease) to a point where invertebrate distribution patterns would be significantly affected. Preliminary analyses of changes in hydraulic conditions with discharge, and the links with shifts in densities of invertebrates and changes in species composition of assemblages are presented here. Further analyses to be done in Ms Schael's PhD thesis are outlined here.

14.2 Methods

Flow types of both sites on the Eerste River (Chapter 13) were mapped, and discharge measured, on eight occasions within a single season (spring) of 1997. The objective was to document changes in wetted area and the proportions of different flow type (Table 14.1). Invertebrates were also collected on four of these occasions, together with allied physical measurements (see Chapters 4 and 13 for collection details). Two sample dates in summer 1997 on Eerste River site 1 are included in the analyses where appropriate, with differences in site length and sampling strategies noted (Section 13.2).

The study was confined to one season in order to eliminate noise in the data from seasonal invertebrate community shifts. Additionally, this should have allowed a wide range of discharges to be studied, as the winter rains gradually ceased and low summer flows ensued. In this case, the preceding winter had lower than normal rainfall, and the spring flows were lower than expected. One major rainfall event toward the end of spring provided the only high flow condition during the study period, with all other discharges studied being fairly similar.

On each sampling episode, each site was sampled within a day or two of the other, with the downstream site (Eerste site 2) being sampled first on all occasions except the last invertebrate sampling episode. Most invertebrate sampling sessions were over two days, with flow-type mapping completed on the first day and

discharge measured on each day of the episode. For ease of reporting, all dates of mapping and sampling are represented by site number and letter codes for each sampling period (Table 14.1).

Table 14.1 Site number, data code, date of map, site area (total and wetted, m^2) along with measured discharge (m^3 s^{-1}) and description of main data types collected. Upper case letters (A-D, M and IS) used in the map code denote periods where invertebrates were sampled, lower case letters (w-z) denote when only flow types were mapped. M = first mapping and sampling date on Eerste River site 1 during the main study (Chapter 5) and IS = intensive sampling for testing hydraulic biotopes (Chapter 11).

Site No.	Data Code	Map Date	Total Mapped Area (m^2)	Wetted Area (m^2)	Discharge (m^3 s^{-1})	Data Collected
1	M[a]	15-Jan-97	326.2	158.2	0.132	substrata & flow maps and invertebrates
1	IS[a]	1-Apr-97	326.2	140.2	0.038	flow map and invertebrates
2	A	15-Sep-97	486.6	251.3	0.509	substrata & flow maps and invertebrates
1	A	18-Sep-97	394.6	221.9	0.184	flow map and invertebrates
1	w	3-Oct-97	394.6	206.0	0.082	flow map
2	w	3-Oct-97	486.6	217.6	0.272	flow map
2	B	8-Oct-97	486.6	248.7	0.339	flow map and invertebrates
1	B	10-Oct-97	394.6	218.3	0.110	flow map and invertebrates
1	x	22-Oct-97	394.6	194.2	0.067	flow map
2	x	22-Oct-97	486.6	215.5	0.216	flow map
2	C	28-Oct-97	486.6	206.8	0.141	flow map and invertebrates
1	C	29-Oct-97	394.6	190.8	0.067	flow map and invertebrates
1	y	10-Nov-97	394.6	190.2	0.072	flow map
2	y	10-Nov-97	486.6	213.0	0.200	flow map
1	z	25-Nov-97	394.6	282.8	0.781	flow map
1	D	28-Nov-97	394.6	236.8	0.451	flow map and invertebrates
2	z	28-Nov-97	486.6	263.4	0.619	flow map
2	D	30-Nov-97	486.6	259.3	0.559	flow map and invertebrates

[a]Site was 40-m in length rather than the 50-m at subsequent mapping trips.

14.3 Physical stability of hydraulic conditions

The first level of assessment was to examine the physical character of the two sites, which are in different geomorphological reach types, as discharge changed over time. Overall changes are described, and the sites compared.

There was a significant positive linear relationship between wetted area (WA) and discharge (Q), where: $Q = 0.0077(WA) - 1.466$ ($R^2 = 0.92$). As discharge increased, wetted area increased (Figure 14.1). However, the changes in wetted area are subtle, and a large change in discharge would be needed for a noticeable difference in wetted area. Measured discharges ranged from 0.038 m^3 s^{-1} in mid-summer of 1997 (IS) at site 1 to 0.781 m^3 s^{-1} in late spring (sampling period z), also at site 1 (Table 14.1). The lowest spring discharge was 0.067 m^3 s^{-1} (sampling period C). Over the measured spring discharges, wetted area ranged from 190.8 m^2 to 282.8 m^2, or 44.3-71.6% of total wetted mapped area respectively. Site 2 had a higher discharge than site 1, as noted in Chapter 13, because of the entry of two tributaries between the sites.

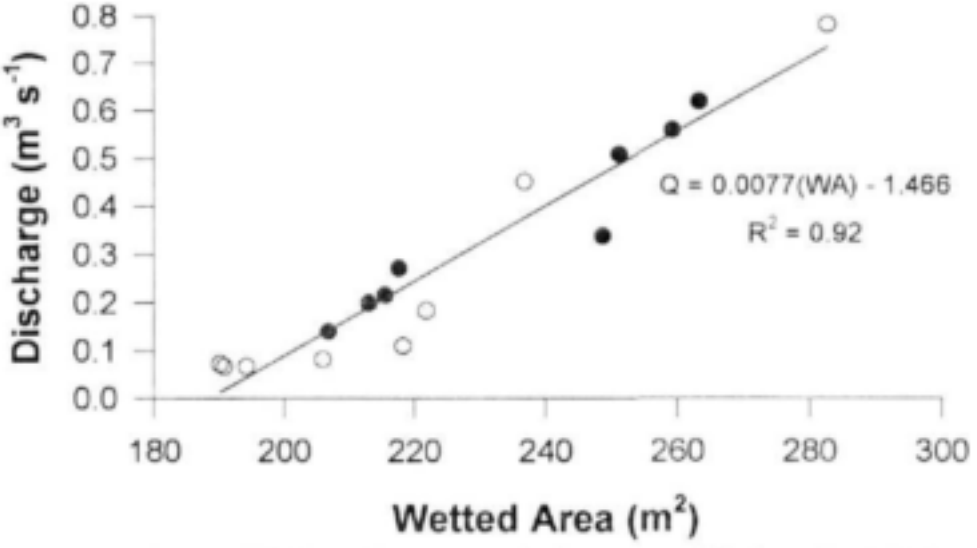


Figure 14.1 **Total wetted area (WA) and measured discharge (Q) for site 1 (O) and site 2 (●) on the Eerste River, on all mapping and sampling occasions shown in Table 14.1.**

The wetted area at site 2 was greater than that at site 1 on all occasions, providing for a greater overall area for invertebrates to settle in site 2 (Figure 14.2). As the total mapped area of site 2 was greater than that of site 1 due to channel size and shape, they can only be directly compared through their percentage of wetted area. Examining percentage of wetted area, site 1 actually had a slightly greater overall percentage of wetted area than did site 2 (ranging from 60 - 48% and 53 - 44% for sites 1 and 2 respectively). The patterns for both sites, however, remain the same, with the first two sampling periods being almost equivalent and the greatest differences being between sampling periods C and D.

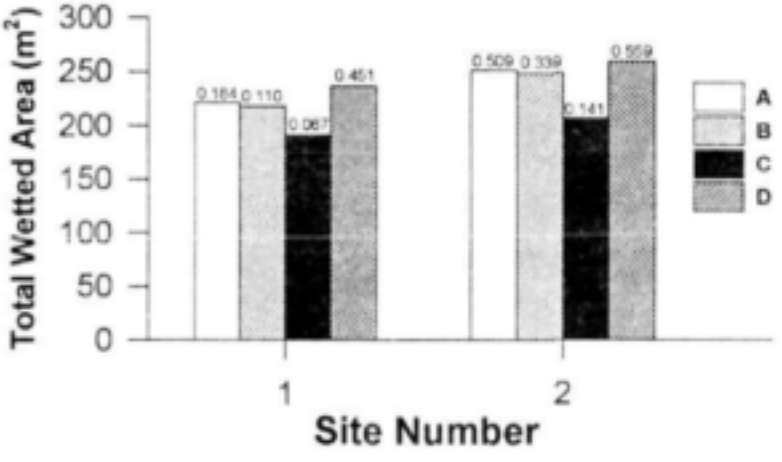


Figure 14.2 **Total wetted area (m^2) on each of the main sampling occasions listed in Table 14.1.** Site 1: A = 18 September; B = 10 October; C = 29 October; D = 28 November 1997. Site 2: A = 15 September; B = 8 October; C = 28 October; D = 30 November 1997. Measured discharges ($m^3 s^{-1}$) on top of each bar.

Although changes in discharge and wetted area were recorded, these had negligible effect on the proportions of different flow types for all but highest measured discharges (Table 14.2). On all mapping

occasions but the last two, at both sites, rippled surface flow (RS) dominated, with undular standing waves (USW) and broken standing waves (BSW) being sub-dominant. On the penultimate sampling occasion, when higher discharges were measured, USW and BSW were the dominant flow types and, as flow dropped, USW dominated on the last sampling occasion. Within site 1, the five flow types used for sampling (BSW, USW, RS, SBT, BPF - Table 13.3) accounted for 77 - 92% of all recorded flow types during the study period. The same flow types accounted for a higher percentage (91 - 97%) of all the flow types at site 2. Site 1 tended to have a wider diversity of flow types with up to nine types in addition to the main five, whereas site 2 had three to four additional flow types. Examining the wetted area to discharge relationships and the types and proportions of various flow types recorded at each site, site 1 appears to be more hydraulically complex and more heterogeneous than site 2.

Analysis of the flow-type proportions (Table 14.2), using the CLUSTER module of Primer (Figure 14.3), reveals three major groups, which are correlated with discharge. One group represents the sampling occasions with the highest mapped discharges, the second represents the lowest mapped discharge during the Intensive Sampling period at site 1, and the third group consists of all of the other mapped discharges (here called the intermediate-discharge group). Within the intermediate-discharge group there are several sub-groups, clustered by site and, to some extent, discharge (Figure 14.3). The data from site 1 in the main sampling period (January 1997: M), link with other site 1 data in one of these sub-groups.

As shown with one sample period (C) in Chapter 13, the five chosen flow types, and the chosen substrata of boulder and large cobble, were appropriate choices of flow/substrata combinations for this discharge-related study of habitat. They constituted the dominant flow-substratum combinations over all the measured discharges, although proportions of the combinations changed with significant changes in discharge (Table 14.2 and Figure 14.4). During the first three sampling occasions, there was little change in the proportions of flow type/substratum combinations, with RS/B (Rippled surface flow over boulder) dominating (Figure 14.4). At site 1, RS/LC and USW/B were sub-dominant, as were USW/B and BSW/B at site 2. With the increase in discharge over the last sampling period, the dominant combinations shifted. At site 1, USW/B was dominant, and BSW/B and RS/B sub-dominant. At site 2, BSW/B was dominant and USW/B and RS/B sub-dominant.

There were thus three main differences between sites throughout the study. First, there was a more even distribution of flows over both boulders and large cobble at site 1 than at site 2 (Section 13.3). Second, there was a low percentage of SBT at site 2 over any substratum, and it completely disappeared as a flow type in the higher discharge conditions (Figure 14.4 and Table 14.2). Third, there was a higher percentage of "other" categories of flow at site 1 than at site 2, with this proportion increasing at the highest discharge.

Table 14.2 **Proportions of flow types (shown as percent) for two sites on the Eerste River on each mapping occasion (codes as per Table 14.1).** The five flow types selected for this study are listed first, from fastest flow to slowest, followed by the other flow types recorded at each site but not used for sampling invertebrates, also listed fastest to slowest. Data codes are listed by sampling period (Table 14.1) within each site. Upper case letters (M,IS, A-D) represent invertebrate sampling and lower case letters (w-z) represent mapping only occasions.

	Site 1										Site 2							
Flow Type	**M**[a]	**IS**[a]	**A**	**w**	**B**	**x**	**C**	**y**	**z**	**D**	**A**	**w**	**B**	**x**	**C**	**y**	**z**	**D**
Broken Standing Waves	12.2	0.5	11.2	13.4	15.1	5.5	7.2	5.6	39.0	20.9	14.6	13.3	13.9	11.7	10.1	6.5	37.5	36.0
Undular Standing Waves	15.5	5.3	16.4	16.6	24.1	10.5	18.3	16.8	25.9	32.3	16.9	31.0	36.8	22.0	24.0	28.9	34.5	36.9
Rippled Surface	40.8	36.0	46.3	45.9	32.1	53.0	41.6	43.5	10.5	18.9	47.2	42.7	40.6	49.0	54.2	43.8	20.7	20.7
Smooth Boundary Turbulent	10.8	34.4	3.8	6.2	2.8	5.2	8.4	5.9	0.0	0.4	1.8	3.0	0.9	0.0	1.6	0.0	0.0	0.0
Barely Perceptible Flow	5.6	6.7	9.5	6.6	10.1	10.9	15.9	17.6	2.1	7.6	10.9	5.5	4.7	12.8	6.1	16.3	1.9	2.4
Free Fall	1.8	0.0	0.2	0.7	0.6	0.3	0.1	0.2	1.7	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Boil	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.1	5.7	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
Cascade	2.5	1.4	1.0	0.8	1.3	0.4	0.5	0.5	1.1	1.2	0.6	0.0	1.1	0.5	0.5	0.2	1.8	1.7
Chute	3.3	2.1	1.5	1.2	1.3	1.1	1.1	0.9	2.8	1.9	2.1	0.6	0.4	1.7	1.2	1.2	0.9	0.7
Stream	1.7	1.3	0.9	1.2	1.3	0.4	0.7	0.7	5.1	2.2	4.7	1.4	1.0	1.1	0.7	0.8	2.2	1.4
Fast Riffle Flow	3.2	9.9	7.3	6.0	10.2	11.1	4.6	4.9	1.1	7.1	1.2	2.6	0.5	0.8	1.6	1.1	0.3	0.3
Slow Riffle Flow	0.1	0.4	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Trickle	1.1	0.4	1.6	1.1	0.3	1.3	0.7	1.6	0.0	0.3	0.0	0.0	0.0	0.3	0.0	0.7	0.0	0.0
No Flow	1.3	2.4	0.4	0.4	0.6	0.3	0.6	2.0	0.7	1.1	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0

[a]Site 1 on these sampling occasions was 40-m in length whereas on subsequent sampling occasions it was 50-m long.

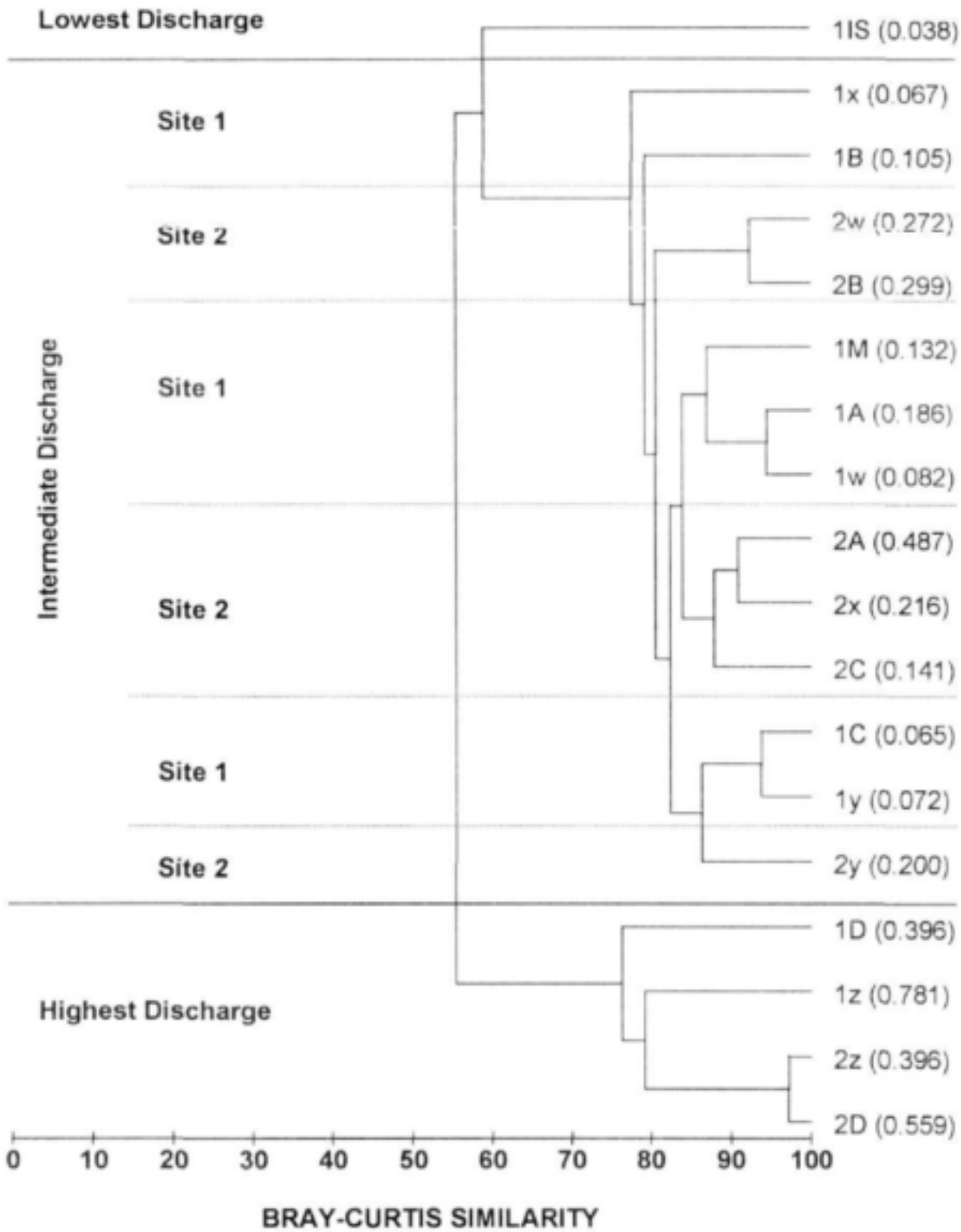


Figure 14.3 Dendrogram of flow-types mapped at sites 1 and 2 on the Eerste River in summer and spring 1997. Solid lines demarcate the three main discharge groups, with site level sub-groups separated by dotted lines. Data codes for site and mapping times as in Table 14.1, with measured discharge ($m^3 s^{-1}$) in parentheses after each code.

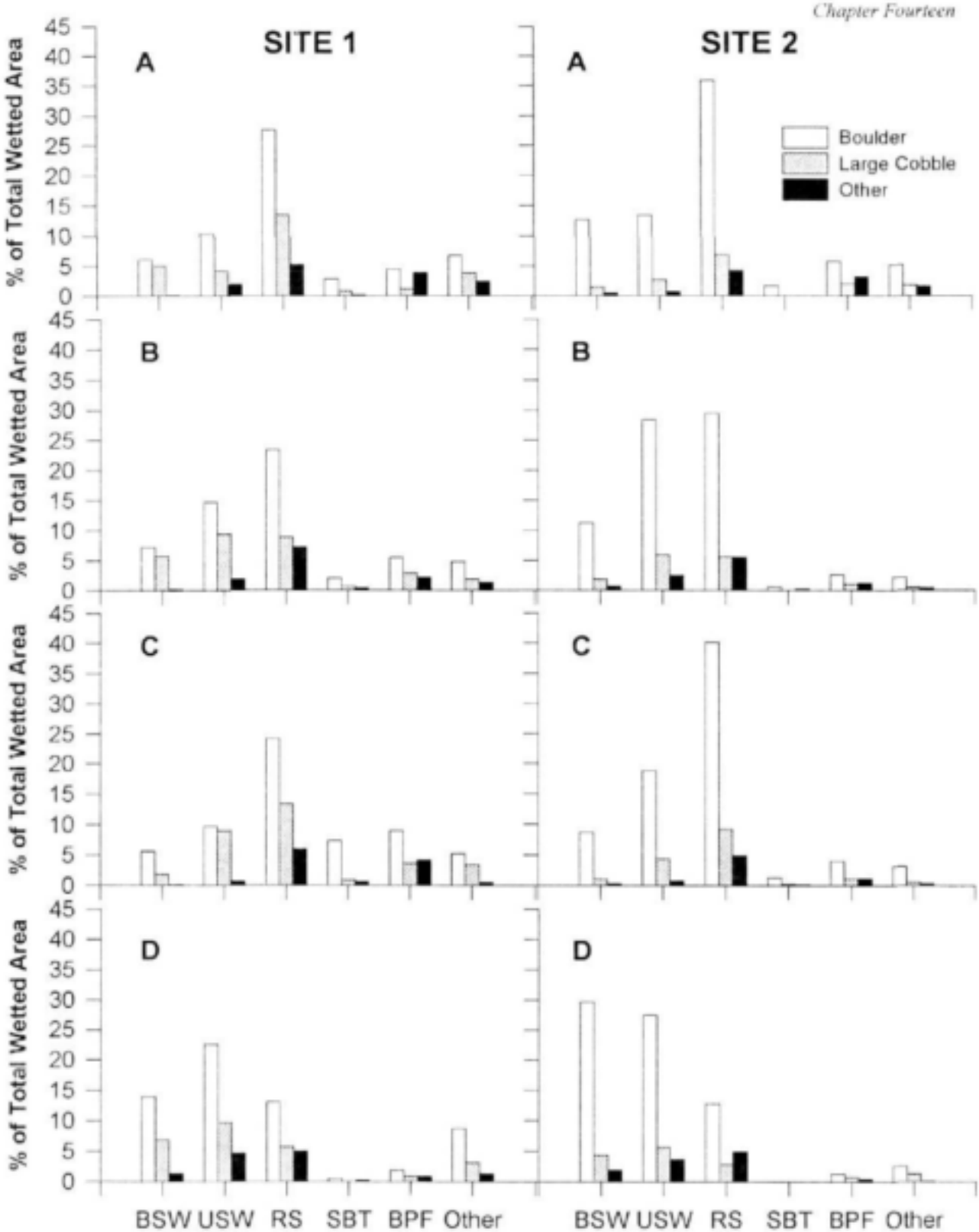


Figure 14.4 Proportions by area of flow-type and substrata combinations for both Eerste River sites on invertebrate sampling dates. Site 1: A = 18 September; B = 10 October; C = 29 October; D = 28 November 1997. Site 2: A = 15 September; B = 8 October; C = 28 October; D = 30 November 1997. All flow types (codes as per Table 2.3) and substrata not used for sampling invertebrates were combined into "other".

Given the flow and substrata combinations available at each site and each invertebrate sampling date (Table 14.2 and Figure 14.4), not all combinations were available at all sites on all sampling occasions (Section 13.3). For example, the increase in discharge during the last sampling occasion resulted in areas of BPF and SBT being small and rare at both sites. BPF and SBT represented respectively 7.6% and 0.4% of site 1, and 2.4% and 0.0% of site 2 during the last sampling period (D). This yielded only 18 invertebrate samples per site on this sampling occasion, as opposed to 27 (site 1) and 21 (site 2) samples during sampling period C. The greater number of available sampling points meeting the established criteria within site 1 during sampling period C could be as a result of the greater number and diversity of morphological units (6 and 3 in sites 1 and 2 respectively, Table 13.1) resulting in a higher diversity of flow and substratum combinations. The combinations sampled for each site during each sampling period are shown in Table 14.3.

Table 14.3 Flow/substratum combinations sampled within each site on 29 October (C) and 29 November (D) at site 1, and on 28 October (C) and 30 November (D) at site 2. Each flow/substratum combination listed was sampled at three different places within each site. Flow and substratum codes as per Tables 2.3 and 2.4.

	Site 1				Site 2			
Flow	C		D		C		D	
Type	Substratum				Substratum			
BSW	B	LC	B	LC	B	LC	B	LC
USW	B	LC	B	LC	B	LC	B	LC
RS	B	LC	B	LC	B	LC	B	LC
SBT	B							
BPF	B	LC			B			

When data on all the combinations of flow type and substratum present in the spring study were analysed, three groups of similar sampling occasions emerged (Figure 14.5). The first group, splitting off at 53% similarity with the rest, consisted of data collected during the highest discharges. This reflected the pattern shown by flow-type distributions. Within this group, each site formed its own sub-group, with samples from site 2, 97% similar and those from site 1, 72% similar. The second and third groups were site specific, and encompassed all the intermediate discharges. They had a common similarity level of 68%. The MDS plot clearly illustrates these different groups (Figure 14.6). There are two different planes of separation, one by site and the other by discharge.

If the flow type/substratum data from the summer sampling occasions (M and IS) are added, a similar pattern emerges. The data from M link with the other site 1/intermediate discharge samples (Figure 14.7). Also, the data from the IS sampling occasion, with the lowest discharge, split off as a new, separate group at a level of 45% similarity. The MDS plot now illustrates three planes of separation (Figure 14.8). The first is by site, and the second and third distinguish samples taken at low, intermediate or high discharges.

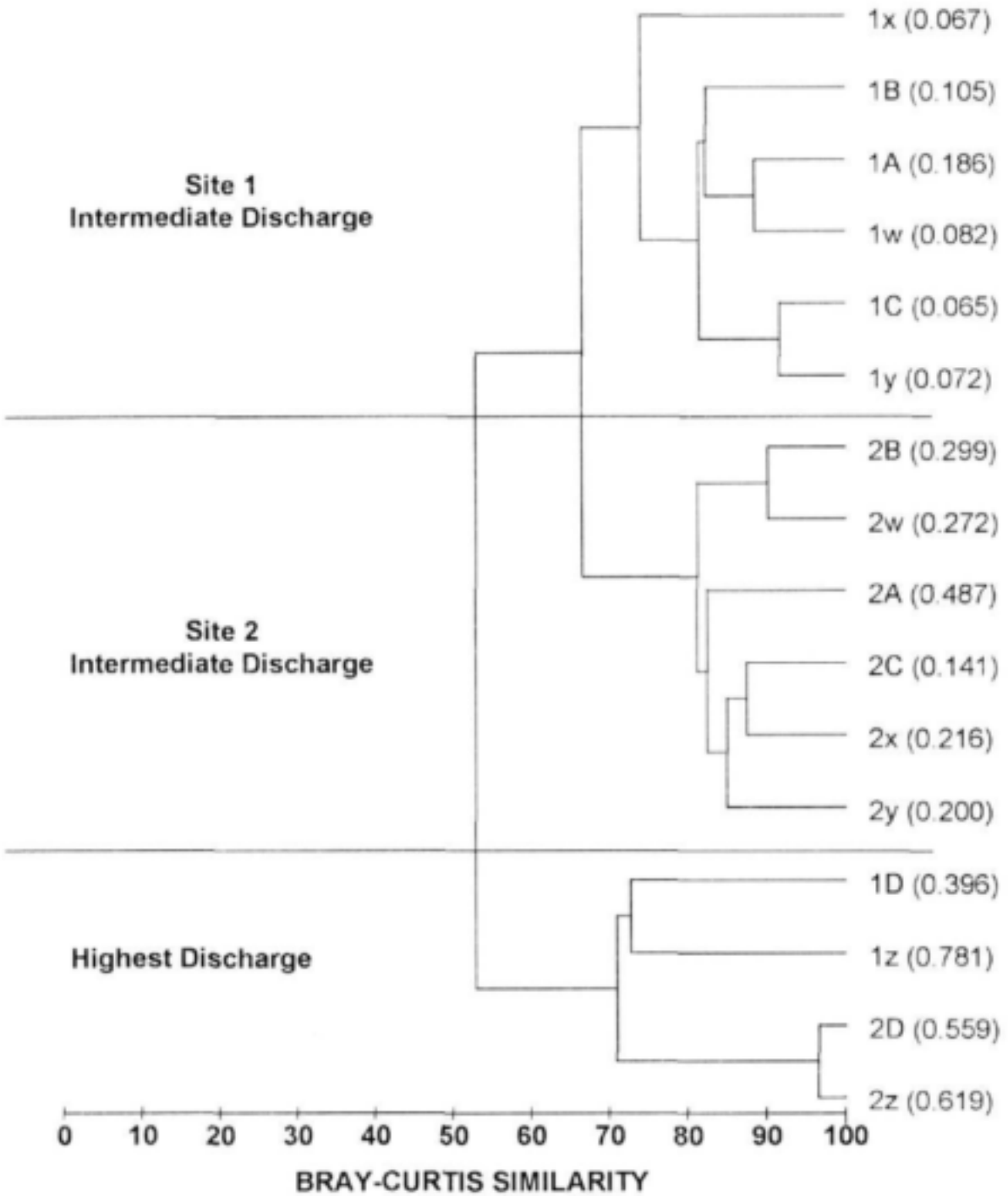


Figure 14.5 Dendrogram of flow-type and substrata combinations mapped at sites 1 and 2 on the Eerste River in spring 1997. Data codes for site and mapping times as in Table 14.1, with measured discharge ($m^3 s^{-1}$) in parentheses after each code.

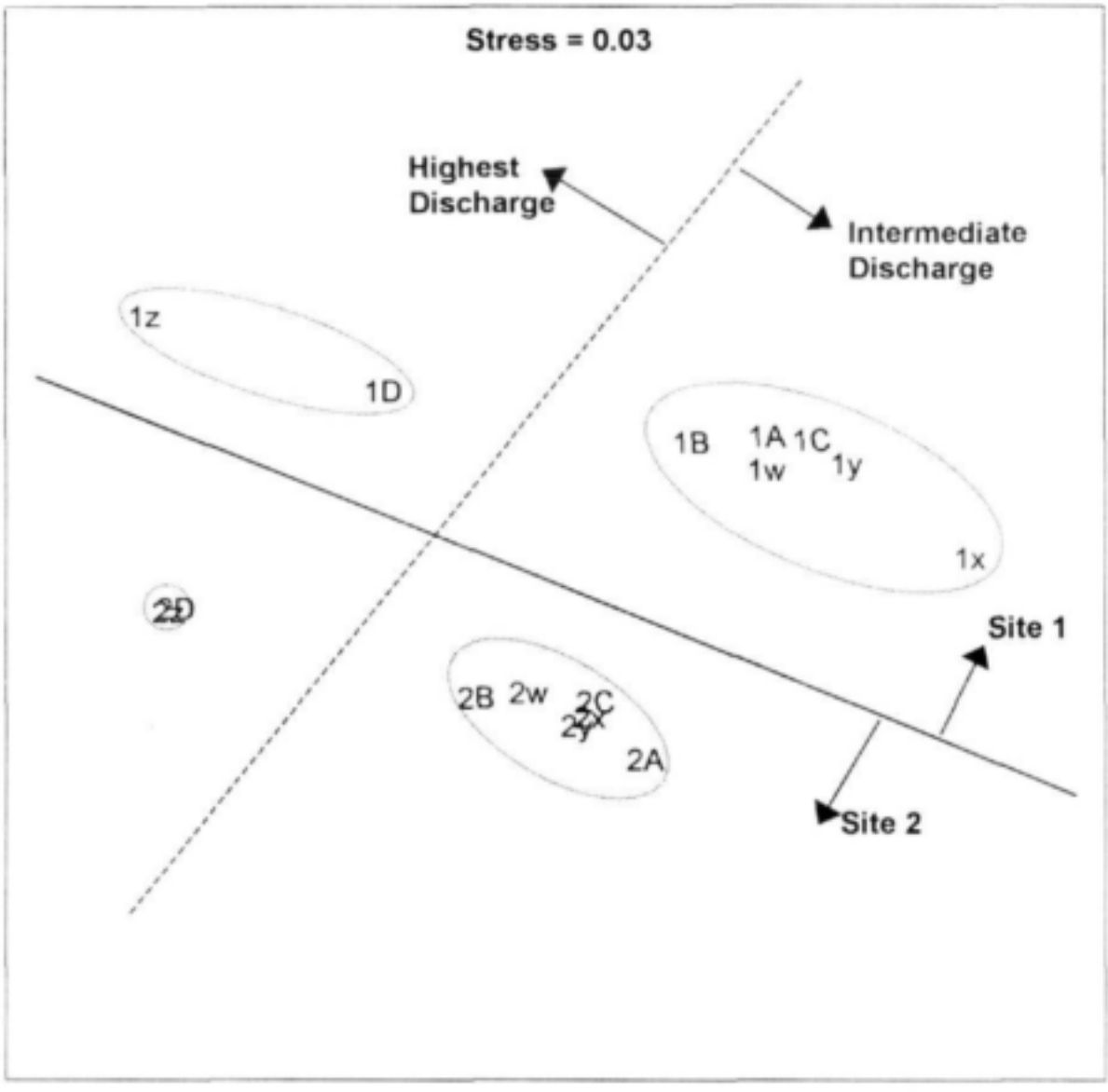


Figure 14.6 MDS plot of flow-type and substrata combinations mapped at sites 1 and 2 on the Eerste River in spring 1997. Data codes for site and mapping periods as in Table 14.1.

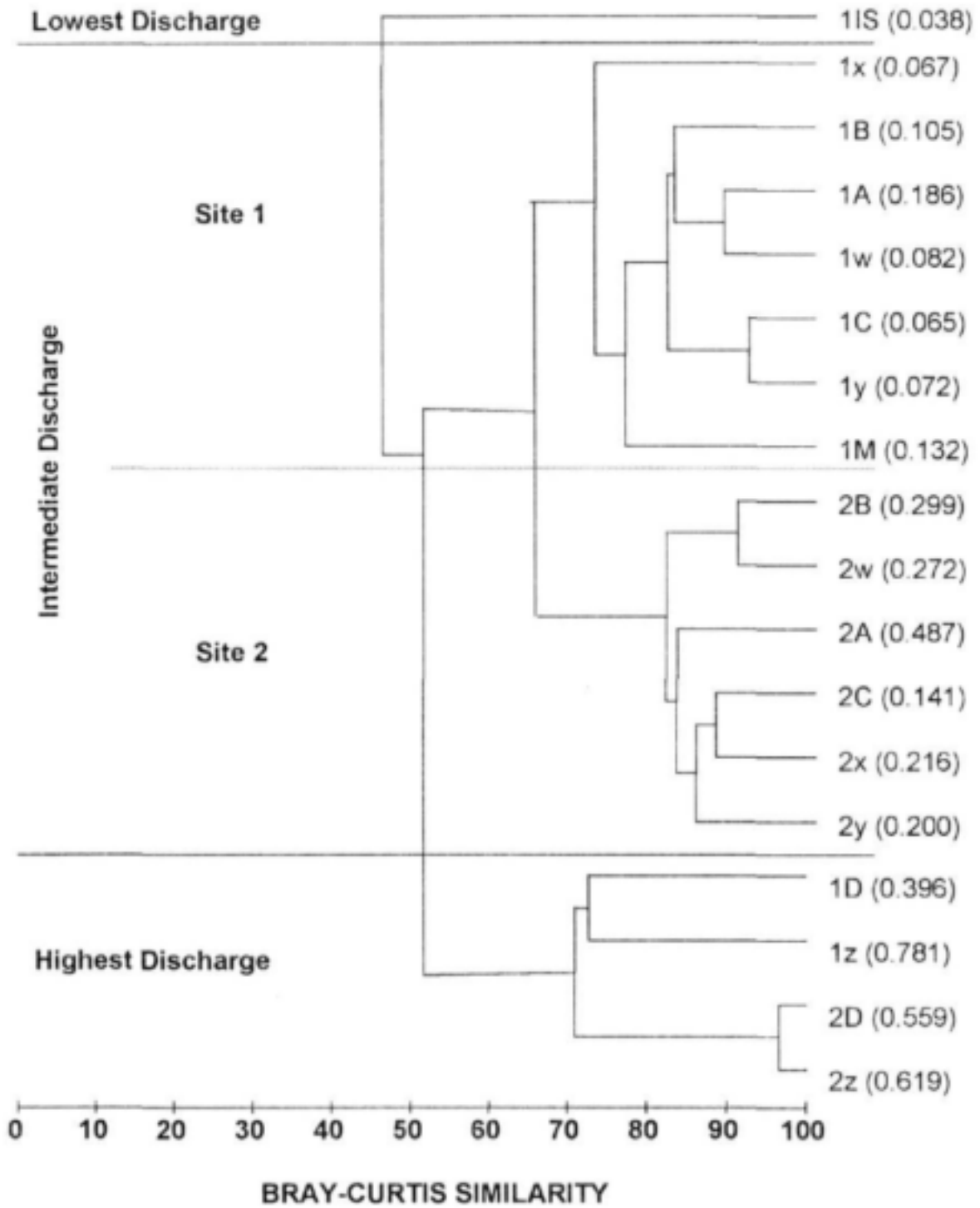


Figure 14.7 Dendrogram of flow-type and substrata combinations mapped at sites 1 and 2 on the Eerste River in summer and spring 1997. Data codes for site and mapping times as in Table 14.1, with measured discharges in parentheses after each code.

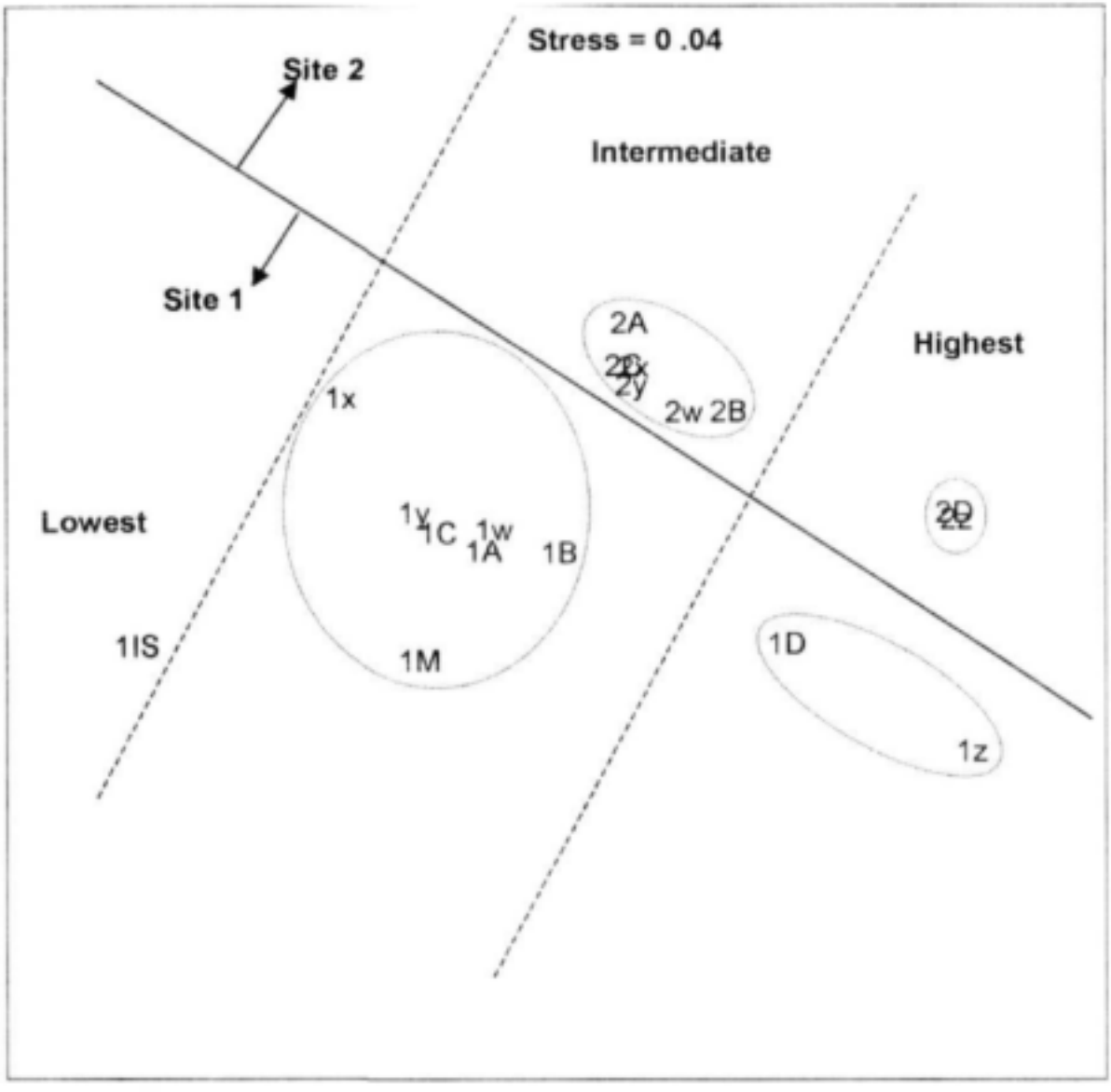


Figure 14.8 MDS plot of flow-type and substrata combinations mapped at sites 1 and 2 on the Eerste River in summer and spring 1997. *Data codes* for site and mapping times as in Table 14.1.

In general, wetted area and flow-type distributions are fairly stable with steady intermediate discharges and need a large shift, up or down, in discharge to effect an appreciable change. Taking the average of all discharges and wetted areas within each classified group (high or intermediate) and site, the percent change in discharge needed to change wetted area can be calculated. In order to increase the wetted area in site 1 by 24%, an 83% change in discharge was needed. For site 2, a change in discharge of 53% was needed to change the wetted area by 14%. Given there was only one low discharge event measured, and that was at one site, a comparison can not be made between the low and intermediate groups (as well as the total mapped area being less than that of the subsequent sites).

14.4 Physico-chemical and chemical comparisons between discharges and reaches

Temperature, pH and conductivity of the water at each site were recorded, as was air temperature. Overall, there was little measured difference in these variables between sites or sampling periods. Air temperature was also similar at both sites during each sampling period, but did show a continuous increase over the season. The pH at site 1 on three sampling occasions was consistent with the value on the first sampling date being slightly higher. The values at site 2 were also quite consistent but with the value at the last sampling occasion being lower. Although conductivity could not be measured during the last sampling period because of equipment failure the first three sampling dates showed a trend of increasing conductivity at both sites over time. Different sites had higher values on different days. Means are not presented for sampling period D (28 and 30 November) because all measurements were made on the same day.

Table 14.4 Physico-chemical and chemical variables, and air temperature, measurements for each sampling occasion and site. Codes as in Table 14.1. Readings taken over two days of sampling were averaged (sampling times: A, B and C) and means and standard deviations (SD) are given. Conductivity was not measured during sampling period "D".

	Site 1				Site 2			
	A	B	C	D	A	B	C	D
Variable	Mean ± SD	Mean ± SD	Mean ± SD		Mean ± SD	Mean ± SD	Mean ± SD	
Water Temperature (°C)	14.5 ± 0.7	11.5 ± 1.4	14.8 ± 3.2	16.0	15.0 ± 1.4	11.0 ± 2.1	14.8 ± 1.5	15.0
Conductivity (mS cm^{-1})	23.0 ± 7.0	23.9 ± 3.7	29.0 ± 5.9	-	22.4 ± 5.8	24.8 ± 2.1	26.0 ± 1.2	-
pH	5.8 ± 0.0	5.6 ± 0.05	5.6 ± 0.15	5.6	5.6 ± 0.07	5.8 ± 0.0	5.9 ± 0.08	5.3
Air Temperature (°C)	19.3 ± 6.0	22.0	26.0 ± 8.5	27.0	23.3 ± 1.8	20.5 ± 0.7	27.0 ± 2.8	29.0

14.5 Biological comparisons between discharges and reaches

14.5.1 Overall density and species comparisons

The invertebrate samples from sampling periods C and D (Table 14.1) are the only ones for which identifications have been completed to date. This preliminary analysis of invertebrate patterns is thus based on these two sets of data.

Invertebrate densities for each replicate sample within each reach were calculated from species counts. There was a decrease in sample densities of 46% (site 1) and 72% (site 2) from sampling period C to D (Table 14.5). There was not a consistent pattern as to which site had a greater number of animals. As shown in Chapter 13, site 2 had a greater number of animals than site 1 during sampling period C but in sampling period D site 1 had a higher density (Table 14.5).

Table 14.5 Number of samples (N), mean number (#) of animals per square meter and standard error (SE) for each site and each sampling period (data code as in Table 14.1).

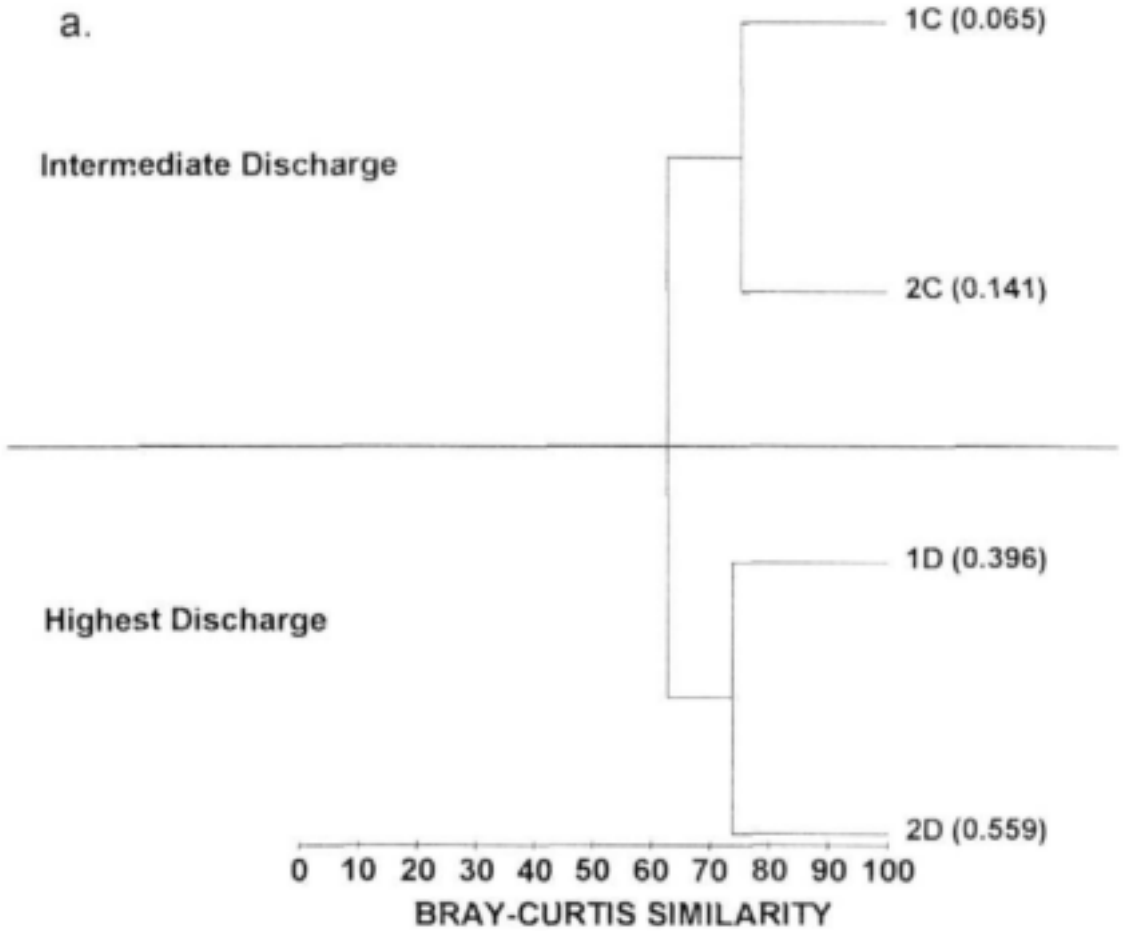
Site	Data Code	N	Mean # / m^2 ± SE
1	C	27	1 755 ± 306
1	D	18	944 ± 130
2	C	21	2 361 ± 409
2	D	18	654 ± 159

A general analysis of variance (ANOVA) on 4^{th} root transformed density data was run (Section 13.4), to reveal overall density patterns between sampling periods (discharge) and sites. Although there is no significant difference between invertebrate densities of each reach, there was a significant difference between the two sampled discharges, with a p-value of 0.0001 (Table 14.6). There was also no significant effect of site with discharge on overall invertebrate densities, $p = 0.076$ at a $p < 0.05$ level (Table 14.6).

Table 14.6 General ANOVA table examining the effect of reach, sampling period (discharge) and their interaction on invertebrate densities. d.f. = degrees of freedom, M.S.S. = mean sums of squares, F = test statistics and P = significance level, with an * denoting statistical significance at $p < 0.05$ level.

	d.f. effect	M.S.S. effect	d.f. error	M.S.S. error	F	P
Reach	1	0.003	80	1.857	0.004	0.948
Discharge*	1	29.673	80	1.857	15.975	0.0001
Interaction	1	6.005	80	1.857	3.233	0.076

In order to take individual species and their densities into account, the full set of data on species distributions (densities 4^{th} root transformed) was analysed for differences between sites (reaches) and discharges (sampling periods) using the agglomerative hierarchical clustering module CLUSTER in Primer. The dendrogram of the cluster analysis supports the ANOVA results (Figure 14.9a), showing a split between the invertebrate samples taken at the highest discharge and those taken at the intermediate discharges, with a 62% similarity. The MDS of the similarity analysis (Figure 14.9b) demonstrates a prominent dissimilarity between samples taken at the two discharges, and a less prominent separation by site. This is similar to the patterns exhibited by the flow/substrata cluster and MDS plots (Section 14.3).



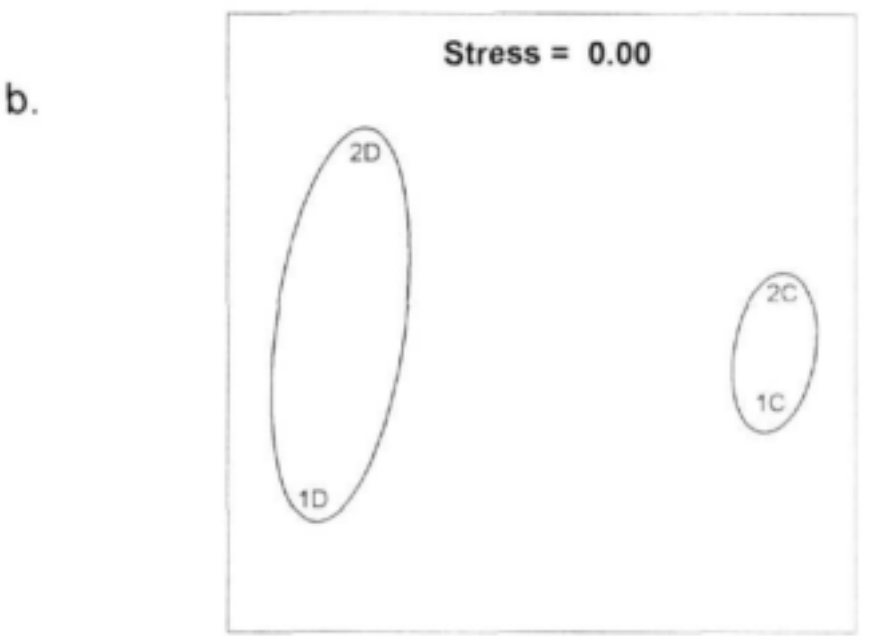


Figure 14.9 **a) Species-level dendrogram for each site and discharge, showing the split between the discharges (discharge in parenthesis after each data code). b) MDS plot.** Data codes for site and mapping times as in Table 14.1.

To include data from the IS sampling, a preliminary data standardisation exercise was completed, as invertebrate sampling methods (Section 4.5 and 13.2 for the later study) differed in these two studies. There were 52 samples and 18 different flow-type/substratum combinations sampled during the IS sampling period, but only five flow types and two substratum categories were used in the latter analysis. Thus, only samples using these categories were included from the latter study. Additionally, the IS sampling was qualitative rather than quantitative, requiring the invertebrate counts from sampling periods C and D to be converted to ratings (Chapter 11).

With this standardisation completed, the resulting dendrograms and MDS plots revealed that the sites clustered by discharge (sampling period) (Figure 14.10) as in the previous analysis. The IS sampling period at site 1 split off from the other two groups at approximately 53% similarity. The other two groups split from one another at 65% similarity, and were not site dependent, but rather discharge dependent. The MDS plot revealed that the invertebrate assemblage from the IS sampling period was less similar to those collected in the C and D sampling occasions than the latter were to each other. This may be because there is a seasonal difference being reflected as well as a difference in discharge. This seasonality aspect will be examined further in Ms. Schael's PhD thesis.

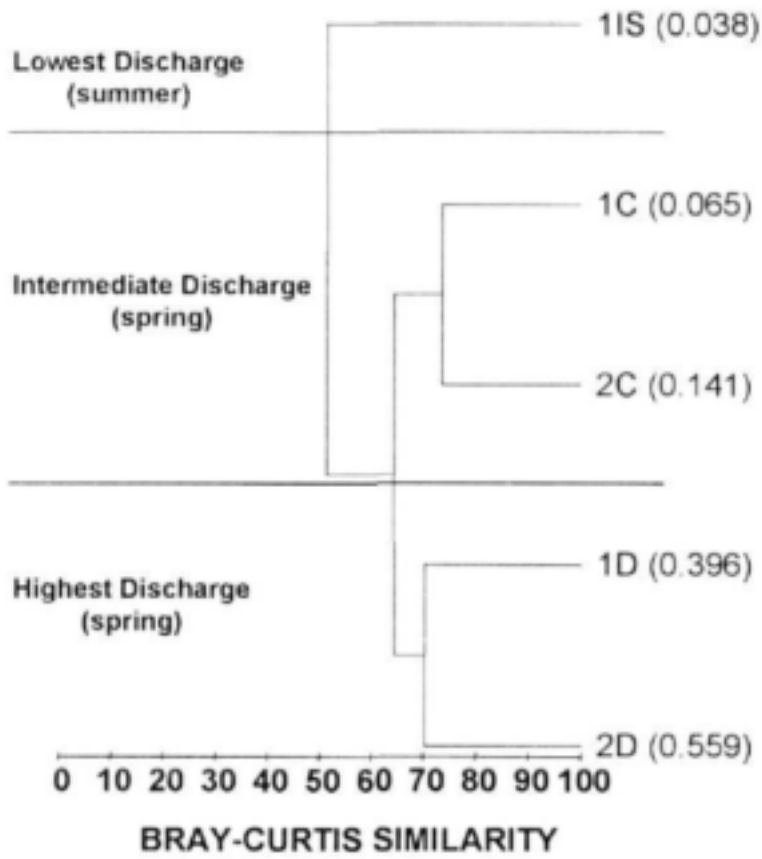
14.5.2 Hydraulic biotopes

The above analyses (Figures 14.9 and 14.10) combined all samples from a site, to represent each site at each sampling date in the analyses with a biological "fingerprint" or species assemblage. This is the same process as was used in Chapter 10 for the testing of biological zones, and is useful to display the overall differences between sampling periods (discharge) and sites. In order to examine the effect of sampling date and site on hydraulic biotopes, however, each sample was included separately in the next round of analyses.

The CLUSTER and MDS outputs revealed that the main split between samples was between hydraulically "fast" and "slow" conditions (Figure 14.11). This is the same result as seen in Chapter 13. All invertebrate samples taken from flow types BSW and USW, and some from RS, whether over boulder or large cobble regardless of sampling period or site, were in the "fast" group. Some taken from RS, and all those taken from BPF and SBT, over either substratum, were within the "slow" group. As in previous analyses at the hydraulic-biotope level (Chapters 11 and 13), the RS flow type occurred in both hydraulic groups, and appeared to be the most hydraulically varied of the flow types chosen for this study. Reference to the actual hydraulic measurements taken on each sampling occasion revealed that each RS in Figure 14.11 was in its appropriate "fast" or "slow" group (Table 14.7).

Within each main hydraulic group there were several sub-groups that could be identified as individual hydraulic biotopes (Figure 14.11). Twenty were recognised in total (Table 14.7): six were bio-rapids, five each were bio-riffles or bio-runs, and three were bio-pools and one a bio-run/pool transition. All of the bio-rapids and bio-riffles occurred in the hydraulically "fast" group, together with one bio-run. All of the bio-pools, and the majority of the bio-runs, were in "slow" group. The same hydraulic biotopes can be detected in the MDS plot, as can a general trend from "fast" hydraulic biotopes at bottom and left to "slow" ones at top and right (Figure 14.12). Ranges of depth and percentages of substrata (Table 14.8), and velocity and Froude number (Table 14.9), for each of the 20 hydraulic biotopes, are similar to those reported in Chapters 11 and 13 for described hydraulic biotopes.

a.



b.

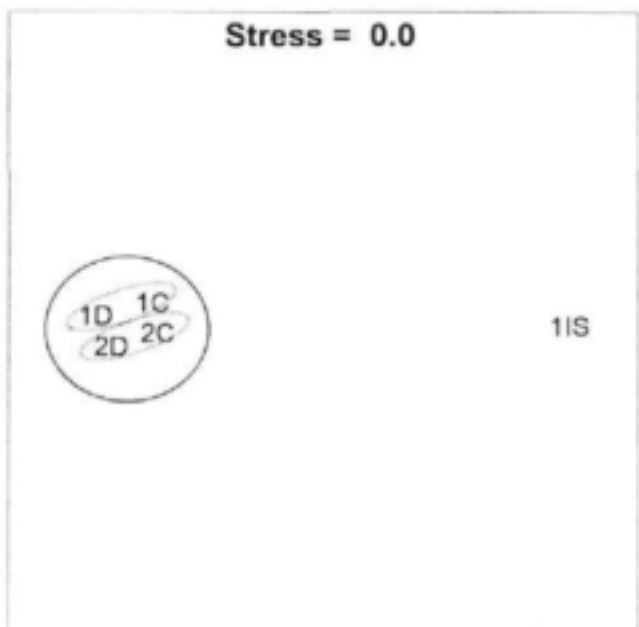


Figure 14.10 **a) Species-level dendrogram for each site and discharge, showing the split between the discharges (discharges in parenthesis after each data code. b) MDS plot.** Data codes for site and sampling times as in Table 14.1.

Mapped substrata areas represent the majority of substratum present in a particular part of the streambed, but it is recognised that there could be small areas within the main patch with different substratum types. Therefore, as stated in Section 13.2, a substratum grid was used at all sample points to determine the percentage of each substratum type present within the 0.5 x 0.5-m area. Table 14.8 reflects the local or micro-scale diversity of the substrata representing the sampling areas.

Table 14.7 **Hydraulic characteristics of the 20 groups of samples from both sites and two discharges on the Eerste River as recognised in Figure 14.11.** The sub-groups are recognised as biologically derived hydraulic biotopes. Site code (site number, data code, and sample number) and flow types are also given. Mean and standard deviation (SD) for the four readings taken within each sampling area are reported. Statistics given: depth (m); near-bed and mean water column (0.6) velocity (m s^{-1}); and Froude number.

Sub-group	Hydraulic Biotope	Site Code	Flow Type	Depth (m)		Near-bed		0.6		Froude Number	
				Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	Bio-riffle (boulder)	1C22	USW	0.31	0.10	0.12	0.11	0.26	0.02	0.155	0.022
		1D6	RS	0.29	0.04	0.01	0.01	0.03	0.02	0.018	0.010
		1D14	RS	0.22	0.19	0.10	0.06	0.15	0.02	0.166	0.031
		1D17	USW	0.56	0.06	0.30	0.02	0.39	0.09	0.167	0.028
		2D17	USW	0.21	0.08	0.28	0.17	0.31	0.28	0.222	0.200
		2D18	USW	0.43	0.02	0.12	0.03	0.17	0.02	0.083	0.010
2	Bio-rapid (boulder)	2D6	BSW	0.23	0.03	0.83	0.16	0.82	0.12	0.545	0.090
		2D11	BSW	0.13	0.04	0.35	0.24	0.40	0.10	0.377	0.130
		2D13	BSW	0.13	0.04	0.73	0.63	1.04	0.52	1.012	0.700
3	Bio-rapid (boulder)	2D2	BSW	0.37	0.09	0.56	0.45	0.98	0.26	0.530	0.181
		2D5	BSW	0.36	0.06	0.69	0.68	1.08	0.58	0.581	0.330
		2D9	USW	0.38	0.04	0.31	0.04	0.30	0.16	0.154	0.081
4	Bio-rapid (boulder)	1D1	USW	0.27	0.04	0.42	0.13	0.58	0.06	0.354	0.033
		1D2	BSW	0.22	0.04	0.28	0.24	0.76	0.23	0.542	0.215
		1D4	BSW	0.18	0.04	0.52	0.25	0.76	0.13	0.592	0.168
		1D5	USW	0.32	0.06	0.06	0.08	0.13	0.08	0.073	0.045
		1D11	USW	0.44	0.06	0.13	0.20	0.35	0.28	0.177	0.149
		1D12	BSW	0.34	0.11	0.33	0.38	0.65	0.19	0.383	0.186
		1D18	BSW	0.47	0.03	0.02	0.04	0.48	0.10	0.224	0.053
		2D10	USW	0.19	0.05	0.43	0.22	0.34	0.13	0.242	0.072
5	Bio-rapid (boulder)	1C19	BSW	0.20	0.10	0.55	0.20	0.48	0.09	0.369	0.094
		2C10	BSW	0.20	0.04	0.77	0.24	0.52	0.14	0.382	0.123
		2C15	BSW	0.15	0.02	0.26	0.15	0.34	0.06	0.291	0.069
6	Bio-run (cobble)	2C2	RS	0.43	0.05	0.14	0.09	0.22	0.08	0.107	0.038
		2C8	RS	0.16	0.03	0.05	0.03	0.08	0.04	0.059	0.031
7	Bio-rapid (boulder)	1C2	BSW	0.16	0.05	0.24	0.15	0.24	0.18	0.203	0.172
		1C5	BSW	0.17	0.05	0.35	0.44	0.49	0.35	0.424	0.379
		1C6	BSW	0.10	0.03	0.36	0.15	0.46	0.12	0.464	0.086
		1C8	BSW	0.07	0.01	0.99	0.38	1.01	0.36	1.246	0.527
		1C11	USW	0.21	0.04	0.17	0.11	0.32	0.10	0.226	0.080
		2C3	BSW	0.35	0.05	0.49	0.22	0.87	0.07	0.472	0.025
		2C4	USW	0.23	0.06	0.19	0.37	0.59	0.26	0.416	0.232
		2C5	BSW	0.09	0.04	0.28	0.10	0.43	0.14	0.475	0.114
		2C6	BSW	0.24	0.04	0.38	0.25	0.36	0.26	0.244	0.186
		2C11	BSW	0.15	0.04	0.17	0.14	0.32	0.18	0.274	0.168
8a	Bio-riffle (cobble)	1C1	USW	0.08	0.02	0.20	0.17	0.22	0.17	0.262	0.199
		1C3	RS	0.20	0.04	0.05	0.06	0.10	0.06	0.074	0.048
		1C4	USW	0.25	0.01	0.42	0.10	0.49	0.09	0.312	0.063
		1C10	USW	0.09	0.03	0.30	0.11	0.31	0.10	0.359	0.154
		1C16	BSW	0.11	0.04	0.35	0.14	0.44	0.11	0.442	0.136
		2C12	USW	0.30	0.04	0.23	0.05	0.28	0.03	0.163	0.018

Sub-group	Hydraulic Biotope	Site Code	Flow Type	Depth (m) Mean	Depth (m) SD	Near-bed Mean	Near-bed SD	0.6 Mean	0.6 SD	Froude Number Mean	Froude Number SD
8b	Bio-riffle (cobble)	2C7	USW	0.17	0.04	0.09	0.10	0.16	0.11	0.132	0.096
		2C9	USW	0.20	0.01	0.18	0.04	0.30	0.02	0.213	0.013
		2C13	USW	0.30	0.03	0.07	0.04	0.16	0.05	0.095	0.028
		2D12	USW	0.45	0.04	0.26	0.24	0.56	0.09	0.264	0.038
9	Bio-riffle (cobble)	1D3	USW	0.27	0.03	0.05	0.06	0.08	0.10	0.050	0.058
		1D15	RS	0.27	0.03	0.06	0.02	0.09	0.05	0.057	0.026
		1D16	RS	0.15	0.02	0.09	0.03	0.11	0.01	0.090	0.016
		2D3	RS	0.46	0.01	0.04	0.01	0.12	0.03	0.054	0.014
		2D4	RS	0.48	0.02	0.19	0.06	0.16	0.06	0.075	0.027
10	Bio-rapid (cobble)	1D13	BSW	0.16	0.04	0.16	0.14	0.18	0.13	0.141	0.096
		2D7	BSW	0.18	0.05	0.35	0.30	0.53	0.26	0.442	0.319
11	Bio-riffle (cobble)	1C18	USW	0.17	0.09	0.12	0.11	0.15	0.10	0.143	0.116
		1D7	BSW	0.14	0.04	0.56	0.21	0.61	0.25	0.515	0.186
		1D8	RS	0.18	0.02	0.13	0.03	0.22	0.04	0.167	0.022
		1D9	USW	0.18	0.03	0.27	0.06	0.35	0.04	0.263	0.046
		1D10	RS	0.54	0.03	0.29	0.08	0.34	0.03	0.149	0.016
		2D8	RS	0.29	0.06	0.15	0.08	0.20	0.04	0.120	0.029
12	Bio-riffle (cobble)	2C16	RS	0.29	0.04	0.24	0.03	0.30	0.02	0.182	0.011
		2D15	USW	0.61	0.01	0.14	0.05	0.21	0.09	0.086	0.038
13	Bio-pool (boulder)	1C7	BPF	0.15	0.03	0.03	0.01	0.05	0.01	0.038	0.006
		1C12	BPF	0.12	0.04	0.01	0.01	0.02	0.01	0.022	0.004
14	Bio-run (boulder)	2C17	BPF	0.43	0.02	0.13	0.01	0.14	0.02	0.067	0.009
		2C18	BPF	0.42	0.05	0.09	0.01	0.11	0.02	0.053	0.013
		2D14	RS	0.48	0.02	0.13	0.03	0.17	0.05	0.078	0.024
15	Bio-run (boulder)	1C20	RS	0.29	0.02	0.13	0.02	0.21	0.04	0.123	0.022
		1C21	BPF	0.16	0.15	0.03	0.03	0.05	0.03	0.051	0.046
16	Bio-pool (boulder)	1C23	SBT	0.41	0.03	0.04	0.01	0.06	0.01	0.029	0.005
		2C1	RS	0.28	0.01	0.00	0.01	0.01	0.01	0.005	0.006
		2D1	RS	0.20	0.02	0.00	0.01	0.03	0.01	0.020	0.010
17	Bio-pool (cobble)	1C14	BPF	0.41	0.01	0.02	0.01	0.05	0.01	0.025	0.007
		1C15	BPF	0.24	0.05	0.03	0.01	0.04	0.01	0.025	0.009
		1C27	RS	0.34	0.02	0.05	0.01	0.14	0.02	0.079	0.012
18	Bio-run (boulder)	1C17	SBT	0.28	0.07	0.07	0.01	0.09	0.01	0.058	0.013
		1C24	RS	0.41	0.06	0.06	0.03	0.12	0.01	0.062	0.008
		1C25	SBT	0.43	0.07	0.02	0.01	0.03	0.00	0.014	0.003
		2C19	RS	0.20	0.03	0.11	0.03	0.15	0.01	0.105	0.016
19	Bio-run/pool (boulder)	1C13	RS	0.34	0.08	0.06	0.06	0.14	0.05	0.082	0.040
		2C14	BPF	0.11	0.03	0.01	0.01	0.02	0.01	0.019	0.005
		2C20	RS	0.44	0.05	0.13	0.05	0.18	0.02	0.085	0.016
20	Bio-run (boulder)	1C9	BPF	0.22	0.07	0.03	0.00	0.05	0.01	0.033	0.003
		1C26	RS	0.50	0.08	0.07	0.05	0.14	0.05	0.061	0.019
		2C21	USW	0.32	0.05	0.10	0.01	0.16	0.01	0.090	0.012
		2D16	RS	0.47	0.02	0.08	0.06	0.14	0.01	0.065	0.008

//Table 14.7 continued.

Although there is not an overwhelmingly strong pattern of site and discharge (sampling period) groupings in the overall pattern (Figure 14.11), there is a pattern within each hydraulic biotope (Tables 14.8 and 14.9). Of the twenty sub-groups, eight were from one site and seven had all but one of its samples from one site. Thus, in total, 15 hydraulic biotopes had a strong affiliation to one of the two sites. The link between hydraulic biotopes and sampling period was stronger, with 13 hydraulic biotopes linked to solely to one discharge, five predominantly representing one discharge but containing a sample from another discharge and only one with no particular affiliation. Hydraulic biotopes from the "slow" group were all classified as linked to sampling period C, as there were only three samples from period D within the "slow" group as a whole. Overall, there were few samples in the hydraulically slower group, as SBT and BPF flow types either disappeared with the higher discharge from sampling period D or did not cover sufficiently large areas to allow sampling (Section 13.2).

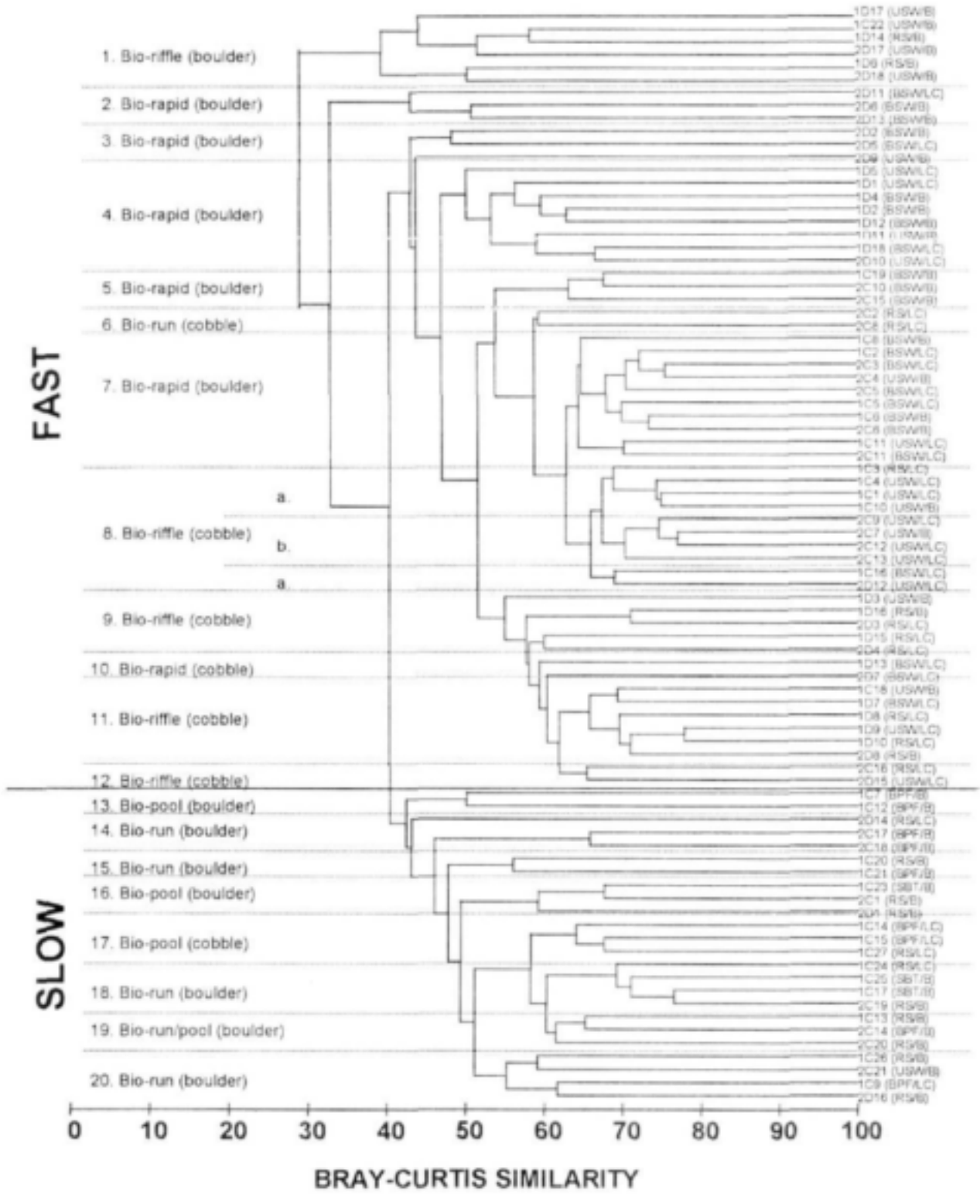


Figure 14.11 Species-level dendrogram for individual samples at the two sites. The solid line represents the split between the "fast" and "slow" hydraulic conditions. Data codes for site and sampling periods as in Table 14.1 and sample point number as in Table 14.7. Flow/substratum (defined in Tables 2.3 and 2.4) combinations are in parenthesis after reach sample code.

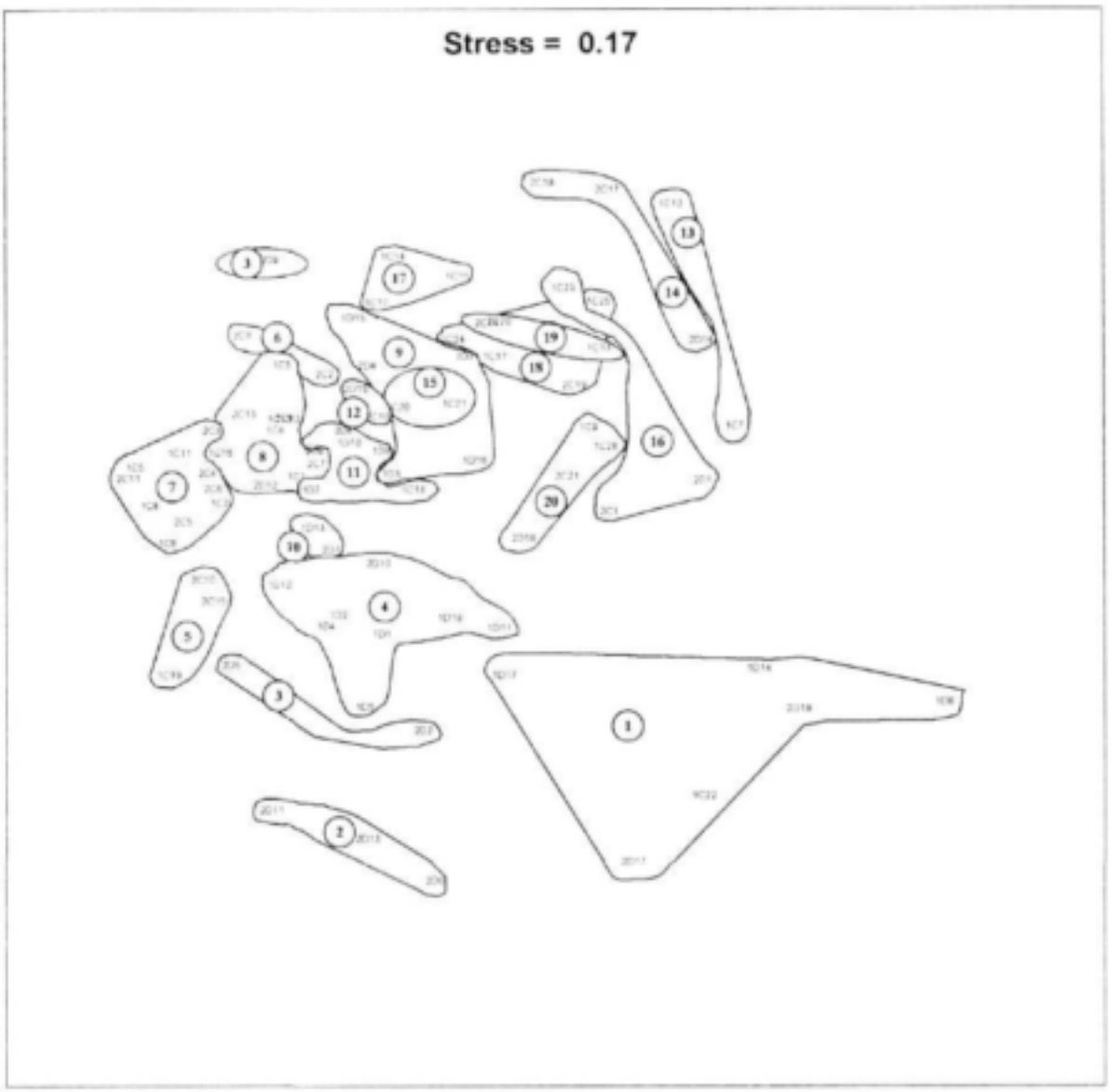


Figure 14.12 Species-level MDS for individual samples at the two sites. Data codes for site and mapping times as in Table 14.1 with the attachment of sampling point number (Table 14.7).

Table 14.8 Summary statistics for each group of samples recognised in Table 14.7: range, mean and standard deviation (SD) of depth and percent composition of substrata. The statistics are listed by hydraulic biotope, sub-group number, site representation, discharge code (Q), and number of samples (N) within each hydraulic biotope. Depth data calculated from the means in Table 14.7. Substratum averages from all contributions within the group. Site and discharge (Q) designation are based on group composition; "none" means that sites or discharges were equally represented in the sub-group; * denotes that the majority of the samples were from that site or discharge, but that one sample in the sub-group was from the other site or discharge. Substrata codes as in Table 2.4.

Hydraulic Biotope	Sub-group	Site	Q	N	Depth (m) Range	Mean	SD	B	Substrata % LC	SC	LG	SG	SA
Bio-pool (boulder)	13	1	C	2	0.12 – 0.15	0.13	0.02	98	2	0	0	0	0
Bio-pool (boulder)	16	2*	C*	3	0.20 – 0.41	0.29	0.11	73	20	5	0	0	1
Bio-pool (cobble)	17	1	C	3	0.20 – 0.41	0.33	0.08	20	49	24	5	1	0
Bio-rapid (boulder)	2	2	D	3	0.13 – 0.23	0.16	0.06	79	9	11	1	0	0
Bio-rapid (boulder)	3	2	D	3	0.36 – 0.38	0.37	0.01	75	15	3	5	3	0
Bio-rapid (boulder)	4	1*	D	8	0.18 – 0.47	0.30	0.11	58	24	11	6	3	0
Bio-rapid (boulder)	5	2*	C	3	0.15 – 0.20	0.18	0.03	85	3	9	3	0	0
Bio-rapid (boulder)	7	none	C	10	0.07 – 0.35	0.18	0.08	40	38	12	9	1	0
Bio-rapid (cobble)	10	none	D	2	0.16 – 0.18	0.17	0.01	30	44	16	8	2	0
Bio-riffle (boulder)	1	none	D	6	0.21 – 0.56	0.33	0.13	88	2	7	3	0	0
Bio-riffle (cobble)	8a	1*	C*	6	0.08 – 0.30	0.17	0.09	13	47	25	8	7	0
Bio-riffle (cobble)	8b	2	C	4	0.17 – 0.45	0.28	0.13	26	29	28	15	2	0
Bio-riffle (cobble)	9	none	D	5	0.15 – 0.48	0.32	0.14	34	31	20	10	2	2
Bio-riffle (cobble)	11	1*	D*	6	0.14 – 0.54	0.25	0.15	29	29	21	16	3	2
Bio-riffle (cobble)	12	2	none	2	0.29 – 0.61	0.45	0.23	34	52	10	4	0	0
Bio-run (boulder)	14	2	C*	3	0.42 – 0.48	0.44	0.03	55	25	8	3	9	0
Bio-run (boulder)	15	1	C	2	0.16 – 0.29	0.23	0.10	76	16	4	4	0	0
Bio-run (boulder)	18	1*	C	4	0.20 – 0.43	0.33	0.11	62	21	13	4	0	0
Bio-run (boulder)	20	none	C*	4	0.22 – 0.50	0.38	0.13	86	2	6	6	0	0
Bio-run (cobble)	6	2	C	2	0.16 – 0.43	0.30	0.19	28	40	32	0	0	0
Bio-run/pool (boulder)	19	2*	C	3	0.11 – 0.44	0.30	0.17	67	18	14	1	0	0

14.6 Conclusions

14.6.1 Changes in physical hydraulic conditions with discharge

Overall, during the relatively low-flow conditions during this study, it required a major change in discharge to significantly change the wetted area and hydraulic conditions. This held equally true for both reach types studied. Flow-type proportions remained steady over a range of similar discharges and only shifted when discharges changed by 84 to 53% (sites 1 and 2 respectively). The shifts in flow-type proportions were fairly site specific, with the more specialised (chute, free fall, trickle, etc.) flow-types being more dominant and widespread in site 1 and very rare in site 2 (Figure 14.3 and Table 14.2).

Table 14.9 **Summary statistics for each group of samples recognised in Table 14.7: ranges, means and standard deviations (SD) of near-bed and mean-column (0.6) velocity (m s^{-1}) and Froude number.** These statistics are listed by hydraulic biotope, sub-group number, site representation, discharge code (Q), and number of samples (N) within each hydraulic biotope. Four individual sites of velocity measurements were made within the area where each invertebrate sample was collected. The means of these values are given in Table 14.7. The values in this summary table are the ranges, means and standard deviations of these means. Site and discharge (Q) designation are based on group composition; "none" means that sites or discharges were equally represented in the sub-group; * denotes that the majority of the samples were from that site or discharge, but that one sample in the sub-group was from the other site or discharge.

Hydraulic Biotope	Sub-group	Site	Q	N	Near-bed Velocity (m s^{-1})			Mean (0.6) Velocity (m s^{-1})			Froude Number		
					Range	Mean	SD	Range	Mean	SD	Range	Mean	SD
Bio-pool (boulder)	13	1	C	2	0.01 – 0.03	0.02	0.01	0.02 – 0.05	0.03	0.02	0.022 – 0.038	0.030	0.012
Bio-pool (boulder)	16	2*	C*	3	0.00 – 0.04	0.01	0.02	0.01 – 0.06	0.03	0.03	0.005 – 0.029	0.018	0.012
Bio-pool (cobble)	17	1	C	3	0.02 – 0.05	0.03	0.01	0.04 – 0.14	0.08	0.06	0.025 – 0.079	0.043	0.031
Bio-rapid (boulder)	2	2	D	3	0.35 – 0.83	0.63	0.25	0.40 – 1.04	0.75	0.32	0.377 – 1.012	0.645	0.329
Bio-rapid (boulder)	3	2	D	3	0.31 – 0.69	0.52	0.19	0.30 – 1.08	0.79	0.42	0.154 – 0.581	0.421	0.233
Bio-rapid (boulder)	4	1*	D	8	0.02 – 0.52	0.27	0.18	0.34 – 0.76	0.51	0.22	0.073 – 0.592	0.324	0.179
Bio-rapid (boulder)	5	2*	C	3	0.26 – 0.77	0.53	0.25	0.34 – 0.52	0.45	0.09	0.291 – 0.382	0.348	0.049
Bio-rapid (boulder)	7	none	C	10	0.17 – 0.99	0.36	0.24	0.42 – 1.01	0.51	0.25	0.203 – 1.246	0.444	0.302
Bio-rapid (cobble)	10	none	D	2	0.16 – 0.35	0.25	0.14	0.18 – 0.53	0.35	0.24	0.141 – 0.442	0.292	0.213
Bio-riffle (boulder)	1	none	D	6	0.01 – 0.30	0.16	0.11	0.03 – 0.39	0.22	0.13	0.018 – 0.222	0.135	0.073
Bio-riffle (cobble)	8a	1*	C*	6	0.05 – 0.42	0.26	0.13	0.10 – 0.49	0.31	0.14	0.074 – 0.442	0.269	0.134
Bio-riffle (cobble)	8b	2	C	4	0.07 – 0.26	0.15	0.09	0.16 – 0.56	0.29	0.19	0.095 – 0.264	0.176	0.077
Bio-riffle (cobble)	9	none	D	5	0.04 – 0.19	0.09	0.06	0.06 – 0.16	0.11	0.03	0.050 – 0.090	0.065	0.017
Bio-riffle (cobble)	11	1*	D*	6	0.12 – 0.56	0.25	0.17	0.15 – 0.61	0.31	0.17	0.120 – 0.515	0.226	0.150
Bio-riffle (cobble)	12	2	none	2	0.14 – 0.24	0.19	0.07	0.21 – 0.30	0.26	0.07	0.086 – 0.182	0.134	0.067
Bio-run (boulder)	14	2	C*	3	0.09 – 0.13	0.12	0.02	0.11 – 0.17	0.14	0.03	0.053 – 0.078	0.066	0.012
Bio-run (boulder)	15	1	C	2	0.03 – 0.13	0.08	0.07	0.05 – 0.21	0.13	0.11	0.051 – 0.123	0.087	0.051
Bio-run (boulder)	18	1*	C	4	0.02 – 0.11	0.06	0.04	0.03 – 0.15	0.10	0.05	0.014 – 0.105	0.060	0.037
Bio-run (boulder)	20	none	C*	4	0.03 – 0.10	0.07	0.03	0.05 – 0.16	0.12	0.05	0.033 – 0.090	0.062	0.023
Bio-run (cobble)	6	2	C	2	0.05 – 0.14	0.10	0.06	0.08 – 0.22	0.15	0.10	0.059 – 0.107	0.083	0.034
Bio-run/pool (boulder)	19	2*	C	3	0.01 – 0.13	0.07	0.06	0.02 – 0.18	0.11	0.08	0.019 – 0.085	0.062	0.037

The same pattern occurred with flow/substrata proportions, with a more site specific pattern emerging (Figures 14.5 - 14.8). This pattern reflected difference in proportions of large cobble and boulder over which the different flow-types were recorded. Site 1 tended to have more boulder over all (Section 13.3), however site 2 had a greater proportion of wetted boulders (smaller boulder material and deeper channel) with three main flow types, RS, USW and BSW than did site 1, which had a more even spread (Figure 14.4).

Future analyses in Ms. Schael's PhD will focus on micro scale patterns of these flow/substrata combinations, through studies of the digitised site maps (e.g. Figures 7.4-7.6). A number of flow/substratum patches will be tracked over time to see how resilient each physical patch is, how long it retains its shape and position within the site, and which changes in discharge or other measured hydraulic variables cause it to shift to another flow type. Flow duration curves and time-series analysis of daily hydrological data will also be completed and linked to the results from the study reported in this chapter, to illustrate the proportion and individual spells of time that the measured conditions are likely to prevail in the sites. Until these analyses are completed, conclusions cannot be drawn on the discharge-related behaviour of individual hydraulic patches within the mosaic of the site, but only on the site as a whole.

14.6.2 Changes in invertebrate densities and species assemblages with discharge

Overall invertebrate densities decreased between sampling periods C and D within both sites. There was a significant effect of sampling time, which is linked to discharge that suggests that the increase of flow during the last sampling periods shifted the numbers of animals. Examining the species composition or "fingerprint" of each site, the importance of this discharge change is also evident. When examining each sample in the context of hydraulic biotopes the pattern remained similar to that of the reach comparison in Chapter 13 where hydraulic preferences superseded affinities to site or discharge. At this point in the analyses it can not be pointed out if animals moved from one area to another due to shifts in local hydraulics (Section 14.6.3), but that there were overall species assemblage shifts.

14.7 Future analyses

Not all of the biological data have been analysed to date, so conclusions can only be based on these two sampling periods. These represented the lowest and highest measured discharges, and revealed a clear pattern of differences both in overall invertebrate densities (Tables 14.5 and 14.6) and species structure (Figure 14.9). The two remaining sampling occasions should show similar results to sampling period C, as the discharges were similar. The report on this will form part of Ms. Schael's PhD.

The implications of hydraulic biotopes (and thus the invertebrate assemblages defining them) identifying with one discharge and, to a lesser extent, one site, requires further careful analysis and thought. Where do the invertebrates from "slow" hydraulic biotopes go in high flows if they do not remain in the "fast" hydraulic biotopes that replace the slow ones? The data suggest that, because the biotas define the hydraulic biotopes, when the slow-flow HBs disappear, so by definition do the slow-flow invertebrates. But is this so, or are they still there, masked by the fast-flow species moving into the area? This can only be answered by tracking the fate of individual species types through the series of samples, as will be done in Ms Schael's PhD thesis.

15. IMPACTS OF ANTHROPOGENIC DISTURBANCE

15.1 Recap

The fifth aim listed for this project (Section 3.6) was to search for trends in the ways that anthropogenic (man-made) disturbances of rivers alter the river ecosystems. Re-iterating Section 3.6, it was suggested that such disturbances could alter the distribution and proportions of hydraulic biotopes, species assemblages, and possibly even of morphological units, away from the ranges recorded for least-disturbed sites. Physical disturbance might result in persistence of the original species assemblage of invertebrates, but in some depauperate form, with few new species. Chemical disturbance, on the other hand, might leave the basic morphological structure intact, but change the overall chemical environment. It could, however, also change physical microhabitat conditions by, for instance, covering rocky-bed elements with algae. Thus, in several ways and depending on its severity, chemical disturbance could change the faunal assemblage, with a loss of original species and either addition of new pollution-tolerant species or, in toxic situations, no additional species. Some other disturbances, such as dams and infestation by alien trees, could provide additional impacts, by changing the river's flow and temperature regimes, destabilising banks, or changing the dynamics of sediment transport.

Within this project it was not possible to investigate the full array of disturbances present in Western Cape rivers. Instead, ten river sites were identified that are within the same bio-region and longitudinal zones as the least-disturbed rivers (Table 5.1), and that had single specific disturbances. The disturbances included bulldozing of the river bed, dams, alien trees and agriculture (Table 15.1). Eight of the sites were within catchments or catchment groups already represented by the least-disturbed rivers (*Olifants*: disturbed river numbers 3, 4 and 5; *Breede*: number 12; *Berg*: number 16; *Palmiet*: number 23; and *Table Mountain*: numbers 26 and 28). Two of the sites were on short rivers (numbers 22 and 25) with their own estuaries.

Table 15.1 Summary of the ten disturbed river sites used in the investigation, and their major anthropogenic disturbances. For more details, see Table 5.1.

River #	River Name	Catchment	Disturbance
3	Noordhoek	Olifants	Bulldozed river bed and banks
4	Middeldeur	Olifants	Agriculture – upstream nutrient enrichment
5	Grootrivier	Olifants	Agriculture – upstream nutrient enrichment
12	Holsloot	Breede	Upstream dam –continual hypolimnetic release with thermal modification to very cold water
16	Wemmershoek	Berg	Upstream dam – no flow in dry season except from minor tributaries. Site bulldozed after sampling – MUs eradicated before mapped.
22	Lourens	Lourens	Orchards, piggery, disturbed banks with alien trees
23	Palmiet	Palmiet	Upstream dams and weirs
25	Davidskraal	Davidskraal	Upstream dam, downstream weir, retaining walls at site
26	Window	Table Mountain	Botanical garden
28	Cecilia	Table Mountain	Alien trees *Populus canescens*, with much woody debris and little surface flow

Abiotic and biotic data were collected and analysed as per Chapter 4, with field mapping and sampling done in the 1997/98 summer low-flow season.

15.2 Biologically-defined groups of sites, with disturbed rivers included

The CLUSTER module in PRIMER, used for grouping the least-disturbed sites (Section 10.2), was re-run with the ten disturbed sites included. The catchment groupings were the same as for the least-disturbed rivers (Figure 10.4), with the Olifants/Berg group separating off first, followed by the Table Mountain streams and then the Breede and the Eerste/Molenaars groups, and lastly the single river from the Palmiet catchment (the Dwars) (Figure 15.1). Overlaid on this pattern, however, was the distribution of the disturbed rivers: four grouped within established catchment groups whilst the other six formed two 'outliers groups'.

Two of the rivers that entered an established group were in the appropriate catchment from a geographical perspective: the Groot appeared with the other Olifants rivers and Window with the other Table Mountain rivers. The two short rivers appeared in two other established groups: the Lourens with the Breede rivers, and the Davidskraal with the Eerste/Molenaars rivers. Neither of these link-ups was with the geographically nearest catchment, which for the Lourens is the Eerste, and for Davidskraal is the Palmiet (Figure 5.1). It is not understood why they joined these catchment groups. The matter is discussed further in Chapter 20.

Three of the four rivers just mentioned (Groot, Lourens, Davidskraal), were among the least similar within their adopted groups, lying between the bedrock and alluvial rivers or near the group outliers. These three rivers were recognised as having agricultural disturbance (Groot, Lourens) and a dam and retaining walls (Davidskraal). Both the Groot and the Lourens sites had approximately natural size channels, and flow regimes that were somewhat modified but that remained perennial with close-to-normal flooding. Their main impacts were from upstream nutrient inputs and bank disturbance. The Davidskraal site had a major dam directly upstream releasing little flow, retaining walls through the site, and a downstream weir that pushed settled fine sediments back into the site. Judging from the invertebrates present, its water quality appeared good, though the dam must have had thermal impacts. The fourth river that joined an established group (Window) runs through Kirstenbosch Botanical Gardens. It has a low level of disturbance of its banks and a near-natural channel width and morphology. From its position well within the Table Mountain group (Figure 15.1), it appears less impacted than the others.

Though set apart from the main groups of least-disturbed rivers, the two outlier groups of disturbed rivers were not necessarily less similar to them than the main groups were to each other. Disturbed Group 1 was more similar to the Eerste/Molenaars and Breede groups (33% similarity) than were the Table Mountain (32%) and Olifants/Berg (27%). It contained rivers with dams (Wemmershoek – B16, Palmiet – P23), agriculture (Middeldeur – O04) and a bulldozed bed (Noordhoek – O03). The Wemmershoek site received no water from its upstream reaches unless Wemmershoek Dam was spilling, but flow from three minor tributaries (Bakkerskloof – river B14 and Zachariashoek – river B15 and one other). It had collapsing banks, extensive sandy deposits on its cobble bed, and appeared to have been widened with a berm and loss of riparian trees on the left bank. The Palmiet site was downstream of one dam (Nuweberg Dam) and agricultural areas, and had recently burnt. It had a bedrock channel that appeared unmodified, and its main

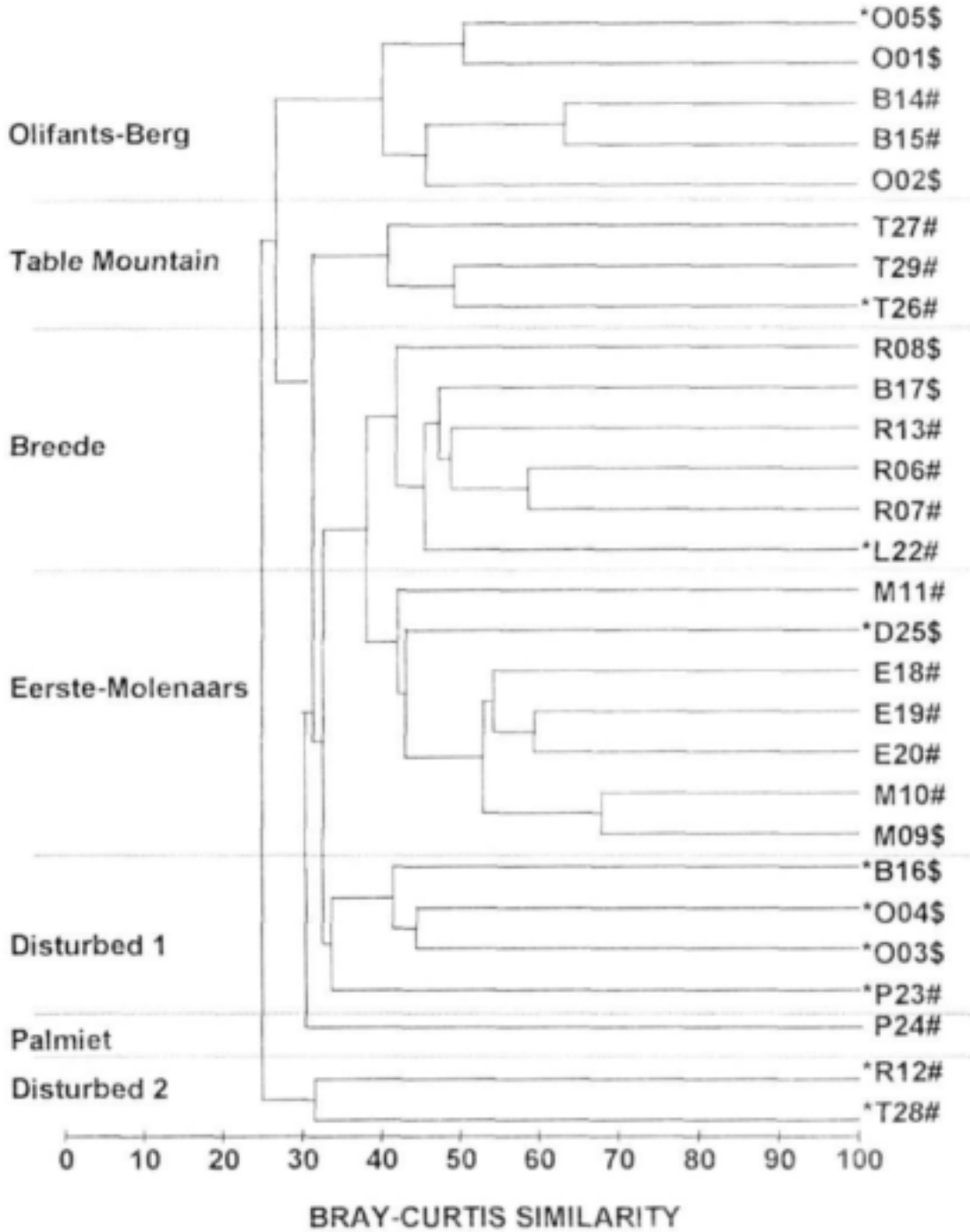


Figure 15.1 **Dendrogram of the 18 least-disturbed sites and ten disturbed sites, using species level data of invertebrates.** The groups recognised in Figure 10.4 are shown, together with two groups of disturbed rivers. # = predetermined mountain zone based on literature; $ = predetermined foothill zone based on literature; * = disturbed rivers.

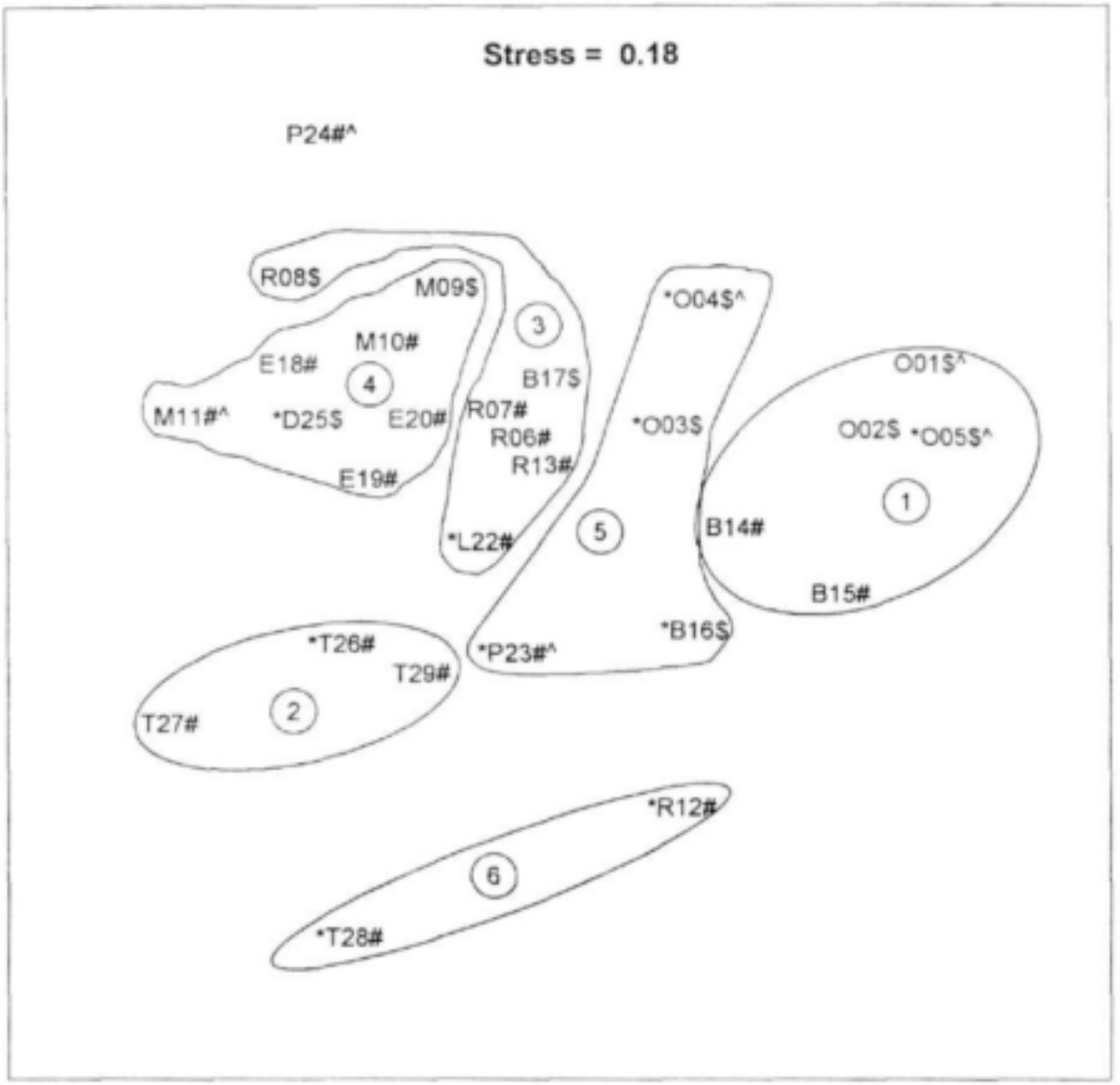


Figure 15.2 Two-dimensional configuration of the 18 least-disturbed sites and ten disturbed sites, using species level data of invertebrates. The groups recognised in Figure 10.4 are shown together with the two groups of disturbed rivers. # = predetermined mountain zone based on literature; $ = predetermined foothill zone based on literature; * = disturbed rivers; ^ bedrock rivers. Numbers represent the different sub-groups: 1 = Olifants-Berg; 2 = Table Mountain; 3 = Breede; 4 = Eerste-Molenaars; 5 = Disturbed 1; 6 = Disturbed 2.

impacts were the reduction in flows and upstream nutrient enrichment. The Middeldeur site had a bedrock channel with spectacular cascades and waterfalls downstream of the site. The channel did not appear to be modified, except perhaps by a greater than usual growth of riparian trees. Its most obvious impact was algal growth from upstream nutrient enrichment. The Noordhoek site was in mountain fynbos with no upstream dams, and so the chemical and thermal regimes were near natural. Its main impact was a bulldozed channel with an artificial cobble berm on the right bank, presumably to constrain flow within a narrow channel. Part of the bulldozing activity had been to create an abstraction channel upstream of the site, to take water to a nearby farm. This resulted in dry-season flows through the site being noticeably lower than natural.

The two rivers in Disturbed Group 2 were least similar to any other river. This group contained rivers with a dam (Holsloot – R12) and alien vegetation (Cecilia – T28). The Holsloot site received a continuous, very powerful, hypolimnetic release. Very cold water (Table 7.1: 12.3 °C, compared to the range 15.3 – 24.1 °C for all other sites) flowed turbulently over a riverbed 90% covered with dense, green filamentous algae. The Cecilia site was choked with woody debris and fallen leaves of *Populus canescens*. There was little surface water. This was the only river in which the abundant invertebrate group Ephemeroptera (mayflies) was not found.

The ordination plot of the same data was drawn with an acceptable stress of 0.18 (Figure 15.2). This also showed the established groups, each (except the Palmiet group with its one river) containing one disturbed river. Only the Wit (R08), which has shown up as an outlier in several earlier analyses, did not sit obviously with its group. Bedrock sites tended to be located around the outer edges of groups. Disturbed Group 1 was centrally placed among the recognised catchment groups, perhaps reflecting that these rivers had lost their catchment and river signatures, and had become increasingly similar to each other. Perhaps unique or sensitive species had been lost, leaving a core assemblage of hardy species that are common to most rivers. This grouping occurred despite the rivers having experienced a range of impacts (see descriptions above). This topic is revisited in Chapter 16.

Disturbed Group 2 was least similar to any other group of rivers (Figure 15.2). This may reflect a much more drastic disturbance, with a loss of even the hardy species, and the presence of a completely new assemblage of invertebrates. Again, this is discussed further in Chapter 16.

Following the conclusions given in Section 10.3, ANOSIM was not used to further explore differences between sites.

15.3 Correlation between biological groupings and environmental variables

BIOENV runs were completed for all groups recognised in Figure 15.1, that is, the Olifants/Berg catchment with the Grootrivier included; The Table Mountain catchments with Window; the Breede catchment with the Lourens, the Eerste/Molenaars catchments with Davidskraal; and the two disturbed groups. The results are not useful in some ways, as they characterise groups of rivers in which at least one river is no longer like the rest – hence the characterisation essentially becomes "noisy". Nevertheless, they provide an indication of how the overall driving variables of the groups changed with a disturbed river added in. If

Table 10.2 (for the least-disturbed rivers) is compared with Table 15.2 (for all rivers), for instance, algae and macrophytes gain prominence once the disturbed rivers have been added.

Table 15.2 Variables used and coefficients derived from the BIOENV matching exercise of biotic and abiotic similarity matrices of all sampled rivers. An * indicates overall best match.

Number of variables	Best variable combinations (ρ_w)
1	*Scirpus* (0.213)
2	Conductivity and macrophytes (0.309)
3	Algae, conductivity and macrophytes (0.326)
4	Algae, conductivity, macrophytes and *Scirpus* (0.338)
5	Algae, conductivity, macrophytes, cobbles and *Scirpus* (0.351)
6	Algae, conductivity, macrophytes, site slope, cobbles and *Scirpus* (0.360)
7	Algae, conductivity, macrophytes site slope, altitude, cobbles and *Scirpus* (0.372)
8*	**Algae, conductivity, macrophytes, site slope, altitude, boulder, cobbles and *Scirpus* (0.381)**

Similarly, algae gains prominence once the Davidskraal is added to the Eerste/Molenaars group (Tables 10.3 and 15.3), and moss once the Lourens is added to the Breede (Tables 10.4 and 15.4).

Table 15.3 Combinations of 12 environmental variables yielding the best matches of biotic and abiotic similarity for the Eerste/Molenaars catchments and Davidskraal grouping. An * indicates overall best match.

Number of variables	Best variable combinations (ρ_w)
1	Altitude (0.764)
2	Conductivity and bedrock (0.839)
3	Conductivity, bedrock and *Scirpus* (0.845)
4	Conductivity, moss, altitude and bedrock (0.856)
5	Algae, colour, site slope, altitude and cobbles (0.871)
6	Algae, conductivity, macrophytes, site slope, altitude and cobbles (0.871)
7*	**Algae, conductivity, colour, site slope, altitude, cobbles and *Scirpus* (0.888)**

Table 15.4 Combinations of 12 environmental variables yielding the best matches of biotic and abiotic similarity for the Breede catchment and Lourens River grouping. An * indicates overall best match.

Number of variables	Best variable combinations (ρ_w)
1	Altitude (0.496)
2	Altitude and boulder (0.655)
3*	**Moss, altitude and boulder (0.660)**
4	Macrophytes, moss, altitude and boulder (0.602)
5	Conductivity, moss, altitude boulder and cobbles (0.595)
6	Conductivity, moss, colour, altitude boulder and gravels (0.579)

Predictably, the best overall match in each case had a lower correlation value than when only the least-disturbed rivers were included.

15.4 Changes in MUs

When the disturbed rivers are included in the analysis of numbers of MUs, all but three of them group together but apart from the zonal groups recognised in Figure 12.1 (Wemmershoek - B16 not included as MUs eradicated, probably by bulldozing). The four main zonal groups: alluvial mountain; alluvial mountain/upper foothill; alluvial lower foothill; and bedrock mountain and foothill, are still apparent (Figure 15.3), although one site (M10 - Elands) has shifted groups from "mountain/upper foothill" to "bedrock mountain and foothill". But superimposed on this is a clear grouping of disturbed rivers, which together are less than 15% similar to almost all reference rivers in terms of the number and types of MUs. Even the two disturbed bedrock rivers group together, but separately from all other rivers including the other bedrock ones. All of the remaining disturbed rivers, except Cecilia (T28), group with the two lower foothill sites (Berg - B17 and Molenaars - M09) and the two outliers (R06 and R13). In terms of their slopes, all but the Groot (O05) should be well within the upper foothill to mountain zone (Tables 12.1 and 15.5), and so the disturbances appear to have transformed them to less heterogeneous sites typical of more downstream reaches. Further analysis is needed to compare, for instance, all the pristine mountain sites with all the disturbed mountain sites, to see which MUs are typical of each and what has been lost with disturbance (Chapter 20).

Table 15.5 Recap of map slope data for the disturbed rivers, and revised zone description based on analyses to date (see Section 15.6). # pre-identified as in a biological mountain zone and $ as in a biological foothill zone.

River Code	River Name	Map slope	Catchment	Revised zone
O03$	Noordhoek	0.020	Olifants	alluvial mountain-transitional
O04$	Middeldeur	0.011	Olifants	bedrock mountain and foothill
O05$	Grootrivier	0.002	Olifants	alluvial foothill
R12#	Holsloot	0.020	Breede	alluvial mountain-transitional
B16$	Wemmershoek	0.010	Berg	alluvial foothill
L22#	Lourens	0.020	Lourens	alluvial mountain-transitional
P23#	Palmiet	0.022	Palmiet	bedrock mountain and foothill
D25$	Davidskraal	0.010	Davidskraal	alluvial foothill
T26#	Window	0.087	Table Mountain	alluvial mountain
T28#	Cecilia	0.220	Table Mountain	alluvial mountain

15.5 Changes in substrata

The attempt to define physical reference conditions in Cape headwater streams (Section 10.6), revealed that there was an insufficiently detailed pattern of distribution of substrata to be able to distinguish river zones purely on the substrata (Figure 10.11). The distribution of flow types was even less useful for this purpose (Figure 10.12).

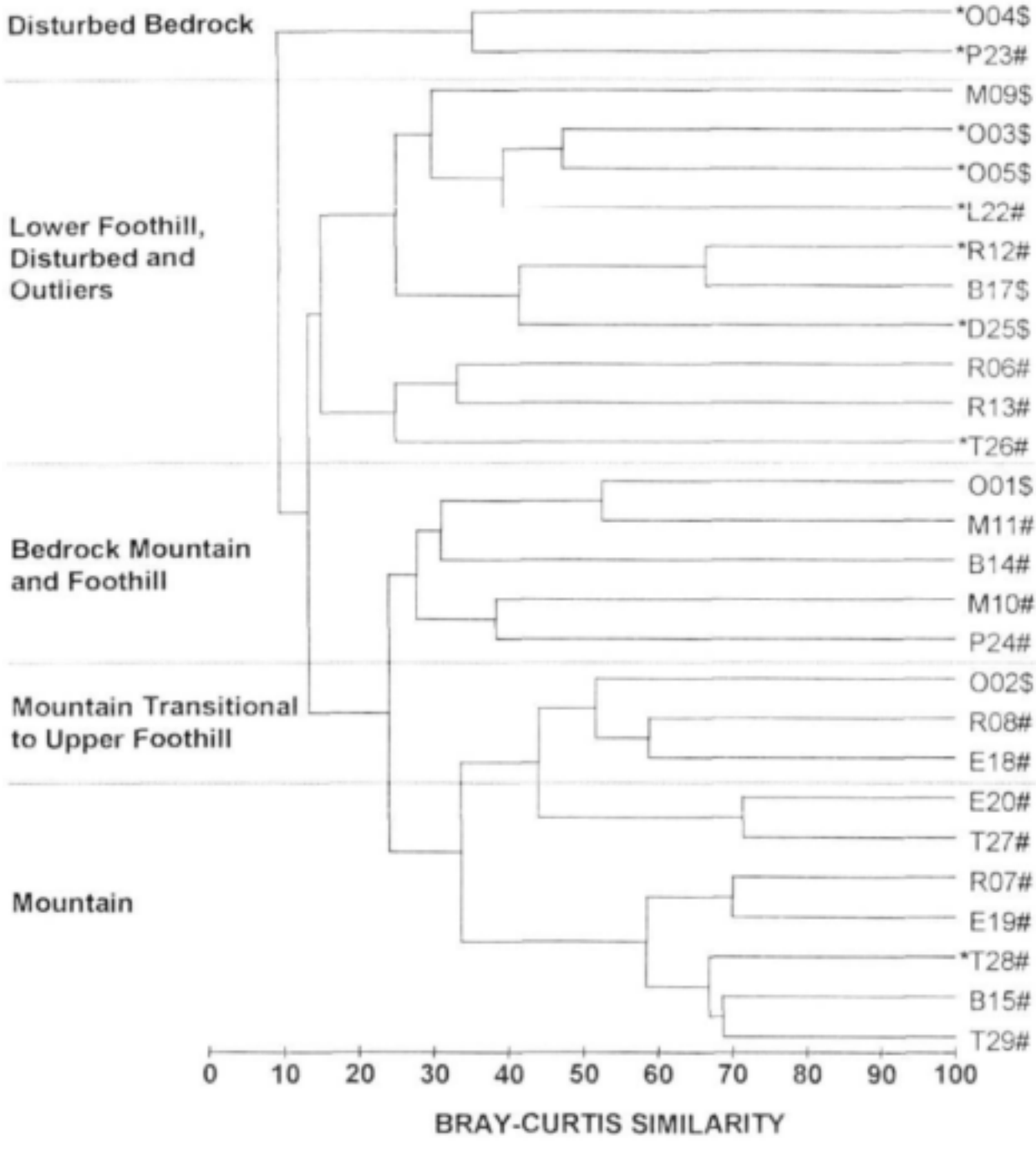


Figure 15.3 **Dendrogram of the similarity between 18 least-disturbed and ten disturbed river sites, based on the number and type of MUs mapped at the sites.** Zones marked on dendrogram are those recognised in Figure 12.1. # = predetermined mountain zone based on literature; $ = predetermined foothill zone based on literature; * = disturbed rivers.

The exercise of grouping rivers by substrata was repeated, however, as it might reveal why some of the disturbed rivers grouped as outliers. On the dendrogram of all 28 rivers, based on substrata data, the three main kinds of river channels – bedrock, mixed alluvial-bedrock, alluvial - were grouped (Figure 15.4). The two disturbed bedrock sites linked with the undisturbed sites, suggesting no major change in substrata. The mixed alluvial-bedrock sites still linked together, as in Figure 10.11. The alluvial group was increased by the inclusion of three disturbed sites (Window, Groot, Holsloot), but the remaining disturbed sites were in a swathe of dissimilar sites which also contained the two lower-foothill sites (Berg and Molenaars).

The MDS ordination of the same data (Figure 15.5) also reflected these groupings, but gave more details on the alluvial and ungrouped sites. The overall trends of the plot were: from left to right - bedrock to alluvial; and possibly from top to bottom – coarse to fine sediments. The least-disturbed bedrock sites were to the left, the least-disturbed mixed alluvial-bedrock sites in the centre, and the least-disturbed alluvial mountain sites formed a tight group to the right of the plot, surrounded by the least-disturbed alluvial foothill sites. The Holsloot (R12) grouped with these foothill sites but toward the top of the plot, perhaps reflecting the coarse sediments in this eroding, high-flow site. The remaining disturbed sites, apart from the two bedrock ones which were located in the bedrock group, were scattered to the lower right of the plot, all located outside any of the established groups. Again, the Window site (T26) appeared the least-impacted, being closest to the established mountain-alluvial group, and the Davidskraal (D25) and Cecilia (T28) sites most impacted.

Considering site slopes, the reference mountain-alluvial group had slopes ranging 0.020-0.080, and the alluvial foothills 0.002-0.026 (Table 5.3). The disturbed alluvial sites to the bottom right of the plot should have grouped within one of these two groups (Table 15.5). If increasing distance from these groups in the MDS plot is interpreted as increasing change in substrata, then the very high-gradient Cecilia site (T28), though with its MUs apparently intact, clearly is the most disturbed in terms of substrata, with Davidskraal (D25) a close second. These two sites are the only ones with more than 60% of their mapped substrata in the gravel and finer categories (Table 15.6). By comparison, among the least-disturbed alluvial rivers, gravels and fines made up 21% or less of the substratum, and among the other disturbed rivers 26% or less. This difference in substrata could partially explain why Cecilia does not group with other Table Mountain sites in terms of fauna (Figure 15.1 and 15.2), although with this reasoning Davidskraal should also be set outside recognised catchment groups. If substratum changes alone do not place sites outside the catchment groups (as happened with Davidskraal), then there must be additional forces influencing invertebrate distributions in Cecilia, and also in Holsloot (R12), for the latter has reasonably "normal" substrata but an unusual species assemblage (Figure 15.5 and 15.2). These forces could be physico-chemical changes (from the alien vegetation in Cecilia and hypolimnetic releases in Holsloot), flow changes (very low flows in Cecilia and very high flows in Holsloot), or temperature changes (very cold water in Holsloot). This matter is discussed further in Chapter 20.

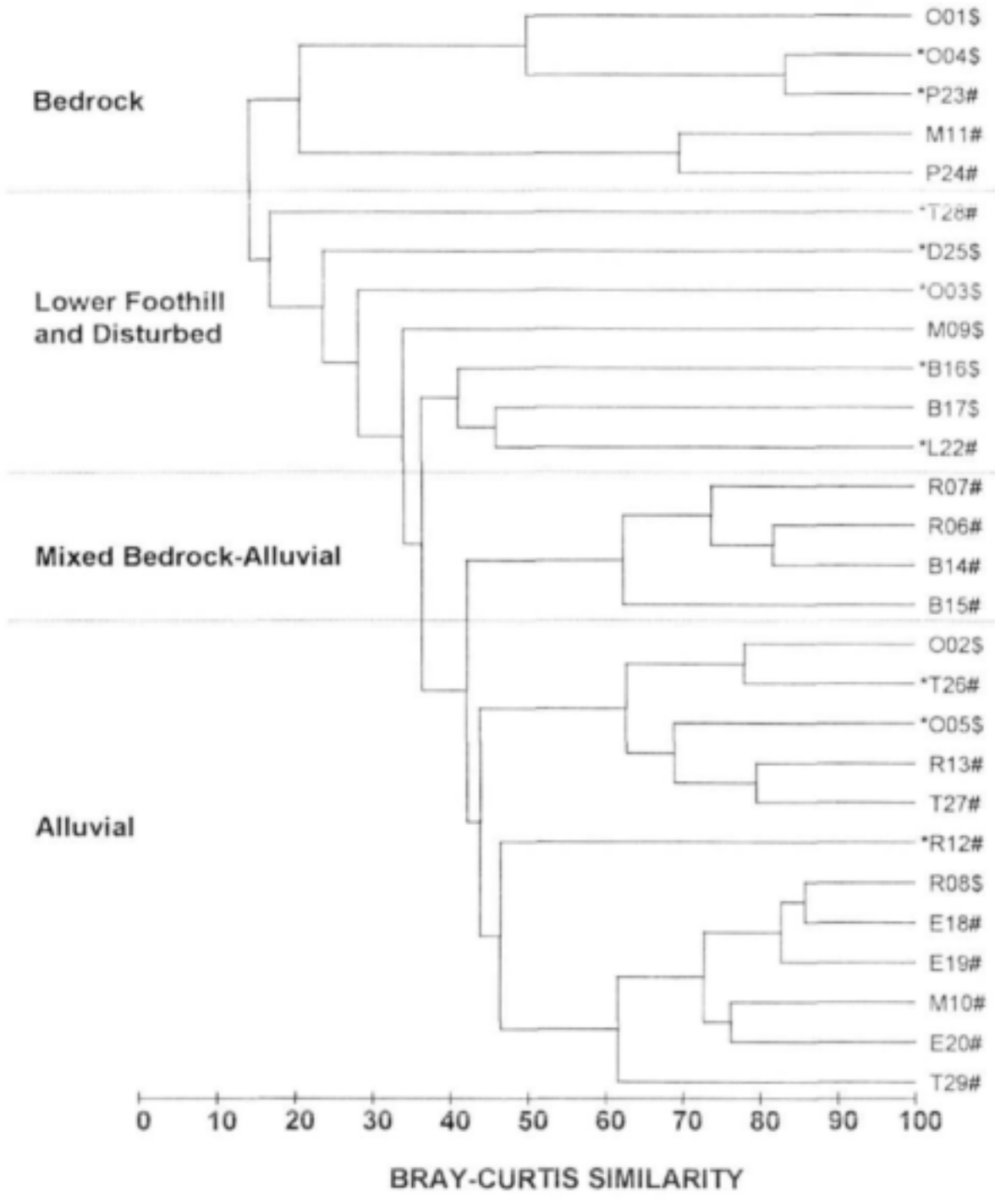


Figure 15.4 **Dendrogram of the 18 least-disturbed sites and ten disturbed sites, using data on categories and proportions of substrata.** The groups of least-disturbed rivers recognised in Figure 10.11 are shown, together with the disturbed rivers. # = predetermined mountain zone; $ = predetermined foothill zone; * = disturbed rivers.

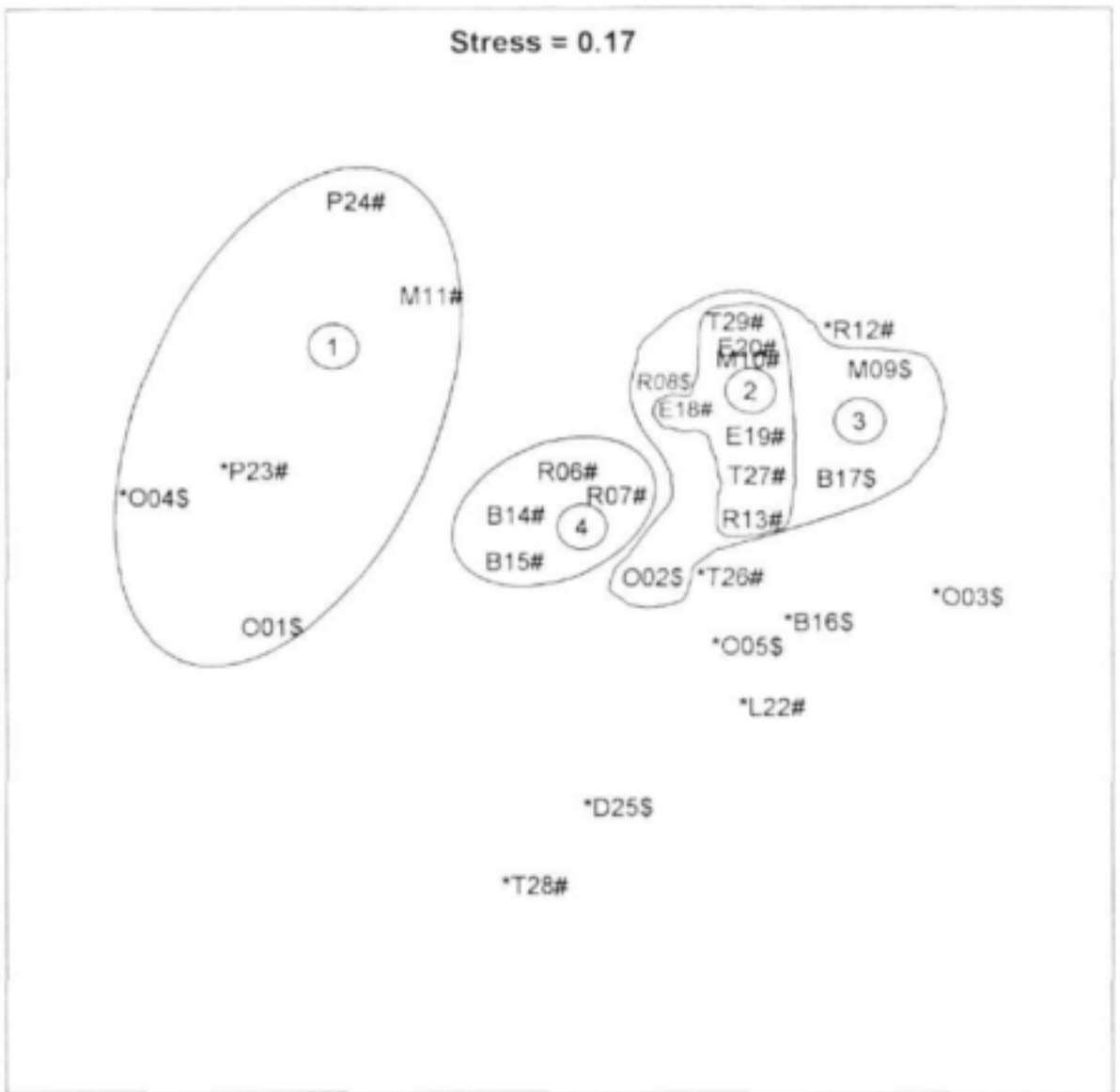


Figure 15.5 MDS ordination of the 18 least-disturbed sites and ten disturbed sites, using data on categories and proportions of substrata. The groups of least-disturbed rivers recognised in Figure 10.11 are shown, together with the disturbed rivers. # = pre-determined mountain zone; $ = pre-determined foothill zone; * = disturbed rivers. Numbers represent different groups: 1 = Bedrock; 2 = Least-disturbed Mountain; 3 = Least disturbed Foothill; 4 = Mixed Alluvial-bedrock.

Table 15.6 Percentages of wetted substrata in ten disturbed rivers, mapped with mixed categories allocated equally to one of the eight main categories. Substrata categories are explained in Table 2.4 with the exception of "plants" which are instream macrophytes not including *Scirpus* and palmiet; "concrete/rubble" which is concrete slabs or rubble instream and on banks; "roots" which are roots of trees or other riparian vegetation.

Substrata	O03$	O04$	O05$	R12#	B16$	L22#	P23#	D25$	T26#	T28#
BR	0.0	98.9	0.0	0.0	0.0	0.0	85.9	0.02	0.0	0.0
B	18.7	0.8	8.0	41.5	21.3	18.6	9.2	6.1	13.2	11.8
LC	44.3	0.0	69.3	15.6	50.8	26.1	0.3	2.9	38.0	16.9
SC	35.4	0.0	7.6	20.5	7.4	29.4	0.1	13.5	39.4	9.6
LG	0.0	0.0	0.0	0.0	0.0	0.0	0.0	36.2	5.6	0.0
SG	0.0	0.0	1.3	10.0	0.0	2.8	0.03	31.8	0.6	3.5
SA	0.3	0.0	11.7	5.3	16.5	18.9	0.0	9.4	2.8	49.1
SI	0.0	0.0	1.9	0.0	0.0	4.3	0.0	0.0	0.0	0.8
Concrete/Rubble	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0
Wood	0.0	0.0	0.2	0.0	0.0	0.0	1.0	0.0	0.4	4.8
Roots	0.0	0.0	0.0	4.5	0.0	0.0	0.0	0.0	0.0	3.4
Palmiet	0.0	0.04	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0
Scirpus	0.0	0.3	0.0	0.0	3.6	0.0	3.0	0.0	0.0	0.0
Plants	1.2	0.0	0.0	1.8	0.4	0.0	0.0	0.0	0.0	0.0

15.6 Changes in hydraulic biotopes, and recognition of an additional longitudinal zone

In Chapter 11, the individual invertebrate samples from the 18 least-disturbed rivers were analysed, to detect conditions (hydraulic biotopes) that supported similar species assemblages. The same analyses were repeated for the ten disturbed rivers and are reported on here. Again, the samples had to be divided into logical groups, in recognition of the PRIMER limitations in terms of number of samples.

During the preceding analyses it had become increasingly apparent that the split of samples from alluvial rivers into mountain or foothill zone was simplistic. Several different sets of data indicate a third zone between these two (Tables 6.1; 6.8; 12.1; 12.2; Figure 12.1; 12.2). Thus, at this point, we suggest recognition of a third zone in alluvial rivers and, pending further discussion with geomorphologists and other ecologists on it, have temporarily called it the mountain-transitional zone (Table 15.5). The zone appears to be related to map slopes of about 0.020-0.030.

In the following analyses of hydraulic biotopes, alluvial mountain and alluvial mountain-transitional were placed in one group, and alluvial foothills in a second. This allocation was done simply to achieve the best balance of numbers per group, and without suggestion of the closest affinity of the new mountain-foothill zone.

15.6.1 Alluvial mountain and mountain-transitional rivers

Five rivers, represented by 51 samples, were included in the analysis. Two were from Table Mountain, one from the Breede system, one from the Olifants, and one (Lourens) within its own small catchment. As

reported in Section 11.3.2, the least-disturbed headwater streams consisted of complex mosaics of small patches with very different hydraulic conditions. Hydraulic biotopes were difficult to characterise, because samples were organised mainly by catchment, and so "groups of samples that might be representing different hydraulic biotopes were divided into three, if not four, main sub-groups" within a catchment group. These very small groups of similar samples were essentially inadequate for good characterisation of hydraulic biotopes.

In the analysis of disturbed rivers, the catchment signature was still very clear, with all samples from any one river holding together (Figure 15.6 and 15.7). Because of this, the hydraulic biotopes again had to be distinguished from very small groups of samples within each catchment group, and patterns detected should be regarded as tentative.

The overall trend appeared to be that each river had a group of bio-pool samples and loose group of faster-water samples. A few of the "fast" samples could best be characterised as being from bio-runs, but most were from groups that could not be distinguished as either riffles or rapids. Some of this confused pattern may have been the result of both mountain and mountain-transitional rivers being included in the analysis, for the former tend to have bio-rapids and the latter to be making the transition toward bio-riffles. Even the high-gradient mountain sites (Cecilia - CR and Window - WS) which should have had bio-rapids, however, presented the same confused picture, suggesting that disturbance may also have played a role.

Closer inspection of the hydraulic details of the sub-groups (Table 15.7) revealed that in most cases the boulder substratum typical of bio-rapids was not present. Fast flow types usually associated with rapids (e.g. USW, CAS) were present, but they flowed over smaller substrata. In Window Stream, for instance, which with its high gradient was clearly a mountain site, bio-rapids should have been very evident (compare with Langrivier and Swartboskloof at the same gradient – Section 11.3.2). Instead of flowing over boulders, however, the flow types CH and CAS flowed over mixed small and large cobble. At the Cecilia site, which is even steeper, CAS and FRF flowed over wood. The mountain-foothill sites showed a similar picture. Noordhoek, for example, had mean velocities and Froude numbers well within those given earlier for bio-rapids, with velocities generally higher than those given for bio-riffles (Section 11.4). All of its fast flow types were nevertheless over mixed large and small cobble. Much the same picture emerged for the Lourens. Only the Holsloot, with its strong, hypolimentic dam release, still displayed a boulder bed with the appropriate flow types, velocities and Froude values.

In summary, in terms of hydraulic biotopes, these disturbed river sites appeared to display two major differences to comparable least-disturbed sites. First, boulder substrata were virtually absent. Second, sorting of cobble and smaller particles was poor, with about half of the invertebrate samples being taken from mixed substrata. The result was a continuing strong catchment signature superimposed on an array of pool biotopes and indistinct fast-flow biotopes with poorly-sorted, relatively homogeneous substrata.

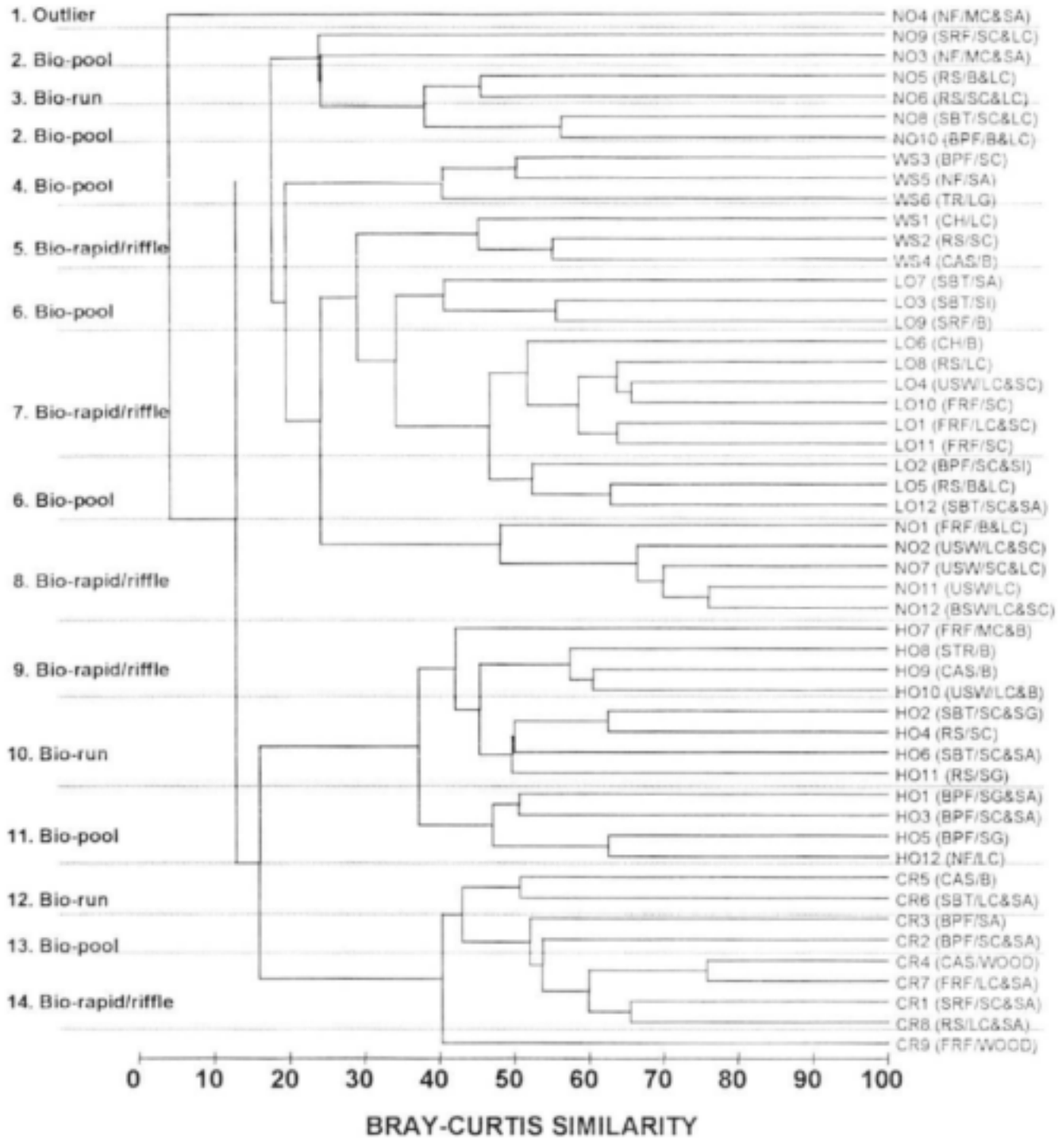


Figure 15.6 Cluster analysis to identify similar invertebrate samples from five disturbed mountain or mountain-foothill sites. Samples are coded by river and invertebrate sample number. NO = Noordhoek; WS = Window Stream; LO = Lourens; HO = Holsloot; CR = Cecilia Ravine. Substratum and flow-type codes as per Tables 2.3 and 2.4.

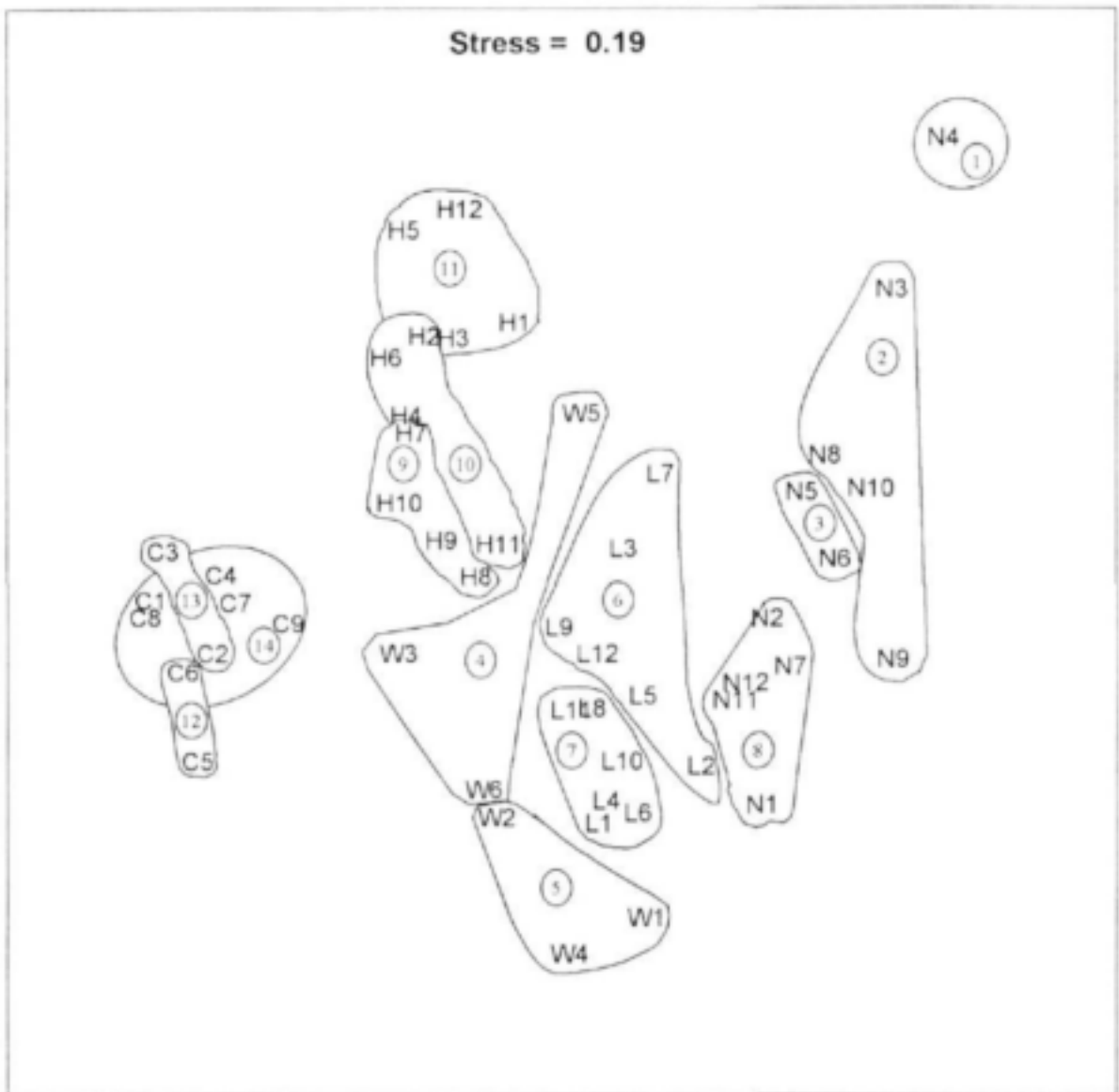


Figure 15.7 MDS ordination of invertebrate samples from five disturbed mountain or mountain-foothill sites. Groups denoted are those identified in Figure 15.6. Samples are coded by river and invertebrate sample number. N = Noordhoek; W = Window Stream L = Lourens; H = Holsloot; C = Cecilia Ravine.

Table 15.7 **Hydraulic characteristics of the 14 groups of samples from disturbed alluvial mountain and mountain-foothill sites, as recognised in Figure 15.6.** Depth (m); mean-column (0.6) and near-bed (NB) velocity (m s^{-1}). NO = Noordhoek; WS = Window Stream; LO = Lourens; HO = Holsloot; CR = Cecilia Ravine. Substratum and flow-type codes as per Tables 2.3 and 2.4. MC = mixed cobble.

Sub-group No.	Hydraulic biotope	Sample code	Flow/ substrata	Depth	0.6	NB	Froude No.
1	Outlier	NO04	NF/MC&SA	0.04	0.01	0.01	0.016
2	Bio-pool	NO09	SRF/SC&LC	0.03	0.07	0.07	0.135
		NO03	NF/MC&SA	0.06	0.01	0.01	0.008
		NO08	SBT/SC&LC	0.08	0.04	0.04	0.049
		NO10	BPF/B&LC	0.15	0.03	0.01	0.025
3	Bio-run	NO05	RS/B&LC	0.14	0.20	0.16	0.181
		NO06	RS/SC&LC	0.15	0.21	0.14	0.181
4	Bio-pool	WS03	BPF/SC	0.24	0.00	-	0.000
		WS05	NF/SA	0.16	0.00	0.00	0.000
		WS06	TR/LG	0.08	0.07	0.11	0.084
5	Bio-rapid/riffle	WS01	CH/LC	0.11	0.45	-	0.422
		WS02	RS/SC	0.12	0.27	-	0.252
		WS04	CAS/B	0.12	0.46	0.54	0.479
6	Bio-pool	LO07	SBT/SA	0.21	0.01	0.01	0.007
		LO03	SBT/SI	0.09	0.08	0.01	0.082
		LO09	SRF/B	0.20	0.00	0.01	0.002
		LO02	BPF/SC&SI	0.09	0.03	0.02	0.035
		LO05	RS/B&LC	0.21	0.00	0.00	0.000
		LO12	SBT/SC&SA	0.22	0.09	0.04	0.059
7	Bio-rapid/riffle	LO06	CH/B	0.12	0.93	1.13	1.030
		LO08	RS/LC	0.30	0.34	0.22	0.200
		LO04	USW/LC&SC	0.23	0.52	0.33	0.373
		LO10	FRF/SC	0.18	0.27	0.13	0.209
		LO01	FRF/LC&SC	0.06	0.18	0.18	0.238
		LO11	FRF/SC	0.06	0.29	0.29	0.380
8	Bio-rapid/riffle	NO01	FRF/B&LC	0.13	0.38	0.28	0.352
		NO02	USW/LC&SC	0.14	0.22	0.19	0.203
		NO07	USW/SC&LC	0.14	0.62	0.54	0.559
		NO11	USW/LC	0.16	0.88	0.76	0.718
		NO12	BSW/LC&SC	0.16	0.42	0.23	0.341
9	Bio-rapid/riffle	HO07	FRF/MC&B	0.06	0.24	0.23	0.348
		HO08	STR/B	0.14	0.89	0.71	0.773
		HO09	CAS/B	0.11	0.55	0.47	0.554
		HO10	USW/LC&B	0.15	0.81	0.67	0.709
10	Bio-run	HO02	SBT/SC&SG	0.29	0.11	0.07	0.065
		HO04	RS/SC	0.53	0.29	0.23	0.128
		HO06	SBT/SC&SA	0.36	0.00	0.00	0.000
		HO11	RS/SG	0.18	0.03	0.03	0.020
11	Bio-pool	HO01	BPF/SG&SA	0.10	0.04	0.02	0.041
		HO03	BPF/SC&SA	0.21	0.01	0.01	0.005
		HO05	BPF/SG	0.19	0.01	0.00	0.006
		HO12	NF/LC	0.05	0.00	0.00	0.000
12	Bio-run	CR05	CAS/B	0.01	0.13	0.13	0.471
		CR06	SBT/LC&SA	0.07	0.08	0.08	0.103
13	Bio-pool	CR03	BPF/SA	0.10	0.05	0.04	0.053
		CR02	BPF/SC&SA	0.05	0.03	0.03	0.039
14	Bio-rapid/riffle	CR04	CAS/WOOD	0.02	0.14	0.14	0.399
		CR07	FRF/LC&SA	0.05	0.28	0.28	0.473
		CR01	SRF/SC&SA	0.05	0.08	0.08	0.108
		CR08	RS/LC&SA	0.04	0.06	0.06	0.096
		CR09	FRF/WOOD	0.01	0.20	0.20	0.572

15.6.2 Alluvial foothill rivers

Three rivers, represented by 36 samples, were included in the analysis. One was from the Berg catchment, one from the Olifants, and one in its own small catchment. The catchment signatures were distinct, with each river's samples clustered together and the Olifants River representative (Groot) splitting off first (Figures 15.8). Each river group contained sub-groups of fast and slow-flow samples, with the exception of the Wemmershoek, the fastest samples of which showed greater similarity to the Davidskraal samples. In the MDS plot, these samples appeared equidistant from Davidskraal and the other Wemmershoek samples. Using the guidelines given in Tables 11.8a and 11.8b, and the accompanying text, nine sub-groups of samples were recognised. The Groot and Davidskraal were represented by riffle, run and pool biotopes, and the Wemmershoek by a large heterogeneous pool group of samples and the two isolated samples from riffle biotopes. There was one outlier sample. On the MDS plot (Figure 15.9), the sub-groups were arranged from the slowest flows at the top of the page to fastest at the bottom, with all rivers well separated.

The hydraulic data associated with the sub-groups (Table 15.8) revealed some mixed substrata, but less so than for the mountain and mountain-transitional sites. This may be because many sample points contained few, if any larger substrata. Twenty-two percent of the samples were collected where sand or silt was the dominant substratum, compared with 3% in the least-disturbed sites. Similarly, 31% of samples were from small cobble, compared with 15% for the least-disturbed sites. These figures cannot be used to indicate the percent composition of substrata at the site, as stratified sampling was not done. They do suggest, however, that the range of conditions was different between the two sets of sites, with the disturbed sites probably having more areas of small substrata than the least-disturbed ones. Overall, these three sites displayed the following characteristics:

- two of them located within a recognised catchment group of least-disturbed rivers (Figure 15.1) (Wemmershoek - B16 did not);
- they retained their river signatures (Figure 15.8);
- two of them retained a fair representation of bio-riffles, bio-runs and bio-pools (Wemmershoek did not).

One might speculate from this that Wemmershoek, with its major modification of channel bed and flow regime, was the most seriously impacted of the three sites, even though visual assessment might have led to the conclusion that Davidskraal was more disturbed.

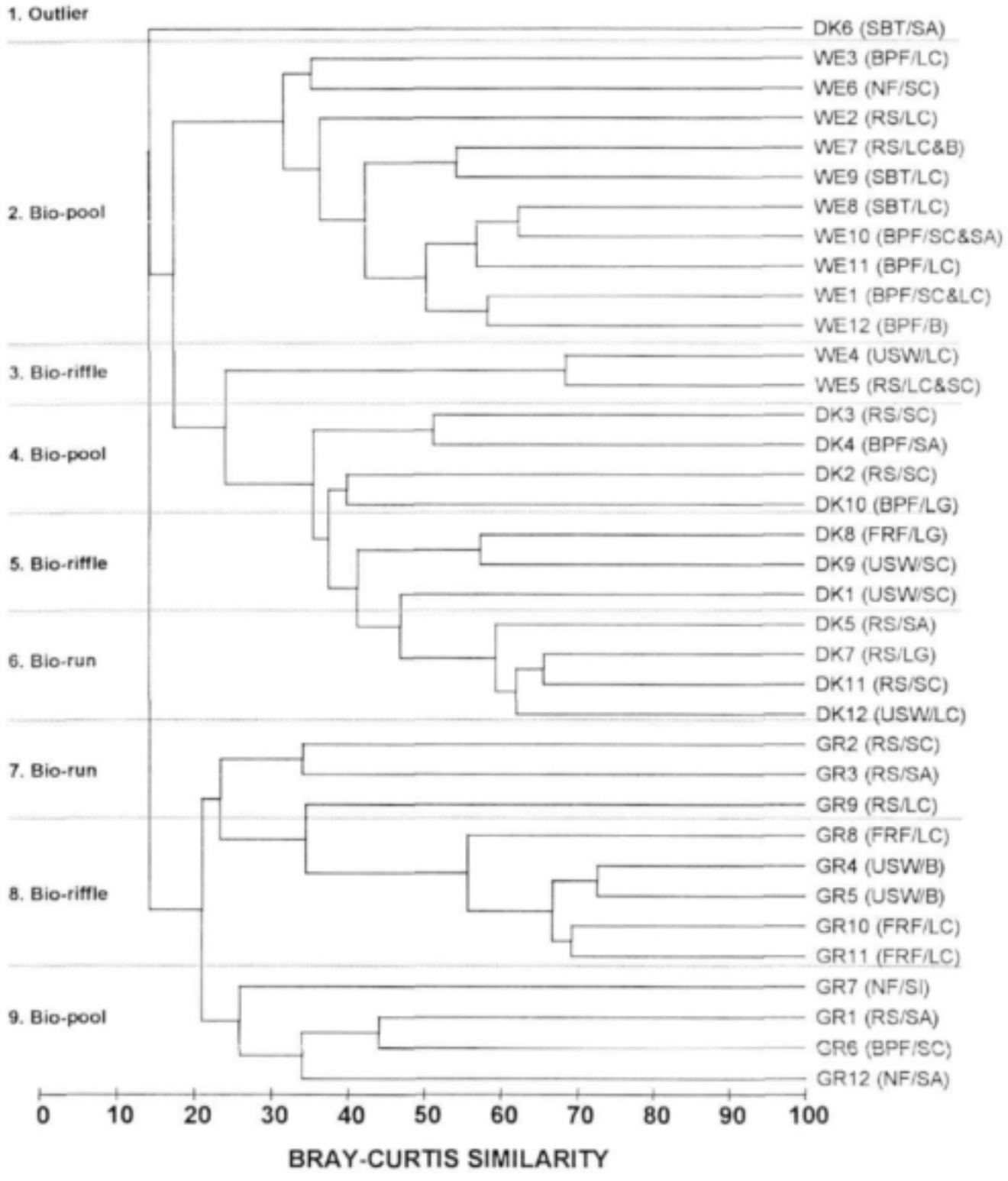


Figure 15.8 Cluster analysis to identify similar invertebrate samples from three disturbed foothill sites. Samples are coded by river and invertebrate sample number. DK = Davidskraal; WE = Wemmershoek; GR = Grootrivrier. Substratum and flow-type codes as per Tables 2.3 and 2.4.

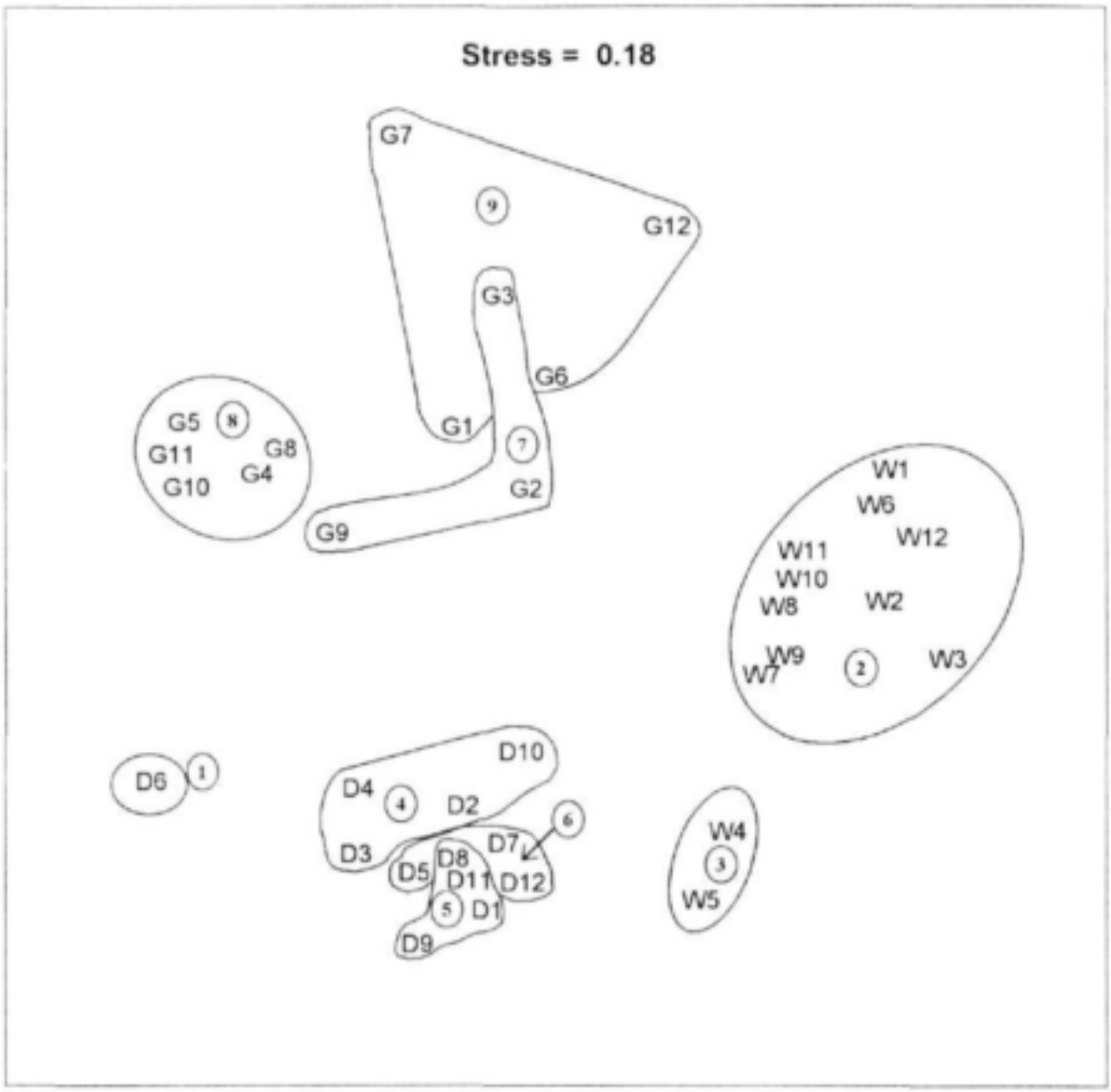


Figure 15.9 MDS ordination of invertebrate samples from three disturbed foothill sites. Groups denoted are those identified in Figure 15.8 Samples are coded by river and invertebrate sample number. D = Davidskraal; W = Wemmershoek; G = Grootrivrier.

Table 15.8 Hydraulic characteristics of the nine groups of samples from disturbed alluvial foothill sites, as recognised in Figure 15.8. DK = Davidskraal; WE = Wemmershoek; GR = Grootrivrier. Substratum and flow-type codes as per Tables 2.3 and 2.4. Depth (m); Mean-column (0.6) and near-bed (NB) velocity (m s^{-1}).

Sub-group No.	Hydraulic biotope	Sample code	Flow/ substrata	Depth	0.6	NB	Froude No.
1	Outlier	DK06	SBT/SA	0.24	0.08	0.04	0.049
2	Bio-pool	WE03	BPF/LC	0.17	0.04	0.04	0.033
		WE06	NF/SC	0.06	0.03	0.03	0.034
		WE02	RS/LC	0.41	0.26	0.09	0.130
		WE07	RS/LC&B	0.14	0.08	0.08	0.072
		WE09	SBT/LC	0.24	0.16	0.14	0.109
		WE08	SBT/LC	0.11	0.06	0.05	0.064
		WE10	BPF/SC&SA	0.10	0.06	0.04	0.055
		WE11	BPF/LC	0.08	0.03	0.03	0.038
		WE01	BPF/SC&LC	0.37	0.03	0.03	0.017
		WE12	BPF/B	0.32	0.06	0.06	0.032
3	Bio-riffle	WE04	USW/LC	0.14	0.58	0.39	0.0529
		WE05	RS/LC&SC	0.08	0.34	0.34	0.396
4	Bio-pool	DK03	RS/SC	0.23	0.08	0.04	0.054
		DK04	BPF/SA	0.26	0.06	0.01	0.038
		DK02	RS/SC	0.08	0.08	0.08	0.078
		DK10	BPF/LG	0.08	0.00	0.00	0.002
5	Bio-riffle	DK08	FRF/LG	0.04	0.21	0.21	0.322
		DK09	USW/SC	0.08	0.33	0.25	0.429
		DK01	USW/SC	0.08	0.47	0.41	0.607
6	Bio-run	DK05	RS/SA	0.08	0.15	0.13	0.173
		DK07	RS/LG	0.09	0.07	0.05	0.084
		DK11	RS/SC	0.11	0.17	0.13	0.159
		DK12	USW/LC	0.08	0.40	0.39	0.458
7	Bio-run	GR02	RS/SC	0.13	0.07	0.04	0.066
		GR03	RS/SA	0.08	0.07	0.04	0.077
		GR09	RS/LC	0.21	0.19	0.06	0.134
8	Bio-riffle	GR08	FRF/LC	0.19	0.35	0.21	0.251
		GR04	USW/B	0.14	0.48	0.31	0.461
		GR05	USW/B	0.14	0.51	0.49	0.508
		GR10	FRF/LC	0.09	0.17	0.13	0.205
		GR11	FRF/LC	0.12	0.33	0.15	0.297
9	Bio-pool	GR07	NF/SI	0.11	0.00	0.00	0.000
		GR01	RS/SA	0.07	0.06	0.05	0.079
		GR06	BPF/SC	0.09	0.00	0.00	0.003
		GR12	NF/SA	0.04	0.00	0.00	0.000

15.6.3 Bedrock mountain and foothill rivers

Two bedrock sites, represented by 24 samples, were included in the analysis. The Middeldeur is in the Olifants catchment, and the Palmiet in its own catchment. Again, there were good catchment groupings, but the faster-flow sub-groups from each river grouped with each other rather than each river first linking its fast and slow sub-groups (Figure 15.10). The one slow-flow sample from the Palmiet was an outlier. In the MDS plot (Figure 15.11), samples from the two rivers remained distinct and the rapid, run and pool from the Middeldeur remained linked, so the suggested over-riding of fast flow types over the catchment signature was not supported, and the trend would not be particularly strong.

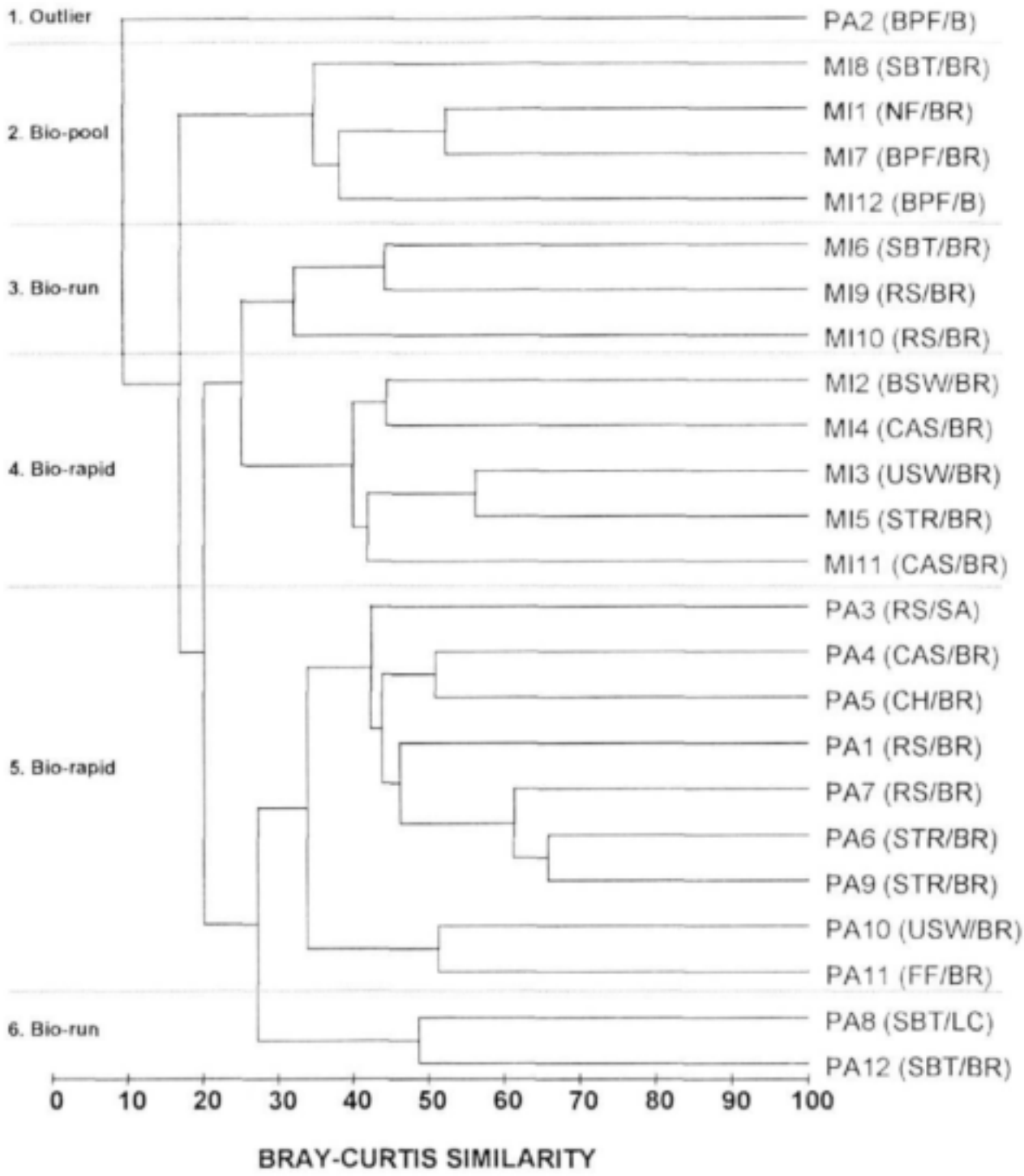


Figure 15.10 Cluster analysis to identify similar invertebrate samples from two disturbed bedrock sites. Samples are coded by river and invertebrate sample number. PA = Palmiet; MI = Middeldeur. Substratum and flow-type codes as per Tables 2.3 and 2.4.

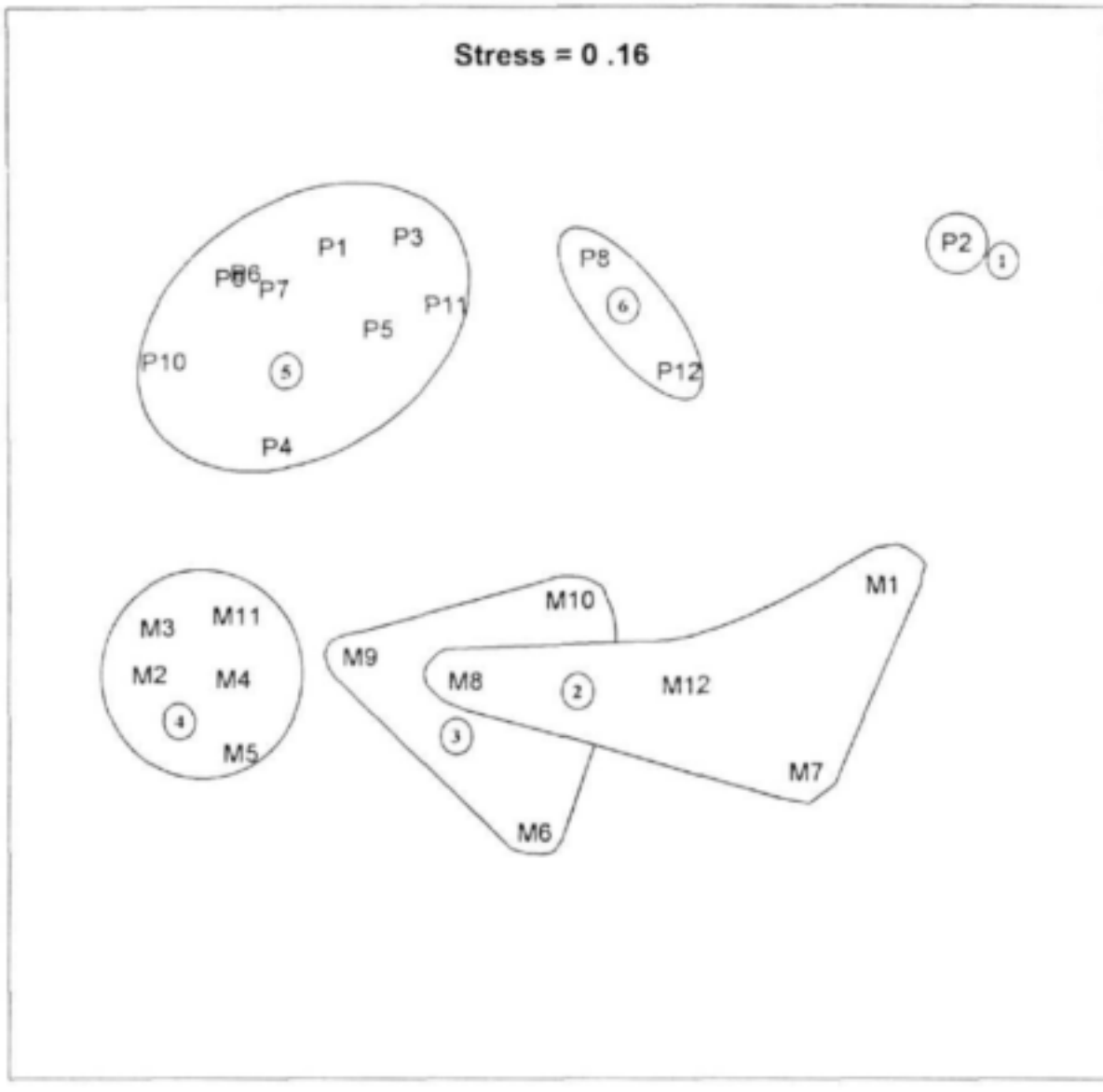


Figure 15.11 MDS ordination of invertebrate samples from two disturbed bedrock sites. Groups denoted are those identified in Figure 15.10. Samples are coded by river and invertebrate sample number. P = Palmiet; M = Middeldeur.

The hydraulic data (Table 15.9) revealed that bio-rapid and bio-run sub-groups were clearly distinguishable within the fast-flow groups. This mirrored the situation with the least-disturbed bedrock rivers (Figure 11.5a), and possibly reflects the fact that substratum conditions can change less with disturbance than in an alluvial river. Therefore, as long as chemical and flow changes are not too great, it might be presumed that the different fast-flow biotopes, at least, will continue to support distinct communities.

Table 15.9 Hydraulic characteristics of the six groups of samples from disturbed bedrock sites, as recognised in Figure 15.10. PA =Palmiet; MI = Middeldeur. Substratum and flow-type codes as per Tables 2.3 and 2.4. Depth (m); Mean-column (0.6) and near-bed (NB) velocity (m s^{-1}).

Sub-group	Hydraulic biotope	Sample code	Flow/substratum	Depth	0.6	NB	Froude No.
1	Outlier	PA2	BPF/B	0.09	0.25		0.269
2	Bio-pool (bedrock)	MI08	SBT/BR	0.31	0.12		0.066
		MI01	NF/BR	0.23	0.00		0.000
		MI07	BPF/BR	0.18	0.13		0.025
		MI12	BPF/B	0.66	0.08		0.033
3	Bio-run (bedrock)	MI06	SBT/BR	0.28	0.26		0.160
		MI09	RS/BR	0.31	0.25		0.147
		MI10	RS/BR	0.69	0.08		0.032
4	Bio-rapid (bedrock)	MI02	BSW/BR	0.47	0.21		0.119
		MI04	CAS/BR	0.14	0.36		0.302
		MI03	USW/BR	0.30	0.46		0.280
		MI05	STR/BR	0.24	0.61		0.415
		MI11	CAS/BR	0.23	0.79		0.597
5	Bio-rapid (bedrock)	PA03	RS/SA	0.53	0.25		0.108
		PA04	CAS/BR	0.36	0.54		0.354
		PA05	CH/BR	0.12	0.74		0.696
		PA01	RS/BR	0.23	0.54		0.369
		PA07	RS/BR	0.15	0.49		0.398
		PA06	STR/BR	0.19	1.07		0.842
		PA09	STR/BR	0.42	1.67		0.882
		PA10	USW/BR	0.52	0.60		0.281
		PA11	FF/BR	0.01	-		-
6	Bio-run (bedrock)	PA08	SBT/LC	0.12	0.14		0.055
		PA12	SBT/BR	0.30	0.22		0.138

15.7 Conclusions

In terms of their invertebrate assemblages, some disturbed rivers retained their catchment signature, whilst other did not. Acknowledging this, it is suggested that the impact of disturbance could be rated on a scale of 1-4 that reflects how well a river, as represented by its invertebrate biota, resists change and retains its catchment signature. Rivers that:

- retain their catchment signature and are located well within a catchment cluster could be demonstrating a state of mild disturbance (Rating 1);
- remain within their own catchment cluster, but as an outlier, could be demonstrating a moderate level of disturbance (Rating 2);
- relocate outside their catchment group, but still within the overall grouping of the region's catchments, could be demonstrating a high level of disturbance (Rating 3).

- relocate outside their catchment group, and also outside the overall grouping of the region's catchments, could be demonstrating a severe level of disturbance (Rating 4).

A variation on this theme is provided by rivers that relocate to another catchment group, perhaps through the introduction of species from that catchment. These rivers could probably sit at any of the disturbance levels, depending on the nature of the impact from the donor catchment.

Using this interpretation, examples of all levels of disturbance are present within the studied rivers (Figure 15.2). Window Stream (T26) exhibits some alteration of MUs, substrata and a confused riffle-rapid biotope, but in most ways clusters very closely with the other Table Mountain streams, suggesting that it is mildly disturbed (Rating 1). This stream runs through the Kirstenbosch National Botanical Gardens, and has some disturbance of its banks, including the presence of alien oaks *Quercus robur* and some abstraction of water.

An example of an outlier within a group (Rating 2) is the Groot (O05). This site retained its catchment signature, but as the site within its group that was furthest from all other groups. In terms of MUs and substrata, it was also located among a loose group of disturbed rivers. It retained distinct species assemblages in riffles, runs and pools, however. The river runs through the Cedarberg Wilderness Area, but is subject to extensive abstraction of water in upstream farming areas.

Those sites sitting outside catchment groups but still with an overall similarity to the other catchment groups (B16 Wemmershoek; P23 Palmiet; O03 Noordhoek; O04 Middeldeur), could be seen as highly disturbed (Rating 3). These rivers appear to have lost their individual signatures, ands become like kinds of generalised rivers of that bioregion. Possibly, by this stage of disturbance, sensitive species have disappeared, and any coarser bioregion identity is provided by hardy, opportunistic species.

The most disturbed sites are probably those sitting outside any catchment groups (Rating 4). Cecilia (T28) and Holsloot (R12) provide examples, being least similar to any other river in terms of invertebrate assemblages. They exhibit alteration in either MUs or substrata, but no more so than any other of the disturbed rivers. Their hydraulic biotopes are no more disrupted than any other of the rivers, with runs, riffle/rapids and pools distinguishable. It is suggested that their greater dissimilarity is due to chemical and physico-chemical change as well as physical change. Holsoot receives very cold, hypolimnetic water from a dam, and the riverbed was covered with filamentous algae, drastically reducing the normal rocky habitat. Cecilia has deciduous alien trees growing into the tiny channel, its flow is reduced to a trickle, and the bed is choked with leaves and other debris from the trees, with unknown effects on water chemistry. The natural riparian vegetation of the region is evergreen with far lower leaf-fall loads scattered over most of the year (King 1981), and so such clogging of the river channel and bed as seen in Cecilia is not natural.

There is one example of a site relocated to another catchment group. The Berg (B17) site appears with the Breede River group (Figure 10.4), in what might be an upstream influence of an inter-basin transfer of water. Breede River water enters the Berg about 1 km downstream from our Berg site, and may temporarily change the upstream species assemblage of the Berg site during the summer months of water transfer. This topic is discussed further in Section 10.2.

The above trend is suggested based on species composition and a coarse assessment of abundances (Table 10.1). It is possible that some rivers are more disturbed than the data suggest because species could be markedly rarer than normal without the abundance rating being affected. Additionally, the trend does not indicate an obvious relationship between type of disturbance and degree of impact. The two most impacted sites had quite different disturbances (alien trees and a dam), whilst other very disturbed sites were impacted by farming, dams and bulldozing. Some of the less disturbed sites were also downstream of farming.

Further analysis of the species data is needed to understand what kinds of species changes were linked to each river and thus to each disturbance, and to ascertain the relationship between kind of disturbance and level of disturbance. Specifically, the data should be assessed to test if some disturbances (e.g. the mainly physical ones) provide a depauperate version of the original set of species, and perhaps a less drastic disturbance to ecosystem functioning, than others (mainly the physico-chemical or chemical ones) where major species changes occur. This topic is re-visited in Chapter 20.

This project focused on the physical variables, and an underlying trend that seemed to emerge is that disturbed rivers exhibit loss of physical heterogeneity of the riverbed. First, at the largest scale, Morphological Units (MUs) had been obliterated in some rivers, seemingly through bulldozing or becoming in-filled by fine sediments. Second, fast-flow hydraulic biotopes were difficult to distinguish in some rivers, with bio-rapids in alluvial mountain and mountain-foothill zones appearing most vulnerable to change. In all disturbed sites in such zones, bio-rapids had been replaced by mixed rapid/riffle species assemblages. Bio-riffles and bio-runs in mountain-transitional zones retained their identities better, as did bio-rapids and bio-runs in bedrock rivers, presumably because such sites were not losing their natural substrata to the extent that higher-slope sites were. At this stage it is not understood why high-gradient sites should be losing boulder substratum. Third, many sites exhibited poor sorting of sediments into size classes, with mapping of substrata for disturbed sites being noticeably more difficult than for the reference sites. The overall impression was that physical heterogeneity was being lost at several scales.

16. SPECIES DISTRIBUTIONS AND BIODIVERSITY PATTERNS

16.1 Catchment and river signatures

An unexpected finding of this project was that, when working at the species level of invertebrate identification, each catchment and river had a clear identity. Such a phenomenon had been suspected before (Eekhout *et al.* 1997). At that time, however, it had been thought possible that the grouping of invertebrate samples by river might have been due either to the analytical methods used, or to the fact that different specialists collected and identified the animals in each of the studied rivers (sampling and/or identification bias). No such bias could be attributed to this study, because the same small group of people did the invertebrate collections and identifications for all 28 rivers, and in a standardised way. The results, that in least-disturbed rivers the invertebrate samples grouped very strongly by catchment and by river (Chapters 10 and 11), provides compelling proof that catchment and river signatures do exist. Samples from disturbed rivers also grouped by river, but some of these disturbed rivers appeared to have lost their catchment signature (Chapter 15).

Further proof that the analytical methods employed were not producing nebulous signatures comes from Chapter 14. Here, invertebrate samples were taken from two sites in adjacent reaches within one river. If the analytical methods had been causing the signatures in some way, then each site should have shown up as a different "river". But this did not happen, with the grouping of samples being based on current speed (fauna from fast or slow-flowing areas grouping independently) and then on discharge (i.e. sampling date), and not on site.

16.2 The nature and underlying causes of catchment and river signatures

Two possible reasons for the signatures can be suggested, and more might suggest themselves to the reader. They could be due to some unique species within each river and catchment. Alternatively, they could be due to unique combinations of common species within each river and catchment.

The first explanation could reflect biogeographical influences, with catchments being isolated from each other to some extent, and the catchment divides offering barriers to the distribution of some species. The grouping together of the Olifants and Berg Rivers in the catchment analyses, in isolation from the other studied catchments, perhaps supports this theory. They are the only two catchments studied that drain into the Atlantic Ocean and in the distant past the main stems of the two rivers shared a common estuary. But could it be that species moved down from the headwaters of one of these river systems to a lowland confluence with the other, and thus back up to the headwaters of the other system, more easily than they could move across a single line of mountains to a third unrelated catchment? Even if this could happen, this explanation does not reveal why the Eerste and Molenaars systems grouped together in the catchment analysis. These two rivers are not linked, and are not geographically contiguous as the Berg system lies in between their headwaters. Additionally, the Molenaars is a tributary of the Breede, and so the expectation might be that it would link with that system rather than with the Eerste.

The second explanation for the signatures suggested above is that they reflect unique combinations of common species and thus, perhaps, differences in ecosystem functioning. There could be differences in the driving variables of the catchments, in terms of their geological, geochemical, climatic or other nature. These could be resulting in subtle chemical signals characteristic of each river or catchment, or ones based on different levels or kinds of nutrient processing, and so on.

Sections 16.3-16.7 serve to briefly introduce some of the data available for further analysis of such biogeographical and biodiversity issues. Only data from the least-disturbed rivers are used.

16.3 Species numbers and assemblages per catchment

The original summary data set of species (Appendix 8.1) consists of average rated-abundances per site for 287 species. These species represented eight phyla, 26 orders, 83 families and 171 genera. Because of PRIMER restrictions on the number of species, the data set was reduced to 149 species, by deleting any species that occurred in only one of the 18 rivers *and* that had an average abundance rating of <1. This, for instance, excluded all the Hydracarina.

The data set based on these 149 species revealed diverse but different assemblages in each catchment (Table 16.1). The Eerste/Molenaars group of sites had 99 species, the Breede 71 species, the Olifants/Berg 57 species, and the Table Mountain group 42 species. The Dwars site, sole member of the Palmiet catchment group, had 35 species.

Table 16.1 **Species average abundance ratings and distributions per catchment.** Species also found in the Dwars River (only representative of the Palmiet catchment that is least disturbed) are represented by an * on the species number (No.)

		Catchment Group			
No.	Species/Morph Type	Breede	Olifants-Berg	Eerste-Molenaars	Table Mountain
1*	*Paramelita nigroculus*	0.40	0.00	0.00	2.17
2	Dryopidae sp.1	0.40	0.00	0.72	0.00
3	Dryopidae sp.2	0.00	0.00	0.42	0.00
4	*Strina* sp. 1	1.60	0.00	1.41	0.00
5	*Strina* sp. 2	0.00	0.50	0.00	0.00
6	Dytiscidae sp. 2	0.00	0.50	0.00	0.00
7*	Elmidae sp.	0.00	1.00	1.57	0.00
8	Elmidae sp. 1	0.00	0.00	1.42	0.83
9	Elmidae sp. 2	0.35	0.00	1.57	0.50
10	Elmidae sp. 3	0.00	0.00	0.92	0.00
11*	*Epidelmis* sp. A	0.25	0.00	1.73	3.17
12	*Epidelmis* sp. B	0.53	0.00	1.48	0.90
13	Helodidae sp. 2	1.10	0.00	0.39	1.00
14	Helodidae sp. 4	0.20	0.44	0.00	2.17
15*	Helodidae sp. 5	0.00	0.00	2.13	0.00
16*	Helodidae sp. 6	1.90	1.37	1.49	1.25
17*	Helodidae sp. 7	0.40	1.19	0.64	0.00
18	Hydrophilidae sp. 1	0.00	0.00	0.00	1.00
19*	Cyclopoida sp. 1	0.20	0.00	0.50	0.00
20	Cyclopoida sp. 2	0.00	0.00	0.17	0.00
21	Cyclopoida sp. 3	0.00	0.00	0.50	0.00
22	*Atherix* sp. 1	0.00	0.00	0.33	0.00
23*	*Atherix* sp. 2	1.93	0.00	0.76	0.50
24	*Atherix* sp. 3	1.40	0.00	0.17	0.00
25*	*Atherix* sp. 4	1.80	0.67	0.31	0.50
26	*Elpona barnardi*	0.00	0.00	0.00	1.00

No.	Species/Morph Type	Catchment Group			
		Breede	Olifants-Berg	Eerste-Molenaars	Table Mountain
27	*Elporia capensis*	0.00	0.00	1.44	0.00
28	*Elporia uniradius*	0.60	0.00	0.33	0.00
29	*Bezzia* sp.	0.60	0.00	0.00	0.00
30	*Bezzia* sp. 1	0.00	0.00	0.21	0.50
31	*Bezzia* sp. 2	0.00	0.50	0.25	1.00
32	*Forcipomyia* sp. 1	0.40	0.00	0.54	0.00
33	*Forcipomyia* sp. 2	1.09	0.00	0.73	0.00
34	*Aphrotenia barnardi*	0.00	0.00	0.00	0.75
35*	*Aphrotenia tsitsikamae*	0.00	0.00	0.17	0.00
36	*Corynoneura dewulfi*	0.00	0.00	0.33	0.00
37*	*Corynoneura* sp. 1	1.27	1.71	2.08	2.16
38	*Cricotopus albitibia*	0.40	0.00	0.00	0.00
39	*Cricotopus dibalteatus*	0.00	0.00	0.00	1.06
40	*Cricotopus kisantuensis*	0.82	0.25	0.50	2.00
41	*Cricotopus* sp. 1	1.25	1.48	1.19	1.21
42	*Cricotopus* sp. 2	0.00	0.00	0.33	0.00
43	*Cricotopus* sp. 3	0.00	0.00	0.00	1.00
44	*Cricotopus* sp. 6	0.40	0.00	0.00	0.00
45	*Eukiefferiella calviger*	0.20	0.25	1.70	0.50
46	hairy orthoclad	0.60	0.25	0.00	0.00
47*	*Notocladius capicola*	2.31	1.90	1.74	0.00
48	Orthoclad gen. nov.	0.00	0.00	0.33	0.00
49	*Orthocladius* sp. 1	0.00	0.00	0.58	0.50
50	*Orthocladius* sp. 2	0.00	0.00	0.50	0.00
51*	*Parakiefferiella biloba*	0.00	0.00	0.00	0.50
52	*Parametriocnemus scotti*	0.27	0.86	0.94	2.38
53*	*Polypedilum* E sp.	1.58	0.00	1.92	0.00
54	*Polypedilum* U sp.	1.56	1.69	1.14	1.33
55*	*Rheocricotopus capensis*	1.58	1.58	2.06	2.15
56*	*Rheotanytarsus fuscus*	2.02	1.46	1.03	1.40
57	*Stempellinella truncata*	0.00	0.00	0.17	0.00
58*	*Tanytarsus* sp. 1	1.57	1.50	1.00	0.50
59*	*Tanytarsus* sp. 2	0.00	0.00	0.17	0.00
60*	*Thienemanniella* sp. 1	0.80	1.16	1.82	0.50
61	*Thienemanniella* sp. 2	0.45	0.00	0.00	0.00
62	*Thienemanniella* sp. 3	0.80	0.35	0.00	0.00
63*	*Tvetenia calvescens*	1.61	1.58	1.76	1.00
64	*Penicoma* sp. 1	0.00	0.00	0.00	0.00
65	*Penicoma* sp. 2	0.00	0.00	0.00	0.63
66*	*Limnophila nox*	1.67	0.45	0.00	0.00
67	*Limonia* sp. 1	0.80	0.00	0.25	0.00
68	*Limonia* sp. 2	0.00	0.00	0.50	0.00
69*	*Afroptilum sudafricanum*	0.60	1.33	1.26	0.00
70	*Baetis harrisoni*	3.24	2.11	3.35	2.30
71	*Baetis latus*	0.00	0.00	0.00	0.00
72	*Bugilliesia sp. nov.*	0.00	0.75	0.00	0.00
73	*Cheleocloeon excisum*	1.68	1.94	0.33	0.00
74	*Cloedes inzingae*	0.00	0.88	0.00	0.00
75	*Cloedes sp. nov.*	0.85	0.00	1.75	0.00
76	*Dabulamanzia sp. nov.*	0.00	0.00	0.83	0.00
77	*Demoreptus capensis*	2.00	2.07	2.84	0.00
78	*Gen. nov. sp. nov.*	0.00	0.00	0.67	0.00
79	*Labiobaetis sp. nov.* 1	1.77	0.00	0.00	0.00
80*	*Labiobaetis sp. nov.* 2	0.20	0.00	0.92	1.31
81	*Pseudocloeon sp. nov.*	0.00	0.00	0.00	0.00
82*	*Pseudocloeon vinosum*	1.07	1.34	0.17	1.25
83	*Pseudopannota maculosa*	0.00	0.75	0.00	0.00
84	*Caenis capensis*	0.00	1.63	0.00	0.00
85	*Caenis* sp. 1	1.00	0.25	0.00	0.00
86	*Caenis* sp. 2	0.00	0.88	0.00	0.00
87	*Caenis sp. nov.*	0.00	0.50	0.00	0.00
88	*Afronurus harrisoni*	1.30	0.00	0.67	0.00
89	*Adenophlebia auricalata*	0.00	0.50	0.00	0.00
90	*Adenophlebia peringueyella*	0.00	1.02	0.00	0.00
91	*Aprionyx peterseni*	2.20	1.25	1.93	0.00
92	*Aprionyx rubicundus*	0.00	0.00	0.99	0.00
93	*Aprionyx tabularis*	0.00	0.00	0.83	0.00
94*	*Castanophlebia calida*	2.08	1.00	1.73	0.00
95	*Castanophlebia albicanda*	0.00	0.00	0.00	0.00
96	*Chloroterpes nigrescens*	0.60	0.00	0.61	0.00
97	*Euthralus elegans*	1.11	0.00	0.00	0.00
98*	Ephemerellidae sp. 1	0.00	0.00	0.00	0.00
99	*Ephemerellina barnardi*	0.00	1.65	1.00	0.00
100*	*Nadineteila crassi*	0.70	0.00	1.63	0.00
101	*Lestagella penicillata*	1.71	1.71	1.69	0.00

No.	Species/Morph Type	Catchment Group			
		Breede	Olifants-Berg	Eerste-Molenaars	Table Mountain
102	*Lithoglaea harrisoni*	1.33	0.25	0.65	0.00
103	Coroxidae sp.1	0.00	0.00	0.17	0.00
104	*Laccocoris limigenus*	0.40	0.00	0.00	0.00
105*	*Laccocoris spurcus*	0.67	0.00	0.00	0.00
106	*Microvelia major*	0.60	0.00	0.33	0.00
107*	*Protojanira prenicei*	0.00	0.00	0.00	0.00
108	*Chloroniella perigueyi*	0.70	0.25	0.75	0.00
109	*Taeniochauloides ochraceopennis*	1.08	0.75	0.21	0.00
110	*Leptosialis africana*	0.00	0.00	0.17	0.00
111*	*Enallagma* sp. 1	0.00	0.00	0.00	0.00
112	*Pseudagrion* sp. 1	0.20	0.00	0.29	0.00
113*	*Pseudagrion* sp. 2	0.00	0.00	0.00	0.00
114*	*Notogomphus* sp. 1	0.83	0.00	0.00	0.00
115	*Paragomphus* sp. 1	0.40	0.00	0.00	0.00
116	*Trithemis* sp. 1	0.40	0.00	0.00	0.00
117	*Allocnemis leucosticta*	0.60	0.00	0.17	0.00
118	*Chlorolestes* sp. 1	0.40	0.00	0.00	0.00
119	*Chlorolestes* sp. 2	0.00	0.00	0.33	0.00
120	*Chlorolestes* sp. 3	0.00	0.00	0.50	0.00
121	*Aphanicerca bicornis*	0.45	0.00	2.01	0.00
122	*Aphanicerca capensis*	1.00	0.00	2.40	0.00
123	*Aphanicerca lyrata*	0.40	0.00	0.93	0.00
124	*Aphanicercella barnardi/scutata*	0.00	0.00	1.96	0.00
125	*Desmonemoura pulchellum*	0.00	0.50	1.10	0.00
126*	*Barbarochthon brunneum*	0.52	0.50	0.74	0.00
127	*Parecnomina resima*	0.30	1.58	1.11	0.00
128	*Cheumatopsyche afra*	0.00	1.46	0.00	0.00
129	*Cheumatopsyche maculata*	0.00	2.28	0.77	0.00
130	*Cheumatopsyche* sp. 1	0.00	0.00	0.33	0.00
131	*Cheumatopsyche* sp. 2	0.00	0.00	0.94	0.00
132	*Cheumatopsyche tomasseti*	0.00	0.75	0.00	0.00
133	*Sciadorus acutus*	0.00	0.00	0.28	0.00
134	*Hydroptila* sp. nov.	0.00	0.50	0.00	0.00
135	*Orthotrichia barnardi*	0.00	0.00	0.33	0.00
136	*Athripsodes* (Bergensis group) sp.	0.00	1.56	0.46	2.08
137	*Athripsodes* (Harrisoni group) sp.	0.00	0.00	0.67	0.00
138	*Athripsodes bergensis*	0.00	0.58	0.00	0.00
139	*Athripsodes harrisoni*	0.00	0.00	0.36	0.00
140	*Athripsodes schoenobates*	0.00	0.35	0.00	0.00
141	*Leptecho helcotheca*	0.00	0.50	0.00	0.00
142*	*Leptecho scirpi*	0.00	0.00	0.00	0.00
143	*Leptecho* sp. E	0.00	0.00	0.56	0.00
144	Leptoceridae sp. 1	0.00	0.00	0.50	0.00
145	*Leptocerus ?schoenobates*	0.00	0.00	0.42	0.00
146	*Oecetis modesta*	0.00	0.50	0.00	0.00
147*	*Petrothrincus circularis*	0.27	1.09	0.65	0.00
148	Philopotamidae sp. 1	1.08	0.50	0.00	0.00
149	Philopotamidae sp. 2	0.00	0.00	0.33	0.00

//Table 16.1 continued

16.4 Species contributing to within-catchment similarity

The SIMPER module in PRIMER was used to investigate within group characteristics of the Eerste-Molenaars, Breede, and Olifants-Berg groups of rivers. The Table Mountain group and the single Palmiet river (Dwars) were excluded because too few rivers were studied to allow comparisons. In the three groups analysed, 10-13 species contributed 50% to the average similarity, and 16-24 species contributed 75%. This left a long tail of 41-55 rarely occurring species contributing the other 25% of the similarity (Table 16.2-16.6).

Table 16.2 **Species contributing to within-group similarity of the Breede catchment group of rivers.** Species number (No.) and species or morph type are given for those contributing 75% to the average similarity, together with their average abundance rating, ratio, percent and cumulative percent. The ratio is calculated from the average abundance of a species within its group and the standard deviation of this. Therefore a high ratio indicates that it is a characteristic species of that catchment group (Clarke and Warwick 1994).

No.	Species/Morph Type	Average abundance	Ratio	Percent	Cumulative percent
70	*Baetis harrisoni*	3.24	4.38	7.91	7.91
11	*Epidelmis* sp. A	2.51	7.77	6.55	14.46
91	*Aprionyx peterseni*	2.20	5.29	5.50	19.96
47	*Notocladius capicola*	2.31	16.00	5.49	25.45
94	*Castanophlebia calida*	2.08	5.96	5.12	30.57
56	*Rheotanytarsus fuscus*	2.02	12.49	5.11	35.68
23	*Atherix* sp. 1	1.93	3.34	3.95	39.63
66	*Limnophila nox*	1.67	3.61	3.86	43.49
101	*Lestagella penicillata*	1.71	4.45	3.79	47.28
16	Helodidae sp. 6	1.90	1.15	3.41	50.69
63	*Tvetenia calvescens*	1.61	4.52	3.25	53.94
73	*Cheleocloeon excisum*	1.68	1.16	3.05	56.99
79	*Labiobaetis sp. nov.* 1	1.77	1.04	2.84	59.83
77	*Demoreptus capensis*	2.00	0.90	2.81	62.64
25	*Atherix* sp. 4	1.80	1.01	2.68	65.33
54	*Polypedilum* U sp.	1.56	1.02	2.56	67.88
55	*Rheocricotopus capensis*	1.58	1.04	2.50	70.38
37	*Corynoneura* sp.	1.37	1.15	2.43	72.81
53	*Polypedilum* E sp.	1.58	1.02	2.28	75.09

Table 16.3 **Species contributing to within-group similarity of the Olifants-Berg catchment group of rivers.** Species number (No.) and species or morph type are given for those contributing 75% to the average similarity, together with their average abundance rating, ratio, percent and cumulative percent.

No.	Species/Morph Type	Average Abundance	Ratio	Percent	Cumulative percent
73	*Cheleocloeon excisum*	1.94	7.27	6.37	6.37
129	*Cheumatopsyche maculata*	2.28	9.20	6.35	12.72
47	*Notocladius capicola*	1.90	4.79	5.10	17.81
37	*Corynoneura* sp.	1.71	2.34	5.04	22.85
70	*Baetis harrisoni*	2.11	3.55	4.94	27.79
54	*Polypedilum* U sp.	1.69	5.68	4.87	32.67
41	*Cricotopus* sp. 1	1.48	5.41	4.73	37.40
55	*Rheocricotopus capensis*	1.58	2.36	4.66	42.05
56	*Rheotanytarsus fuscus*	1.46	2.53	4.52	46.57
77	*Demoreptus capensis*	2.07	1.59	4.50	51.08
127	*Parecnomina resima*	1.58	5.86	4.22	55.30
58	*Tanytarsus* sp. 1	1.50	6.26	4.18	59.48
63	*Tvetenia calvescens*	1.58	2.99	4.15	63.63
84	*Caenis capensis*	1.63	2.65	3.99	67.61
60	*Thienemanniella* sp. 1	1.16	5.37	3.56	71.17
101	*Lestagella penicillata*	1.71	0.82	3.50	74.67

Table 16.4 **Species contributing to within-group similarity of the Eerste-Molenaars catchment group of rivers.** Species number (No.) and species or morph type are given for those contributing 75% to the average similarity, together with their average abundance rating, ratio, percent and cumulative percent.

No.	Species/Morph Type	Average abundance	Ratio	Percent	Cumulative percent
70	*Baetis harrisoni*	3.35	1.33	5.51	5.51
77	*Demoreptus capensis*	2.84	1.35	4.70	10.20
122	*Aphanicerca capensis*	2.40	3.07	4.47	14.67
15	Helodidae sp. 5	2.13	10.08	4.23	18.90
37	*Corynoneura* sp.	2.08	5.01	4.21	23.11
121	*Aphanicerca bicornis*	2.01	6.57	4.01	27.12
55	*Rheocricotopus capensis*	2.06	5.61	3.98	31.10
124	*Aphanicercella barnardi/scutata*	1.96	9.08	3.78	34.88
53	*Polypedilum* E sp.	1.92	6.28	3.70	38.59
63	*Tvetenia calvescens*	1.76	7.38	3.66	42.24
60	*Thienemanniella* sp. 1	1.82	3.98	3.47	45.71
91	*Aprionyx peterseni*	1.93	1.35	3.04	48.75
11	*Epidelmis* sp. A	1.73	4.90	3.00	51.75
47	*Notocladius capicola*	1.74	2.92	2.92	54.67
7	Elmidae sp.	1.57	6.56	2.82	57.49
94	*Castanophlebia calida*	1.73	1.16	2.41	59.90
8	Elmidae sp. 1	1.42	1.34	2.16	62.06
16	Helodidae sp. 6	1.49	1.20	2.14	64.20
100	*Nadinetella crassi*	1.53	1.26	2.14	66.34
27	*Elporia capensis*	1.44	1.10	1.96	68.30
4	*Strina* sp. 1	1.41	1.19	1.87	70.17
12	*Epidelmis* sp. B	1.43	0.78	1.67	71.84
9	Elmidae sp. 2	1.57	0.77	1.65	73.49
101	*Lestagella penicillata*	1.69	0.76	1.65	75.14

Table 16.5 **Species contributing to within-group similarity of the Table Mountain catchment group of rivers.** Species number (No.) and species or morph type are given for those contributing 75% to the average similarity, together with their average abundance rating. As there are only two rivers in this group there are no ratios or percentages.

No.	Species name	Average abundance
11	*Epidelmis* sp. A	3.17
136	*Athripsodes* (Bergensis group) sp.	3.08
52	*Parametriocnemus scotti*	2.38
70	*Baetis harrisoni*	2.30
94	*Castanophlebia calida*	2.18
1	*Paramelita nigroculus*	2.17
14	Helodidae sp. 4	2.17
37	*Corynoneura* sp.	2.16
55	*Rheocricotopus capensis*	2.15
95	*Castanophlebia albicanda*	2.00
40	*Cricotopus kisantuensis*	2.00
101	*Lestagella penicillata*	1.94
56	*Rheotanytarsus fuscus*	1.40
54	*Polypedilum* U sp.	1.33

No.	Species name	Average abundance
80	*Labiobaetis* sp. nov. 2	1.31
82	*Pseudocloeon vinosum*	1.25
16	Helodidae sp. 6	1.25
41	*Cricotopus* sp. 1	1.21
102	*Lithogloea harrisoni*	1.20
39	*Cricotopus dibalteatus*	1.06

//Table 16.5 continued

Table 16.6 Species representing the Dwars River. Species number (No.), species or morph type and average abundance rating.

No.	Species/Morph Type	Average abundance
80	*Labiobaetis sp. nov.* 2	4.42
17	Helodidae sp. 7	4.10
15	Helodidae sp. 5	3.30
19	Cyclopoida sp. 1	3.00
142	*Leptecho scirpi*	3.00
11	*Epidelmis* sp. A	3.00
107	*Protojanira prenticei*	3.00
25	*Atherix* sp. 4	3.00
7	Elmidae sp.	3.00
56	*Rheotanytarsus fuscus*	3.00
63	*Tvetenia calvescens*	3.00
16	Helodidae sp. 6	2.88
35	*Aphrotenia tsitsikamae*	2.71
53	*Polypedilum* E sp.	2.67
94	*Castanophlebia calida*	2.67
113	*Pseudagrion* sp. 2	2.50
66	*Limnophila nox*	2.40
23	*Atherix* sp. 2	2.33
100	*Nadinetella crassi*	2.33
60	*Thienemanniella* sp. 1	2.33

Two main taxonomic Orders are represented in every group: Diptera (flies) and more specifically the sub-order Chironomidae (non-biting midges), and Ephemeroptera (mayflies). Two of the three main groups (Breede and Eerste-Molenaars) also had contributions from Coleoptera (beetles). Plecoptera (stoneflies) and Trichoptera (caddis flies) each appear in only one catchment group, but are important contributors within their groups.

16.5 Species contributing to between-catchment dissimilarity

SIMPER was also used to compute between-group dissimilarities, based on the average dissimilarity between all pairs of inter-group sites. As an example, every site from the Olifants/Berg catchment group was compared with every site from the Breede catchment group, and the average dissimilarity of the groups then disaggregated to derive the separate contributions to it of each species (Appendix 16.1).

With large numbers of species in each catchment group, it is not surprising that dissimilarity between groups does not rest with a few species. Twenty to 34 species are needed to account for 50% of the dissimilarity between different catchment groups, with up to 88 species needed to account for 90% of the

dissimilarity. These are extraordinarily high numbers when compared with, for instance, marine data such as that for a Bristol Channel study of zooplankton (Clarke and Warwick 1994). There, five species accounted for 50% of the dissimilarity and 12 species for 90%.

16.6 Species that typically occur in all the catchments

The top-scoring species in terms of their contribution to group similarity were also approximately the most abundant species (Table 16.1). Species with high average abundance were ones that were found at very consistent levels in the sites within their groups, and would thus be good typifiers of their catchments. Those with high average abundances in several catchment groups would be typical members of all these, and thus not good catchment indicators. Such common species included the leptophlebiid mayfly *Castanophlebia calida*, the baetid mayflies *Baetis harrisoni* and *Demoreptus capensis*, the ephemerellid mayfly *Lestagella penicillata*, the chironomids *Corynoneura sp.*, *Notocladius capicola*, *Rheocricotopus capensis*, *Rheotanytarsus fuscus*, *Polypedilum* E sp. and *U sp.*, *Thienemaniella* sp. 1 and *Tvetenia calvescens*, and the coleopterans Helodidae sp. 6 and *Epidelmis* sp. A.

16.7 Species from single catchments and contenders for catchment indicator species

The 216 invertebrate samples taken from the least-disturbed rivers reveal that a number of species were confined to one catchment group (Table 16.1). Thirty-one species were recorded only in the Eerste/Molenaars group, 17 in the Olifants/Berg group, ten in the Breede group, seven in the Table Mountain group and four in the Palmiet tributary. It is not suggested that the species shown occurring in only one catchment are endemic to those catchments. Single sets of samples taken at one place and time cannot provide that information. Additionally, many species were present in very low numbers, and may well have been rare species, present in the other catchments but not collected. It might be significant, however, that for the Eerste/Molenaars and Olifants/Berg groups, a high percentage of 30-31% of the species listed were found in only one catchment. In the remaining three groups, a much lower 11-16% of the species were found in only one catchment. Overall, it would be worth investigating if the Eerste/Molenaars and Olifants/Berg catchments have a higher biodiversity or higher proportion of rare species than neighbouring catchments.

Of the species found in only one catchment, those with high average abundances would be good contenders as discriminators of that catchment. Species meeting this requirement were, for instance, the trichopteran *Cheumatopsyche afra* for the Olifants/Berg catchment group, and the stonefly *Aphanicercella barnardi*, the blephariceríd midge *Elporia capensis*, and the helodid beetle (Helodidae species 5), for the Eerste/Molenaars catchment group. These species could be investigated further to ascertain if their distributions are limited to single catchments.

16.8 Summary

Sections 16.3-16.7 indicate that the database created in this project contains a wealth of information. This would repay further investigation, particularly in the fields of catchment and river signatures, catchment biodiversity, and biogeographical distribution patterns. The topic is re-visited in Chapter 20.

17. SPECIES-SPECIFIC HYDRAULIC HABITAT

17.1 Introduction

In the summary of Chapter 11, it was noted that the hydraulic biotopes identified were larger in area and described broader hydraulic conditions than expected. They appear to describe the characteristic set of hydraulic conditions experienced by broad assemblages of species, with these being in areas that are sufficiently hydraulically distinct, in terms of flow type and substratum, to be coarsely distinguishable by eye. Hydraulic biotopes do not, however, describe and locate the very specific conditions in which one species within that assemblage might be found. They describe, for example, a bio-rapid with turbulent water flowing over boulders, which supports many species in a variety of microhabitats, but they do not single out any one of those microhabitats, such as a chute where water is forced at speed between two boulders, which might be the only kind of hydraulic condition in that bio-rapid in which a specific species of simulid (blackfly) larvae occurs.

To describe the physical conditions typically inhabited by a single species, rather than by an assemblage of species, it is necessary to work at a finer resolution than hydraulic biotope. It is suggested in Chapter 11 that this level of detail could be called the *hydraulic habitat* of the species. This is an appropriate unit for the study of species, as it will directly describe the conditions in which that species was found. A description of the hydraulic habitat of a species could be derived through making many measurements of where the conditions where the species was found, and developing a profile of its typical physical habitat. In this chapter, the process of doing this is begun. The work will be continued in Ms Schael's PhD. thesis.

17.2 SI curves

SI (Suitability Index) curves (Bovee 1986) are created from frequency plots of the numbers of individuals of a species occurring over the measured range of a single variable. They can be used to graphically illustrate the response of a species to single hydraulic variables such as water velocity. The curves for continuous data tend to have a bell shape (or some part of it), with the highest point representing the hydraulic condition (i.e. in this case, the water velocity) at which most individuals of the species were found. These high values tend to be viewed as the optimal conditions for that species. SI curves of a range of hydraulic variables, such as water depth, water velocity and substratum size, would collectively describe the optimal hydraulic habitat of a species (Figure 17.1).

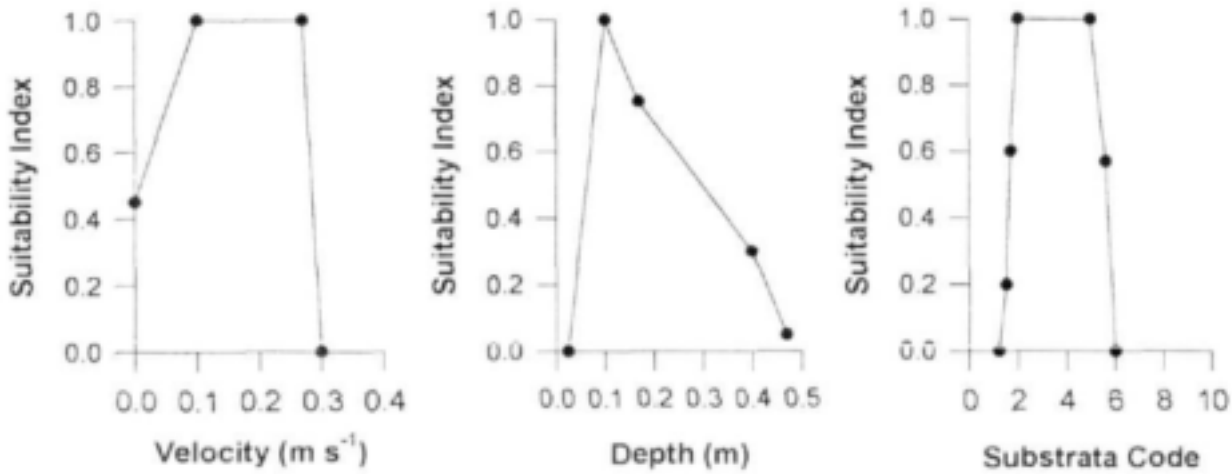


Figure 17.1 Examples of Suitability Index (SI) curves (from Bovee 1982; Bullock *et al.* 1991; King and Tharme 1994).

These three variables are used in flow-assessment methods such as the Instream Flow Incremental Methodology (IFIM) (Bovee 1986), because they are the variables that are routinely used in hydraulic models. An environmental hydraulic model, such as PHABSIM II in IFIM, simulates the condition of the hydraulic environment in terms of these three variables over a range of discharges, and then links this with known optimum conditions for selected species, described using the same three variables. The output from PHABSIM II, which can be used in negotiations over water allocations for river maintenance, is a graph of available habitat over the range of modelled discharges. Additional SI curves showing the species' distribution related to, for instance, the occurrence of filamentous algae or overhead shade, cannot be incorporated into hydraulic models, but can be used separately to provide further detail of optimal habitat.

There are many aspects to consider when creating SI curves, such as choosing an appropriate analytical approach (e.g. frequency analysis, regression analysis, nonparametric tolerance intervals), pooling data from different rivers and sampling dates; coding abundances; differentiating between utilisation, availability and preference curves; and so on. King & Tharme (1994) explained these aspects with examples, and Bovee & Zuboy (1988) provided a more detailed treatment of all aspects. It is not the intention to repeat these analyses here with the data from this project, but rather to demonstrate the kinds of data available and point out their potential. Further analyses will be completed by Ms Schael in her thesis.

17.3 The available data

The project database can be used to extract all hydraulic records linked to any one species collected during this project. Each record for the species will consist of the following relevant data:

- river;
- date sampled;
- sample number, linked to a specific mapped collection point within the site;
- life stage of the species (larva, pupa, nymph, adult);
- number of individuals;
- numbers converted to an abundance rating;
- flow type;
- substratum;
- average depth from all readings taken at that sample point;
- average near-bed velocity from all readings taken at that sample point;
- average 0.6 depth velocity from all readings taken at that sample point.

All other data linked to the samples could, of course, be accessed also.

17.4 Production of SI curves

Three species displaying different responses to hydraulic conditions are used to demonstrate what can be gleaned about their optimal hydraulic habitats. The full range of velocities in which all three species were found was divided evenly into 11 classes. All records for each species were then allocated to one velocity class. The abundance ratings for each species within each velocity class were added, to give a final coarse indication of the conditions in which most of the individuals were found. It is stressed that there are procedures for analysing and pooling data (Bovee & Zuboy 1988) that have not been followed in this brief example, but which anyone creating SI curves should be aware of and adhere to where possible. The same publication also describes how to smooth the frequency plots to produce curves, and how to standardise the plot through allocating the highest point of the curve a value of one. Each value of the variable being displayed then has a suitability between 0 (no individuals recorded - unsuitable habitat) and 1 (most individuals recorded - optimal habitat).

17.4.1 *Rheotanytarsus fuscus*

This chironomid (midge) larva lives on rocky surfaces, and creates a net to trap food particles passing in the current. It had been assumed that it preferred fast-flowing conditions, which would bring the particles to its net. The histogram of velocity-related distributions suggests this is not necessarily so. The highest number of individuals occurred in the lowest velocity class (0.00–0.01 m s^{-1}) with a diminishing number of individuals at velocities up to more than 1.00 m s^{-1} (Figure 17.2). If the data were separated by river, they showed the same pattern, indicating that the picture is not an artefact of pooling data.

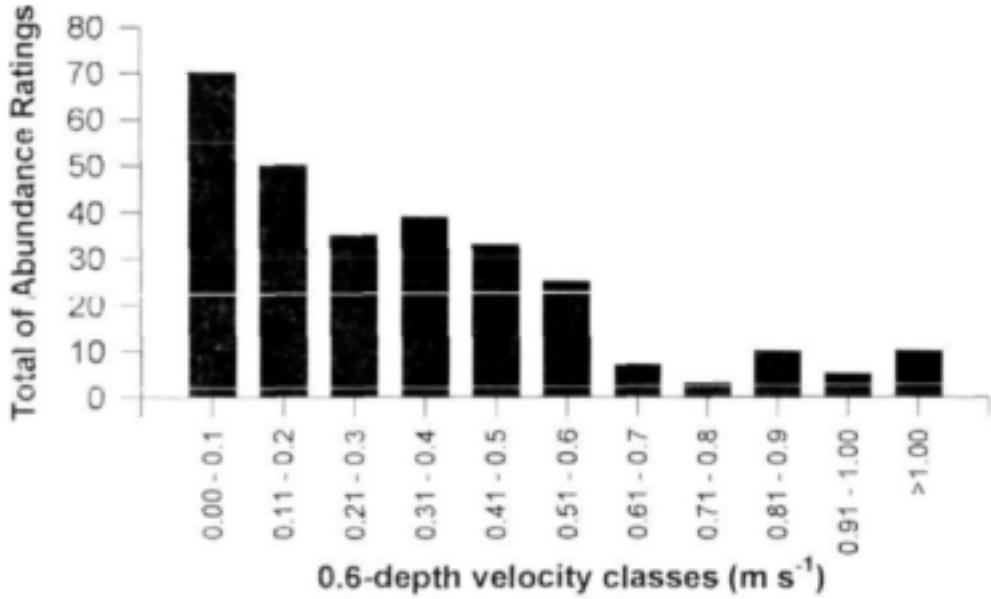


Figure 17.2 Frequency plot of distribution of the midge larva *Rheotanytarsus fuscus* in terms of 0.6-depth water velocities. The 0-0.1 m s^{-1} velocity class would be recognised as representing the "optimum habitat", and would provide the high point of the SI curve. All occurrence records of *R. fuscus* from this project have been pooled.

It remains possible that the low values were measured in areas of hydraulic cover among boulders and cobbles, in what were otherwise fast-flowing areas. To investigate this, the flow types in which the species occurred were assessed. *R. fuscus* was found in the full range of flow types from "No Flow" to "Chute" and "Cascade", with a mild bias toward the slower flow types. In terms of hydraulic biotopes (HBs), a similar pattern emerged to that pertaining to flow types, with the species occurring in all the recognised HBs (Table 17.1). However, it was most common in fast HBs, 61% of the samples it was in were collected from bio-riffles through bio-rapids. The slower HBs, bio-pool and bio-run, accounted for 33.6% of the samples in total. In terms of Morphological Units (MUs), *R. fuscus* was collected from 18 different types, with five types (Plane-bed, Pool, Riffle, Rapid, and Step) each accounting for more than 10% of the samples containing the species (Table 17.2). Plane-bed MUs yielded the largest percentage of samples (24.6%) and the greatest variability of flow types.

Two possible explanations for the wide range of flow types, HBs and MUs inhabited by *R. fuscus* are as follows. First, the species may need a mix of flows to deliver food particles (fast flows) and settle them (slower flows) for it to capture and consume. Or, second, there may be another factor, such as water chemistry, temperature or shade, that is a stronger determinant of their distributions, and they are relatively flow-insensitive. For instance, of the 134 samples with *R. fuscus*, 40% were from disturbed rivers where there may have been heightened levels of nutrients and suspended solids that favour this species. Species-specific studies are needed to test these hypotheses.

Table 17.1 **The percentage of samples within various HBs for the three species.** The "fast" category refers to Newlands River samples, which were not allocated to HBs. The "unknown" samples are from the Wit River because it was not analysed for HBs. The "undetermined" samples were not allocated to an HB.

Hydraulic Biotope	Percentage of Samples		
	R. fuscus	*D. capensis*	*C. excisum*
Bio-Pool	11.2	7.8	40.0
Bio-Run	22.4	7.8	36.7
Bio-Run/Pool	0.7	0.0	0.0
Bio-Riffle	20.1	28.1	6.7
Bio-Rapid/Riffle	13.4	6.3	6.7
Bio-Rapid	27.6	48.4	5.0
Bio-Stream	0.7	0.0	3.3
"Fast"	1.5	0.0	0.0
unknown	2.2	1.6	0.0
undetermined	0.0	0.0	1.7

Table 17.2 **The percentage of samples within different types of MUs for each species.** "Indeterminable" denotes samples from Wemmershoek River, where MUs had been obliterated and so were not mapped.

Morphological Unit	Percentage of Samples		
	R. fuscus	*D. capensis*	*C. excisum*
Pool	20.1	20.3	15.0
Run	6.0	4.7	18.3
Plane-bed	24.6	21.9	28.3
Riffle	11.9	15.6	8.3
Rapid	11.9	14.1	3.3
Step	10.4	9.4	1.7
Bar	0.7	1.6	5.0
Lateral Bar	0.7	3.1	0.0
Mid-channel Bar	2.2	4.7	0.0
Lateral Channel	0.0	4.7	0.0
Secondary Channel	0.7	0.0	0.0
Backwater	0.7	0.0	1.7
Bedrock Pavement	1.5	0.0	3.3
Step/Pool	3.0	0.0	0.0
Plane-bed/Pool	2.2	0.0	0.0
Canal	0.7	0.0	0.0
Stream	0.7	0.0	0.0
Indeterminable	1.5	0.0	15.0

17.4.2 *Demoreptus capensis*

Of all the baetid mayflies in Western Cape rivers, this species is most distinctly linked with areas of large cobble and boulder in fast, turbulent water. The most common flow types in which it was recorded were Undular and Broken Standing Waves (USW and BSW), Fast Riffle Flow (FRF) Chutes (CH) and Cascades (CAS). Its velocity-related distribution reflects this, with abundances over all the sites where it occurred peaking in the 0.41-0.50 m s^{-1} velocity class (Figure 17.3). Data from individual rivers showed the same general trend. Individuals did occur over the full range of velocities, however, with more in the size classes lower than the optimum than in those higher.

D. capensis mostly occurred in fast HBs (Table 17.1). Eighty three percent of the samples containing this species were from bio-riffles, bio-rapids or some combination of these. The low measured velocities could have been taken in areas of hydraulic cover within turbulent waters, but clearly the effect of being within a patch of what is considered hydraulically fast water plays a role in the distribution of *D. capensis*. There were ten different MUs represented by these samples. Of those, four MU types had >10% of the samples, with Plane-bed dominant followed by Pool (Table 17.2). It should be noted that a geomorphological Pool could have moderate rather than slow water velocities, and be recognised as a Run by ecologists (see discussion in Chapter 14).

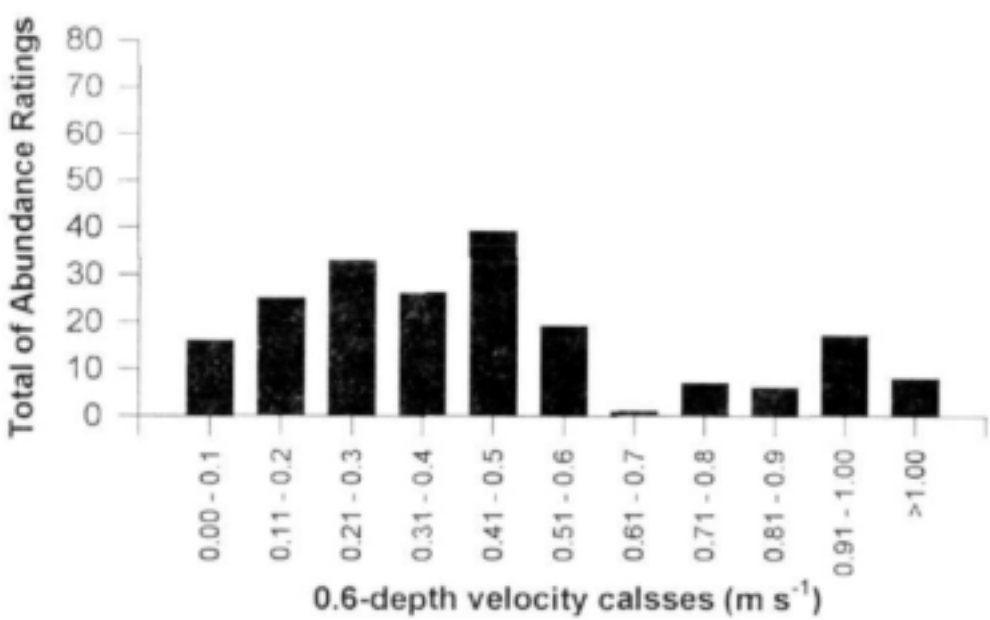


Figure 17.3 **Frequency plot of distribution of the baetid mayfly nymph *Demoreptus capensis* in terms of 0.6-depth water velocities.** The 0.41-0.50 m s^{-1} velocity class would be recognised as representing the "optimum habitat", and would provide the high point of the SI curve. All occurrence records of *D. capensis* have been pooled.

17.4.3 *Centroptilum excisum*

This baetid mayfly typically occurs in slow-flowing areas, and is most abundant in summer. It was found in the full range of flow types, but when linked with the faster flow types it must have been in areas of hydraulic cover because recorded velocities were almost always close to zero. Its higher abundances were mostly linked to the slower flow types Rippled Surface (RS), Smooth Boundary Turbulent (SBT) and Barely Perceptible Flow (BPF). It was found on a wide range of substrata, from bedrock, through boulder, cobble, gravel, sand, moss and *Scirpus*. Its velocity-related distribution reflects this, with abundances over all the sites where it occurred peaking in the 0-0.10 m s^{-1} velocity class (Figure 17.4). Data from individual rivers showed the same general trend.

C. excisum mostly occurred in slow HBs, with bio-pools and bio-runs accounting for 76.7% of the samples in which it was found (Table 17.1). It was collected from nine different MUs, with three yielding >10% of the samples, and was also in one group of "indeterminable" samples, all from the Wemmershoek River. This river, which contributed 15% of the samples (n=9) containing *C. excisum*, could not be mapped in terms of MUs because the bed was bulldozed after invertebrate sampling was completed but before the MU mapping exercise. Eight of the nine Wemmershoek samples were from bio-pools and one from a bio-riffle. Most were from hydraulically slow conditions, reinforcing the finding that *C. excisum* occurs in slow water.

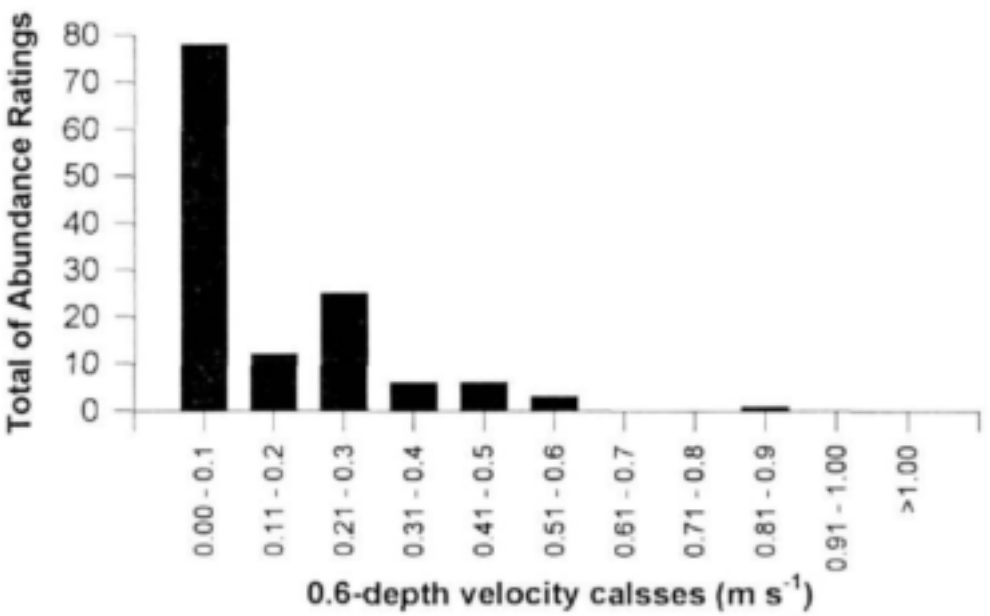


Figure 17.4 Frequency plot of distribution of the baetid mayfly nymph *Centroptilum excisum* in terms of 0.6-depth water velocities. The 0.00-0.10 m s^{-1} velocity class would be recognised as representing the "optimum habitat", and would provide the high point of the SI curve. All occurrence records of *C. excisum* have been pooled.

17.5 Presence and absence of species at individual sites

The above frequency plots were created using all the data collected on each species during this project. Analyses of these data for each species revealed that many samples did not contain any individuals. These absences are of interest in two ways.

First, each species was completely absent from several whole sites, that is, they did not occur in any of the 12 samples collected at each of a number of sites. *R. fuscus* was absent from the Eerste, Langrivier and Swartboskloof sites, all in the same valley, but occurred in every other river sampled. *D. capensis* was absent from 14 rivers and present in 14. It was absent from Wemmershoek on the Berg; Du Toits and Wolwekloof on the Breede; Disa, Window, Newlands and Cecilia on Table Mountain; the Palmiet and its tributary the Dwars; Elandspad on the Molenaars; Davidskraal; and the Groot, Middeldeur and Noordhoek on the Olifants. *C. excisum* was absent from 13 rivers: the Wit on the Breede; Disa, Window, Newlands and Cecilia on Table Mountain; the Eerste, Langrivier and Swartboskloof on the Eerste; the Elandspad and Elands on the Molenaars; Davidskraal; and the Palmiet and Dwars on the Palmiet. Some of these absences might be due to the unsuitability of the river zone sampled or the substrata, or to disturbance, whilst others – such as the complete absence of *D. capensis* and *C. excisum* from all Table Mountain study rivers - may have more obscure explanations related to historical biogeographical distributions. This topic could be explored further with the project's database.

Second, for the rivers where the species did occur, there were great numbers of samples from which they were absent. If only the samples from the rivers where the three species occurred were taken into account, the following statistic emerged:

- *R. fuscus* was absent from 197 out of possible 331 samples (present in 134 or 40% of samples);
- *D. capensis* was absent from 156 out of a possible 220 samples (present in 64 or 29% of samples);
- *C. excisum* was absent from 123 out of a possible 183 samples (present in 60 or 33% of samples).

If a species occurred at a site it could be assumed that the macro-environment, in terms of biological zone, altitude, water chemistry, water temperature, slope, and so on, was suitable. Its absence from some samples taken from that site could then probably be attributed to unsuitable micro-environment. Almost all variables used to describe micro-environment, with exceptions such as "shade", are related to flow: water velocity and depth, substratum particle size, the depth and nature of epilithic growth on rocks, hydraulic cover, the slipperiness of unscoured, silt-covered rocks, the accumulation of filamentous algae, and more. The absence of a species from some samples could then be a flow-related response to one or more micro-environmental conditions being unsuitable. In the above bulleted examples, *D. capensis* might be seen as most selective in terms of velocity (because it was absent from the highest percentage of samples) and thus most sensitive to changes in velocity. By the same reasoning, *R. fuscus* would be seen as least selective and least flow-sensitive. Again, this topic could be explored further with the project's database.

17.6 Conclusion

SI curves are useful tools to develop predictive capacity of how individual species will react to flow changes. A first description of SI curves will be made for a number of species in Ms Schael's PhD. thesis, using the database from this project. Such descriptions should become refined with time, as other studies add data. Such a knowledge base needs to be developed to improve inputs to the environmental flow assessments presently being done in South Africa for setting the Ecological Reserve (DWAF 1998).

The data produced in this project could be further analysed to provide insight on hydraulic sensitivities of species and historical biogeographical distribution patterns.

18. THE HYDRAULIC NATURE OF FLOW TYPES

18.1 Introduction

The categories of flow types used in this project appear to be influenced by three main hydraulic variables: substratum particle size, current speed and water depth. It was noticed that at consecutive points measured along a cross-section, flow type could change if just one of these three variables changed. At the next point, flow type could revert back to that recorded at the first point, but due to a change in a different variable. As an example, the first point may have had Rippled Surface flow type, and certain values for water depth and average velocity. At the next point, with an increase in velocity but no change in substratum or water depth, the flow type may have changed to Undular Standing Waves. At the third point, the flow type might have reverted to Rippled Surface, with the substratum and velocity remaining as at the second point, but with an increase in water depth. It thus seems that any one flow type can be created by different combinations of values of these three variables.

It was speculated that if the values for all measured points could be plotted, with the three variables represented on the x, y and z axes, then the flow types might appear as "clouds" of points in three-dimensional space. If such a relationship could be demonstrated, then it might be possible, for instance, to predict an approximate water velocity by knowing the flow type, water depth and substratum size. These latter three variables do not require sophisticated measuring devices.

Two university engineering departments were thus approached to investigate the hydraulic nature of flow types. Data from this project were provided, and the investigations were done within the routine post-graduate or research programmes of those departments without funding from this project. The results are outlined below.

18.2 University of Stellenbosch results

Analysis of the Abiotic-biotic Links project data was done in the Department of Civil Engineering by Verno Jonkers, under the supervision of Prof. André Görgens. The work was done within WRC project K5/979 ***Hydraulic characteristics of ecological flow requirement components in winter rainfall rivers***, and a separate report on the findings presented to the authors of this report.

The nature of flow types, as discussed in Section 18.1, was not addressed. Instead, each sample point where an invertebrate sample was collected was allocated to one of the original hydraulic biotopes recognised by the geomorphologists (Rowntree 1996). In other words, the ecologically derived hydraulic biotopes listed in Chapter 11 were not used, because they were not yet available when the Stellenbosch work was done. Froude numbers, Reynolds numbers and velocity:depth ratios were calculated for each sample point.

Using these data, three analysis were done:

- the hydraulic characteristics of different types of hydraulic biotopes;
- habitat diversity per river zone (mountain or foothill) and per class of hydraulic biotope;
- distribution of velocities per class of hydraulic biotope.

The conclusions were as follows (Jonkers, pers comm.):

- Different classes of hydraulic biotopes, as defined by a recognised combination of substratum and flow type, had unique hydraulic attributes which held true across both mountain and foothill river zones.
- The same category of substratum provided different degrees of habitat diversity in mountain and foothill reaches, because of the different flow types characteristic of these zones.

18.3 University of Cape Town results

Analysis of the Abiotic-biotic Links project data was done in the Department of Civil Engineering by Sonja Karassellos as a fourth-year undergraduate project, under the supervision of Mr Neil Armitage. The thesis, titled ***Exploring the links between ecological flow types in rivers and local hydraulics***, was submitted in November 1999.

Again, the nature of flow types, as discussed in Section 18.1, was not addressed. Instead, the data provided from the Abiotic-biotic Links project were separated into different flow types, and hydraulic indices such as the Reynolds Number, Froude Number, and Shear Velocity were calculated. This information was used to search for any possible relationships between the visual appearance of a flow and the hydraulic measurements taken of the same flow.

The main findings were as follows.

- There is no clear range in values of the Reynolds Number linked to each flow type. Flow types thus cannot be defined by the Reynolds Number.
- There is a "fuzzy" range of values of Froude Numbers linked to each flow type, with the value increasing from slow to fast flow types. The 25th and 75th percentiles of Froude values linked to each flow type provided a reasonably clear reflection of this trend. The 50th percentile values could be used to divide the flow types into four categories:
    - *Low sub-critical:* NF, BPF, SBT, RS, TR, SRF ($Fr<0.3$);
    - *High sub-critical:* FRF, USW, BSW, CAS, Boil ($0.3<Fr<0.7$);
    - *Transitional:* STR, CH ($0.7<Fr<1.05$);
    - *Super-critical:* FF ($Fr>1.05$).
- There is no correlation between BSW and USW and the hydraulic description of a standing wave, where the Froude number would be equal to one. It is suggested that the wave so recorded is not a true standing wave but is one induced by shallow water flowing rapidly over a bed element such as a boulder or large cobble. The term Induced Wave is suggested as more appropriate in this study of low-flow conditions.

- There is no distinct correlation between Shear Velocity and flow type. Shear Velocity is a measure of the shear stress and velocity gradient near the boundary with the bed, and provides an indication of the increase in shear stress as distance to the bed decreases.
- Site Gradient, Relative Depth and Relative Velocity provided some separation of flow types, but were less useful for this then Froude Numbers.

In conclusion, a new classification was suggested that would group the flow types based on their Froude Number (as listed above). This is quite similar to the reduced number of flow-type categories suggested for consultancy work (Chapter 19). The main differences appear to be that:

- the engineering analysis distinguishes between various categories of turbulent flow, which is not reflected in the distribution of invertebrate assemblages (although it might be in the distribution of individual species within the assemblages);
- the engineering analysis does not distinguish between deep fast flow (RS) and shallow flickering flow (FRF), but the invertebrate assemblages indicate there is an ecological difference;
- the invertebrate distributions indicate that the last two flow types (RS and FRF) are distinguished from slow smooth flow (SBT), but in the engineering analysis all three are grouped in the category of Froude Number <0.3.

19. APPLICATION OF THE HABITAT-MAPPING TECHNIQUE IN ENVIRONMENTAL FLOW ASSESSMENTS

19.1 Introduction

A project to assess the environmental flow requirements for the rivers involved in the Lesotho Highlands Water Scheme provided the opportunity to apply the habitat-mapping techniques initiated in this project, and further develop them.

The overall "health" of a river ecosystem is intimately linked to its flow regime. Rivers as ecosystems function less efficiently when their physical condition is affected by flow manipulation than when in their natural state (Davies & Day 1998). Anthropogenically disturbed rivers often need costly measures to replace "silent services" (such as control of bank erosion or attenuation of floods) once naturally provided by the river ecosystem. Aquatic ecologists are aware that the manipulation of river flow, for water-resource purposes, is affecting both the abiotic and biotic components of rivers (Campbell 1986; Boon *et al.* 1992; McCully 1996; Davies & Day 1998). Disturbed channels are changing in shape and size, and there are widespread reports of areas that used to support specific plant or animal species but that no longer do so. Although flow-related species' disappearances are sometimes due to deterioration in water quality resulting from reduced dilution capacity, loss or deterioration of physical habitat is a contributing, and often dominant, determinant in these disappearances (Statzner & Higler 1986). Stazner & Higler, challenging well-known hypotheses on biotic distributions such as the River Continuum Concept (Vannote *et al.* 1980), argued further that although other physical variables, such as temperature, are important determinants of biotic distributions, on a world-wide scale, stream hydraulics is the major factor affecting biological stream zonation. Similar thinking from other river specialists has resulted in the recognition of environmental flow assessments as an important management tool for the sustainable use of rivers.

Environmental flow assessments are now routinely completed in South Africa for any river targeted for water-resource development. Such assessments are designed to ascertain a modified flow regime for the river, which would allow some abstraction of water whilst maintaining the river at some desired management class (i.e. condition) (Kleynhans *et al.* 1998).

19.2 Role of habitat mapping in environmental flow assessments

Where the Building Block Methodology (King & Louw 1998; King *et al.* 2000) or DRIFT (King and Brown in press) are applied for flow assessments, site-specific information of physical conditions is usually provided from two main sources. Firstly, the geomorphologist completes a reach analysis of the full length of river involved in the flow assessment (Rowntree & Wadeson 1998). This identifies similar stretches of river in terms of *inter alia* altitude, gradient, sediment production and transport, channel type and pattern, and substrata. Each flow-assessment site is located within a specific reach type, aiding understanding of its morphological character. A general geomorphological description of the sites is also usually provided by the geomorphologist, along with some within-site data of substrata and local hydraulics derived from the surveyed cross-sections by the hydraulic modeller.

These cross-sections form the second source of data on physical conditions at a site. The cross-sections are selected jointly by the hydraulic modeller, the ecologists and the geomorphologist. They are placed to describe both representative and critical physical habitats for the biota, and to provide the necessary data for detailed hydraulic modelling. In terms of information on habitat, they provide point-by-point data on wetted area, substrata, cover and water depth. If discharge readings are taken at a section, they also provide data on velocity distributions across the wetted area.

Although velocity distributions across such cross-sections are available for all measured discharges, they are not available for the range of discharges then simulated by the hydraulic modeller. Rather, information is usually produced, per discharge, on simulated water surface elevations (which can be converted to water depths along the cross-section) and an *average* velocity for the cross-section. Thus, information on the range of velocities pertaining at any one cross-section for any one discharge is not available through the modelling techniques presently used with the BBM. One reason for this is that such precise low-flow hydraulic modelling is difficult, and the results are often of uncertain quality (King & Tharme 1994). Another short-coming of the hydraulic modelling is that its results are restricted to a description of conditions at the surveyed cross-sections. It is assumed that the cross-sections describe hydraulic conditions in any similar part of the study site. Thus, for instance, one surveyed cross-section across a riffle is assumed to describe all riffles at the site and, by implication, all riffles within the reach and reach type represented by the site. But to date, details of the rest of the site, such as how many riffles are present and where, are not usually provided.

Specialists involved in environmental flow assessments have stated the need for a broader-based assessment of aquatic habitats at a flow study site. Many have said that they would like a "bird's eye view" of the sites, and to be informed of the mosaic of local hydraulic conditions present. Others would like to be able to assess the position and relevance of the cross-sections within the site as a whole, and know how velocities and depths outside these cross-sections change under different discharges. Input on these perspectives can be made through habitat maps.

19.3 Kinds of habitat-mapping data used in environmental flow assessments

In flow assessments, sites are selected along the river of concern to represent conditions in different parts of the system. Accepting that at larger scales geomorphologists will be placing these sites into a catchment context, the sites then are the primary means by which biophysical specialists judge present and possible future flow-related conditions in the river. Habitat maps of these complete sites, using the mapping techniques described in Chapter 4, provide a perspective on aquatic conditions not previously available in environmental flow work.

The digitised site maps provide information on the distributions and proportions of different substrata and flow types, and of all combinations of these two variables. Flow-type maps drawn at different discharges reveal how hydraulic conditions across the complete sites change with time and, to the extent that flow types are presently understood, inform on what those hydraulic conditions are.

Further information on the site can be gained through hydraulic measurements taken at each site at different discharges within areas with distinctly different hydraulic characteristics, here called hydraulic habitats.

These measurements reveal the depth, velocity and associated hydraulic features of the chosen areas and how these change through the seasons (after Gore *et al.* 1992; King & Tharme 1994; Pusey *et al.* 1995).

The above ideas are summarised in the following conceptual model.

- Environmental macrovariables such as discharge, temperature and chemical regimes, and slope, which vary along a river, are important determinants of the overall distribution of species within a river ecosystem.
- Environmental microvariables, which vary within a site, are important determinants of species' distributions within a site. Physical habitat, or more specifically hydraulic habitat, is one of the primary determinants among these microvariables.
- If suitable hydraulic habitat does not exist at a site, a species will not occur there. If suitable hydraulic habitat does occur but the site is unsuitable in terms of macrohabitat variables, then a species will not occur there.
- Recording the availability of different hydraulic conditions at a site allows an assessment of the suitability of a site for any species, within the greater context of the suitability of the reach and zone in which the site is located.
- Within-site hydraulic conditions can be described through the two main components substrata and flow types. As both of these can be visually identified, hydraulic conditions can be mapped in a simple on-site activity.
- Substrata and flow types can be mapped separately. Additional flow-type maps can be drawn at additional different discharges, as overlays of the original substratum map, to illustrate how conditions change with discharge. Habitat maps of complete sites provide information on the mosaic of hydraulic conditions present there.
- Within-site areas that are visibly hydraulically different can be identified in the field and on the maps. Here termed hydraulic habitats, they can be characterised at different discharges in terms of the hydraulic variables velocity, water depth, flow type and substratum, as well as by any relevant ecological features. These data can be matched with similar data on the conditions required by specific species, to assess habitat suitability.

Application of the within-site component of the conceptual model is described in Sections 19.4-19.7 using data gathered during a project to assess environmental flows for the rivers involved in the Lesotho Highlands Water Project (Metsi Consultants 2000). These data are used with permission of the Lesotho Highlands Development Authority.

19.4 Substratum-flow habitat maps and local hydraulics

For each site, the distribution of substrata was described only once, at winter low flow (June 1998), whilst the distribution of flow types was mapped both then and also at summer low flow (January 1999). The main uncertainty in the exercise was that the second flow map was drawn on a template of the original substratum map. With the water occupying a slightly different area within the channel, it was sometimes difficult to assess exactly where the new wetted edge was located on the original map. This was particularly so when the wetted edge had crept across flat, featureless sand or bedrock. It was felt that this

did not seriously jeopardise the essential message from the exercise, which concerned the variety of hydraulic conditions that the site had to offer at different discharges.

With the overall hydraulic character of the site described, areas of different hydraulic conditions (hydraulic habitats) were delineated within the site and, in each of these, variables describing local hydraulic conditions were measured on the same summer and winter visits described above. Up to four areas per site were chosen for the field measurements, based on the site maps, on acquired knowledge of the site and on an understanding of which hydraulic conditions generally tend to support different riverine biota. In each area, up to 30 hydraulic measurements were taken in a grid pattern, on each visit. Variables recorded were water depth, current speed, flow type and substratum size, as well as general ecological notes such as the presence of algae. The hydraulic measurements were summarised by site and hydraulic habitat, using frequency plots with the variables (substratum size, mean column velocity, water depth) displayed by size class.

In a parallel exercise, the physical attributes of the areas within the sites where key fish and invertebrate species occurred were characterised by ecologists, using the same variables, and the data were presented in frequency plots using the same size classes. Thus, frequency plots of available habitat and used habitat could be matched, to assess the suitability of the sites over time.

19.5 Digitising the maps

All maps were digitised and the flow-substratum proportions summarised using ArcInfo, as described in Chapter 4. The maps were colour coded as follows:

- substrata that consisted of only one class were allocated a solid colour (e.g. areas of boulders were shown by solid purple);
- mixed substrata were allocated a pattern using the base colour of the dominant (by size) particle (e.g. areas of mixed boulders and large cobbles were depicted by a purple pattern, and areas of boulders and sand by a different purple pattern). As a result, the degree of sorting of particle sizes could be registered at a glance;
- flow types were colour-coded for velocity, with fast categories depicted in various shades of red, medium categories in oranges and yellows and slow to no-flow areas in blues and greens.

The surveyed cross-sections and the hydraulic habitats used for hydraulic characterisation were located on the maps, so that information from all relevant specialists could cross-refer.

19.6 Presentation of the data for the workshop

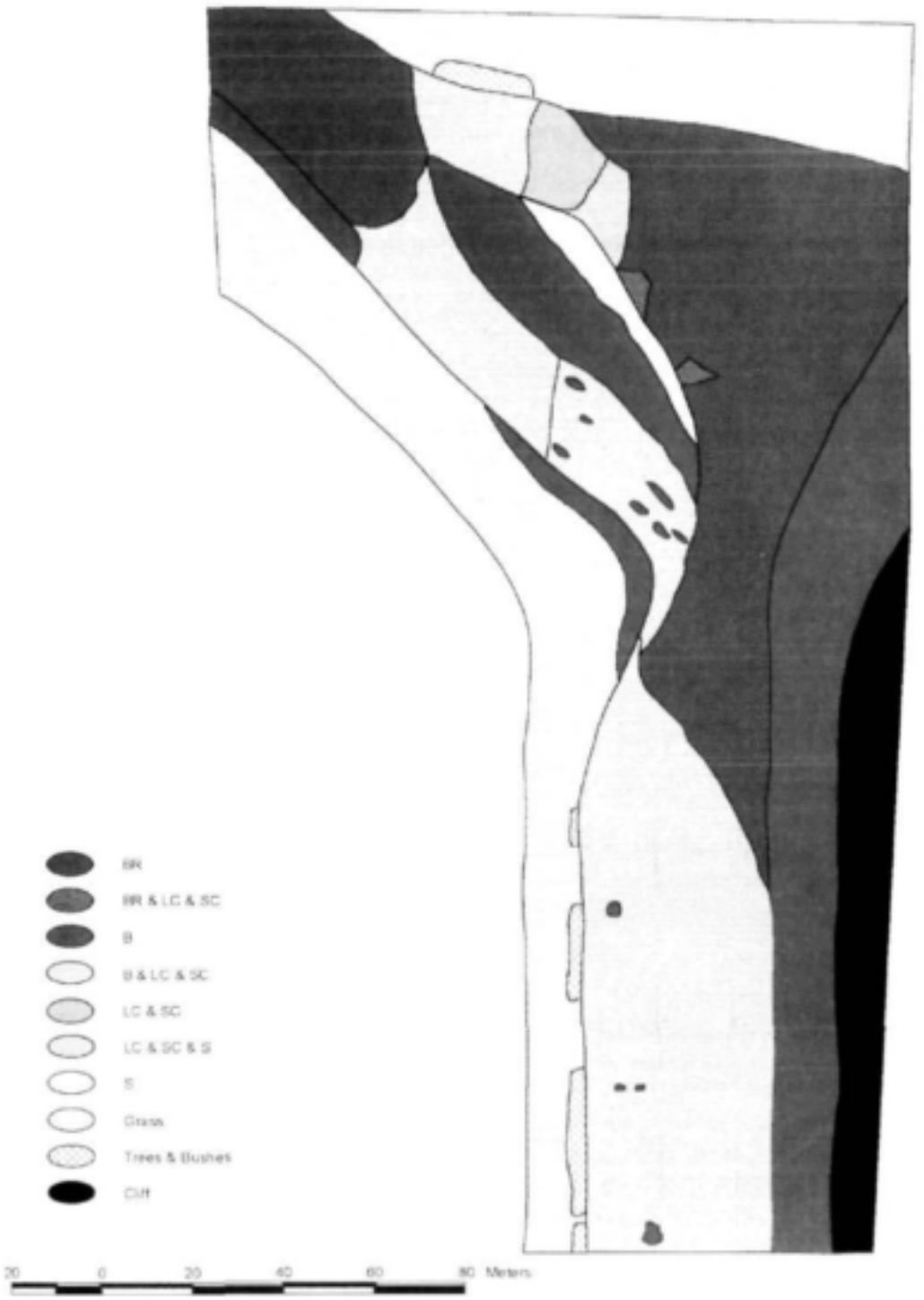
The data provided for Site 7, Marakabei on the Senqunyane River, are used as an example. A3-size colour habitat maps of the site were displayed as wall charts (Figure 19.1a-c). Early coloured versions of the maps were sent to the ecologists before the workshop, so that they could identify relevant areas in their reports. The data also appeared in a written report for use at the workshop.

Figure 19.1a-c **Habitat maps and delineation of different hydraulic habitats (HH) on the Senqunyane River at Marakabei in Lesotho.** Information from Metsi Consultants, 2000. HHs were developed from an original idea from Angela Arthington, Johan Rall and Mark Kennard

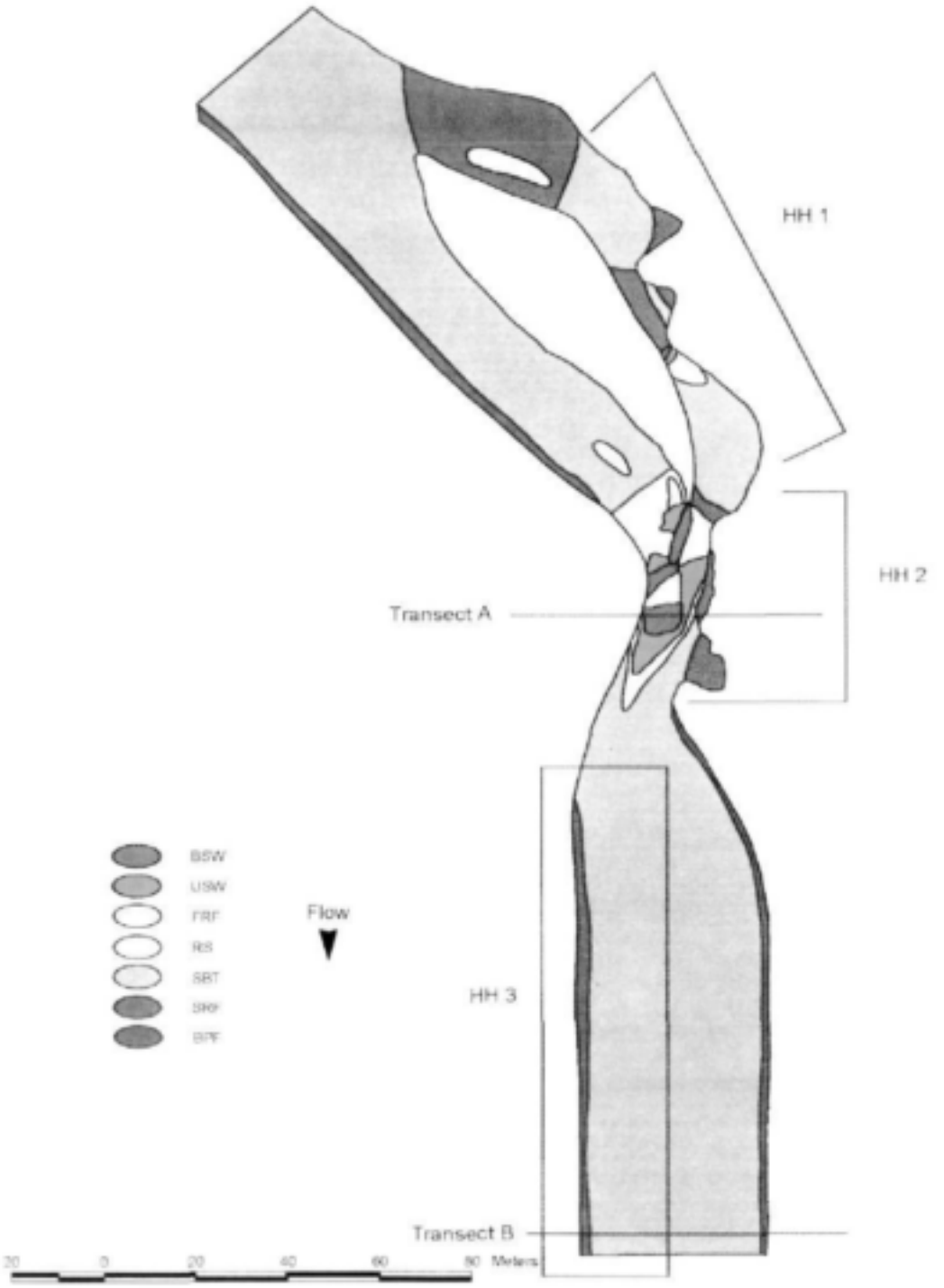
19.1a - Substrata

19.1b – Flow Types in June 1998. Q = 0.76 $m^3 s^{-1}$

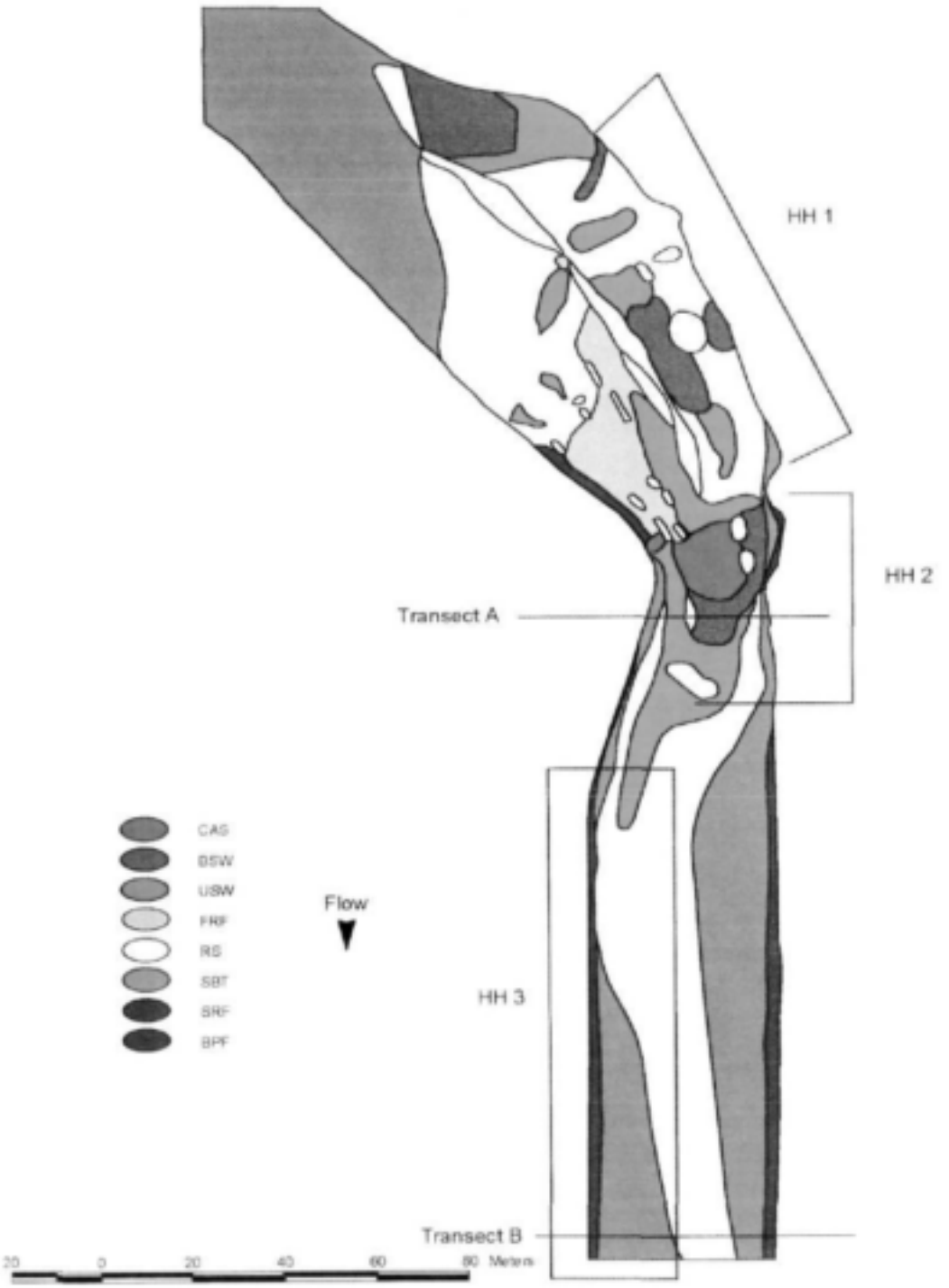
19.1c – Flow Types in January 1999. Q = 16.9 $m^3 s^{-1}$



19.1a - Substrata



19.1b – Flow Types in June 1998. Q = 0.76 $m^3 s^{-1}$



19.1c – Flow Types in January 1999. Q = 16.9 $m^3 s^{-1}$

19.6.1 General overview of the characteristics of IFR Site 7

The site is on the Senqunyane River, about 30 km downstream of the Mohale Dam construction site. It is located on a bend of the river, in a relatively flat-bottomed valley between steep mountain slopes. The river is contained on the bend by a cliff on the left bank and has a mid-channel island on the bend. The river is wide and smooth-flowing in the upper and lower thirds of the sites, but narrower with more turbulent flow around and immediately downstream of the island. Scattered trees line the right bank, with cultivated fields behind them. A footpath runs between the trees and the fields, which is used by people cultivating the fields and by fishermen who fish at the site. The left-bank slopes are uncultivated near the river as they are rocky and steep, but fields occur higher up. The slopes are extensively grazed by domestic herds, which drink at the river.

The site was characterised by a boulder and a mixed boulder-cobble substratum (Figure 19.1a). There were also areas of bedrock, particularly on the outside of the bend and in the upstream end of the site. Small areas of mixed cobble, with or without sand, also occurred between the island and outside bank, and sand along the left side of the island. Overall, bedrock with or without overlying cobbles accounted for 31% of the wetted area, boulder and mixed boulder-cobble 63%, mixed cobble with or without sand 4% and sand 2% (Table 19.1). Single categories of substratum accounted for 43% of the wetted area. Outside of the central narrow area, the wetted width was about 40 m.

Table 19.1 The area (m^2) of wetted substrata covered by different flow types at site 7 (Marakabei) in (a) June 1998 and (b) January 1999. Data derived from ArcInfo. 2000).

(a) Marakabei: June 1998

Flow Type	BR	BR, LC, & SC	B	B, LC, & SA	LC & SC	LC, SC & SA	Total
BPF	175.8	0.0	98.0	525.8	0.0	0.0	**799.6**
BSW	31.1	0.0	1.6	74.7	0.0	0.0	**107.4**
FRF	60.7	26.5	24.9	178.9	23.3	0.0	**314.3**
RS	48.2	0.0	0.0	101.1	0.0	0.0	**149.3**
SBT	2156.2	4.7	236.5	5578.7	60.7	171.1	**8207.9**
SRF	104.2	43.6	0.0	429.4	208.5	6.2	**791.9**
USW	107.3	0.0	0.0	46.7	0.0	0.0	**154.0**
Total	**2683.5**	**74.8**	**361.0**	**6935.3**	**292.5**	**177.3**	10524.4

(b) Marakabei: January 1999

Flow Type	BR	BR, LC, & SC	B	B, LC, & SC	LC & SC	LC, SC & SA	SA	Total
BPF	40.6	0.0	94.8	389.9	0.0	0.0	0.0	**525.3**
BSW	337.2	28.6	0.0	340.2	19.6	9.0	78.3	**812.9**
CAS	174.7	0.0	1.5	33.1	0.0	0.0	0.0	**209.3**
FRF	0.0	0.0	156.6	331.2	0.0	0.0	1.5	**489.3**
RS	993.5	7.5	593.1	2744.2	129.5	132.5	126.5	**4726.8**
SBT	1797.4	0.0	296.6	2352.8	0.0	0.0	0.0	**4446.8**
SRF	0.0	0.0	1.5	69.3	0.0	0.0	0.0	**70.8**
USW	459.1	39.1	137.0	439.6	144.5	39.1	73.8	**1332.2**
Total	**3802.5**	**75.2**	**1281.1**	**6700.3**	**293.6**	**180.6**	**280.1**	12613.4

Upstream of the bend, the water flowed smoothly through a pool-like stretch, with the flow type SBT being predominate in both winter and summer (Figures 19.1b and 19.1c). The stretch downstream of the bend was also smoothly flowing, but flow changed from SBT in winter to incorporate a large central tongue of faster water (RS) in summer. The island was also surrounded by fairly quiet water in winter, with SBT and very shallow, slow flickering flow (SRF), but this changed to fast flow categories for about 40 m downstream. In summer, parts of the island were inundated, and flow around it became deeper and faster, with extended areas of BSW and USW and the introduction of cascades. Overall, 93 % of the wetted area had slow flow types in winter compared to 42% in summer.

Three hydraulic habitats (HHs) were delineated at the site (Figures 19.1b and 19.1c), and their hydraulic conditions measured in winter (June 1998) and summer (January 1999). HH1 was in the two channels around the island. HH2 was downstream in the turbulent water, and HH3 was furthest downstream in the smoothly-flowing area.

The substratum at HH1 consisted mostly of larger categories, with high proportions of bedrock, boulders and large cobble (Figure 19.2a). Velocities were quite low in winter (up to 0.39 m s^{-1}) and typified by SRF and SBT, but increased to a wide range (0.01-1.99 m s^{-1}; BSW, USW and RS) in summer, reflecting the typical heterogeneous flow of fast water over large particles. Depths remained much the same in both seasons, up to 0.79 m. In winter, the rocks in the right channel were clean and non-slippery, whilst those in the left channel had a cover of photosynthesising algae. Downstream, the bedrock was covered with fine silt. Conditions were not recorded in summer.

HH2 was the boulder-bedrock rapid downstream of the island. Although smaller material lay over this area in winter (Figure 19.2b), much of this was swept away in summer leaving, at least at the edge, which was the only area that could be measured, bare bedrock. Velocities typically covered a wide range from very low (in hydraulic cover) to > 2 m s^{-1}. Although the whole area was sufficiently shallow for measurement in winter (up to 0.39 m), most of it was too deep (and fast-flowing) to be entered in summer. Flow categories were FRF, USW, BSW and, in summer, cascades. In winter the rocks were clean (not recorded in summer).

HH3 was a downstream run, with smaller substrata including sand and mud (Figure 19.2c). At the right bank the water was about 0.50 m deep, and depth increased across the river so that by mid-stream it was always deeper than "wader depth". In some areas a narrow strip along the right bank and under the trees had shallower water (0.10-0.50 m). Velocities were very low in winter (SBT and BPF: 0-0.09 m s^{-1}), but in summer increased to 0.49 m s^{-1} in the area that could be waded and perhaps higher further into midstream. In winter, patches of ice covered the water under the trees, and silt and algae were common on the boulders.

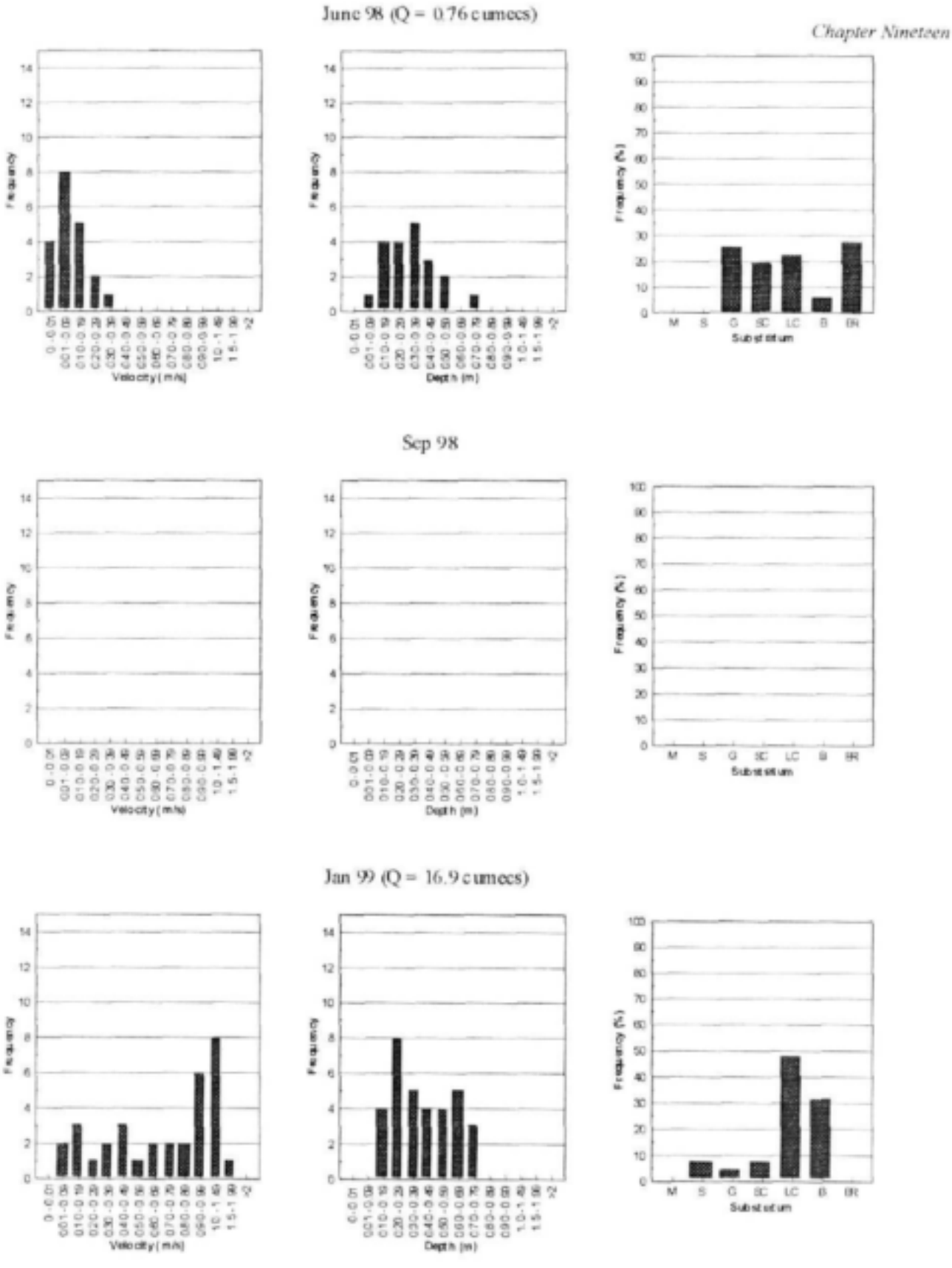


Figure 19.2a Marakabei IFR. Hydraulic Habitat 1.

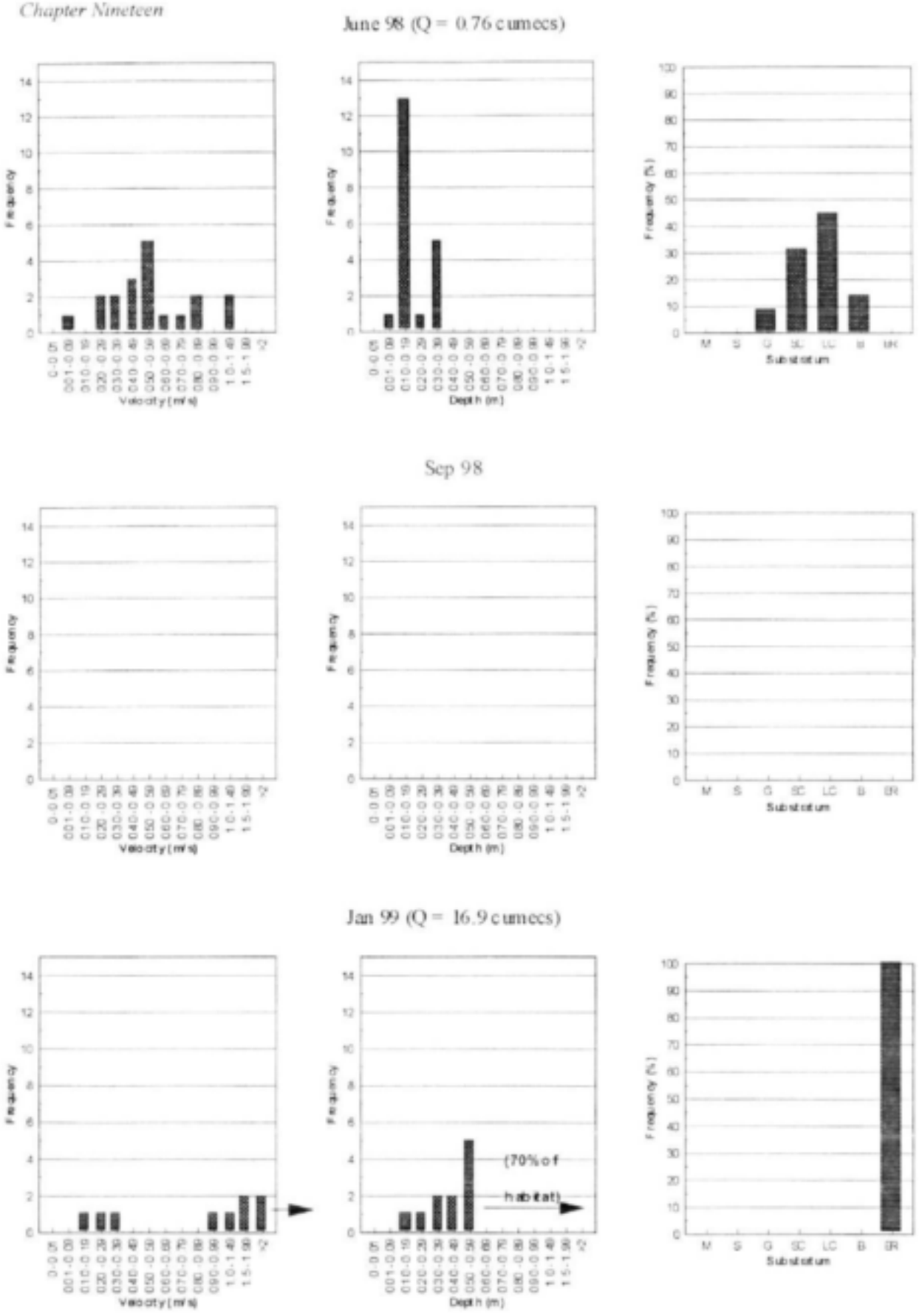
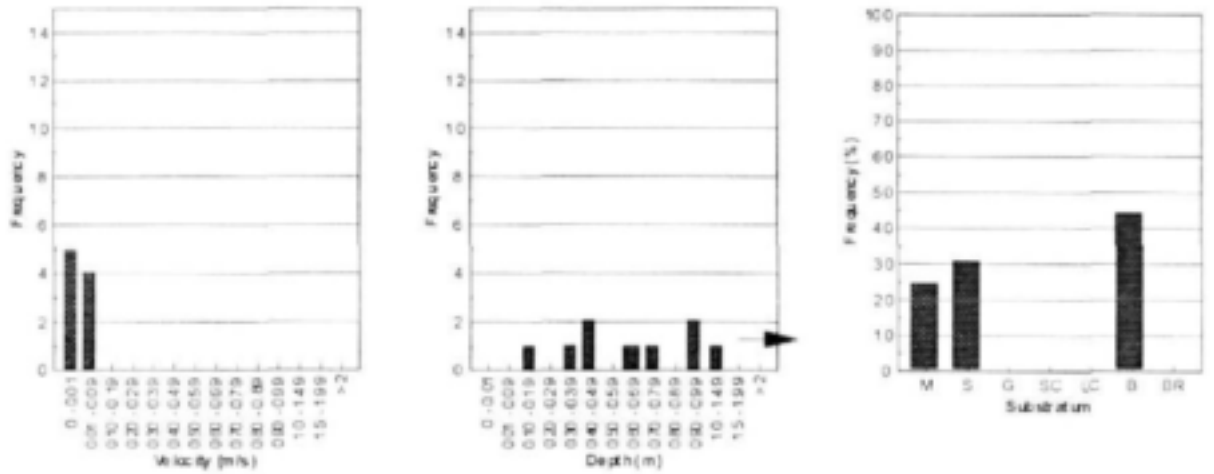
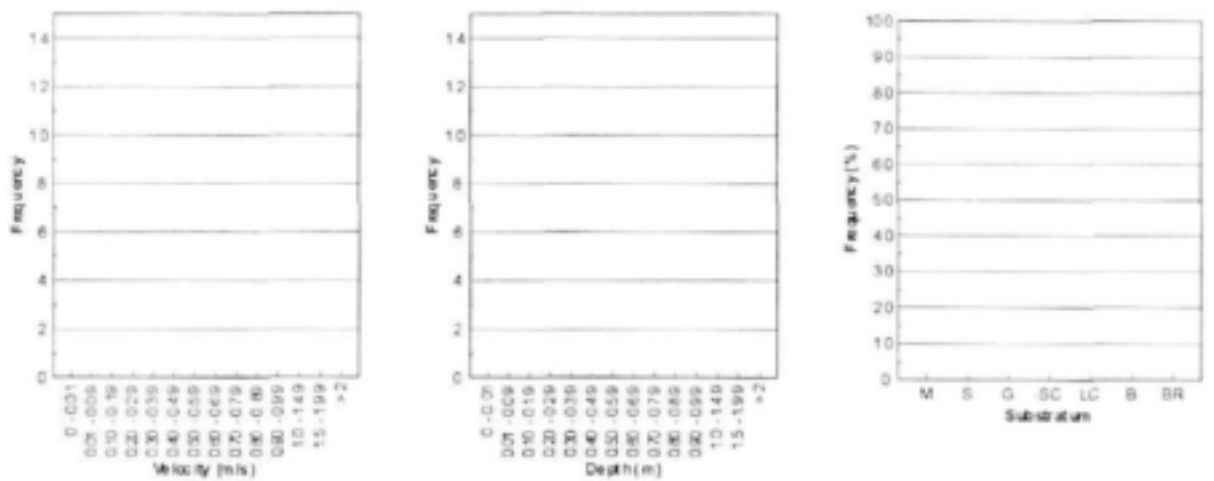


Figure 19.2b Marakabei IFR. Hydraulic Habitat 2.

June 98 (Q = 0.76 cumecs)



Sep 98



Jan 99 (Q = 16.9 cumecs)

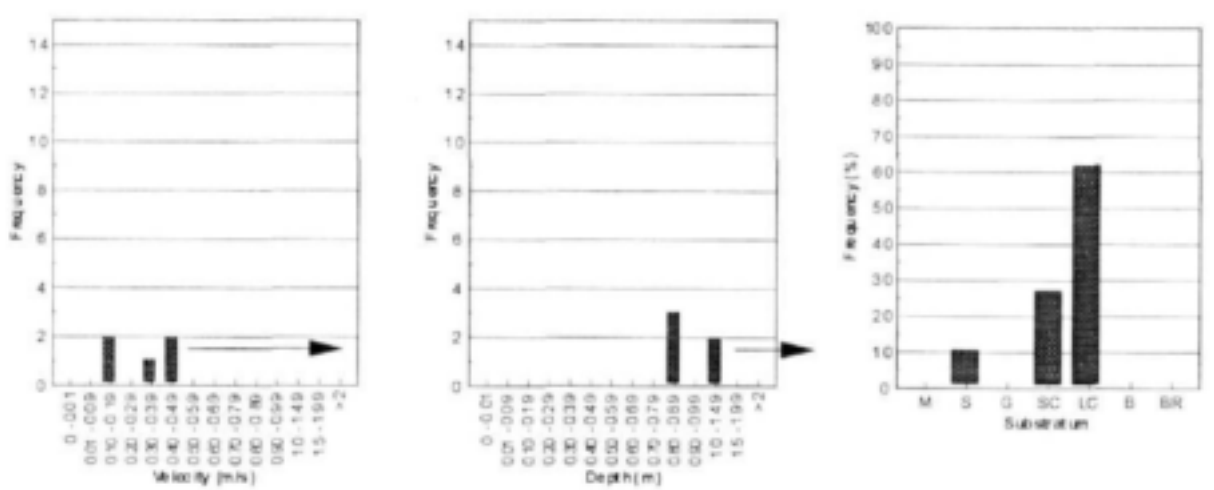


Figure 19.2c Marakabei IFR. Hydraulic Habitat 3.

19.7 Use of the data at the workshop

In the Lesotho environmental-flows workshop, the substratum and flow-type maps were used as a general guide to the nature of the sites. All the specialists found the maps easy to understand and work with, and they felt that they provided a very good "feel" of the sites. They also matched hydraulic-unit data (Figure 19.3 a-c) with data on where specific species occurred, to assess how much habitat was available for each species at different discharges. The application of this technique was limited because only two discharges were measured, and no simulation model existed to go past these data to predict hydraulic conditions at unmeasured discharges. It was not possible, for instance, to assess at what very high or very low discharges suitable habitat would disappear for a species, even if its habitat requirements were known.

In summary, the techniques have great potential, but this needs to be developed through creation of a hydraulic model that can use the data at measured discharges to simulate local hydraulic conditions at unmeasured ones.

19.8 Further development of the techniques

A WRC project (K5/1174) titled *Hydraulic analyses for the determination of the ecological reserve for rivers* began at the University of the Witwatersrand in 2000. Its objectives are to:

- provide hydraulic methods to link hydrological flow characteristics and biotic requirements necessary for setting the full ecological reserve;
- provide hydraulic methods for setting the preliminary reserve, when the hydraulic data are limited;
- develop three-dimensional habitat modelling to assist in the determination of the ecological reserve for rivers;
- develop an index of hydraulic characteristics for quantifying habitat availability.

This seems a likely route for continuing development of the necessary techniques. Liaison between that project's staff and the two authors of this report has been initiated. Dr King sits on the steering committee for the project.

Additionally, the mapping techniques described in this report could be streamlined for use in consultancy work. Based on the results reported for this project, the 14 categories of flow and eight of substratum could be combined into fewer, biologically meaningful categories. As an example, the maps created for another Lesotho site are shown in this reduced form.

The site shown (Figure 19.3) is on the Matsoku River, which appears similar to the Senqunyane site (Figure 19.1) but is a much smaller river. Based on the findings in Chapters 11-15 of this report, the categories of substrata at the site were reduced to four (bedrock, boulder, large cobble, small cobble), as were the flow types (fast ripple, fast turbulent, shallow riffle, slow smooth). In general, these flow types encompassed the larger range of major flow types, as follows:

- fast ripple : RS
- fast turbulent – CH, CASC, FF, BSW, USW
- shallow riffle – FRF, SRF

- slow smooth – SBT, BPF, NF.

It is stressed that this reduction in flow types would probably be adequate for consultancy work, but not for research on species' habitat requirements. The reduced number of categories has an additional advantage in that they do not need to be distinguished on maps in colour.

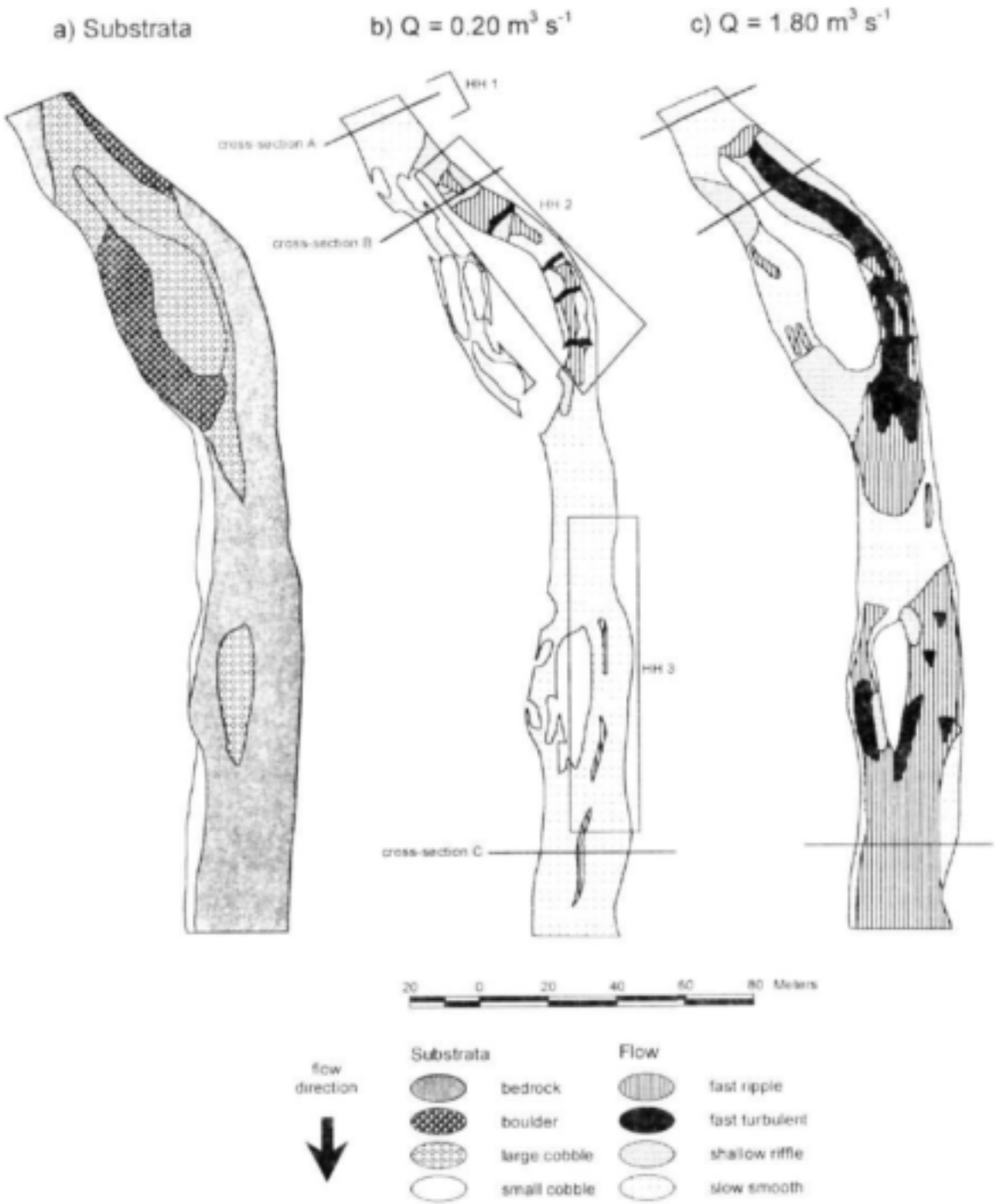


Figure 19.3. Habitat maps and delineation of different hydraulic habitats on the Matsoku River in Lesotho: a) substratum map; b and c) flow-type maps, with three distinctly different hydraulic habitats (HH) delineated (Metsi 2000).

20. Conclusions and recommendations

20.1 Conclusions

A programme of research was carried out that allowed assessment of the ecological relevance of a classification hierarchy for rivers that has been suggested by fluvial geomorphologists. The results are presented in Chapters 10-15, and additional applications of the data are demonstrated in Chapters 16-19. Some analyses, particularly those reported on in Chapters 13 and 14, are further addressed in the PhD thesis of one of the authors of this report.

The decision to identify all invertebrates collected to species or, where the taxonomic literature cannot support this, to "morph species", was critical to the success of the work. "Morph species" refer to animals that could not be identified but could be arranged in groups of individuals with similar appearance. Each "morph species" was decided upon based on features traditionally used to distinguish species in its respective taxonomic Order or Family.

Invertebrate identifications at the species level allowed distribution patterns to be detected that were not apparent at family, or even genus, level. This allowed a more incisive assessment of the geomorphological hierarchy than would have been possible with coarser identifications.

Using the species distributions in 18 relatively undisturbed headwater streams in the Western Cape, the ecological relevance of five aspects of the geomorphological hierarchy were investigated:

- catchments, segments and zones;
- reaches;
- morphological units;
- hydraulic biotopes;
- the temporal stability of hydraulic biotopes over a range of discharges.

Additionally, the impact of anthropogenic disturbance on the measured geomorphological and ecological characteristics of the rivers was investigated, using species distributions in ten disturbed rivers in the same region.

20.1.1 Catchments, segments and zones

Catchments, segments and zones form the highest levels of the geomorphological hierarchy. In this project, sites in several catchments, 28 rivers and two zones (mountain and foothill) were used to test the hierarchy. Segments were not addressed separately, as the terms segment and zone both essentially refer to a stretch of river with much the same characteristics.

At the beginning of this project, it was expected that the invertebrate data would group the studied rivers across the whole study area, by zone. In other words, within the fynbos bioregion (Eckhout *et al.* 1997), where all the study rivers are located, all the sites from the mountain zone were expected to group together,

through having similar invertebrate assemblages. On the other hand, all the sites from foothill zones were expected to group together but separate from the mountain group, because they had similar invertebrate assemblages that differed from those in the mountain zones. This assumption formed the basis upon which bioregions and bio-sub-regions were suggested as the units of management for the South African River Health biomonitoring programme (Brown *et al.* 1996), with sub-regions being the areas within a bioregion that encompass the same zone of many rivers (e.g. one sub-region would encompass all the foothill zones, and another all the mountain zones).

This project has indicated that the assumption is simplistic. Within the Western Cape bioregion, and based on macro-invertebrate distributions, river sites grouped principally by catchment and not by zone. This suggests that each catchment has an individual signature that is sufficiently strong to over-ride the very noticeable changes in species composition down the length of the rivers: mountain and foothill sites within one catchment linked together, rather than with other mountain or foothills sites respectively elsewhere in the bioregion. This occurred despite the undoubted overall similarity of the rivers in the bioregion.

A few of the catchments grouped with another: the Olifants with the Berg, the Eerste with the Molenaars, and all the Table Mountain streams together. The link-ups were not always between geographically contiguous catchments, but might still be attributable to biogeographical dispersal patterns in some cases. The Olifants and Berg, for instance, are the only two catchments that drain to the west coast, and may have once had a common estuary (Hendey 1983). Table Mountain stood once as an isolated island off the African mainland, which may be responsible for the high degree of endemism exhibited by its aquatic biotas (Wishart and Day in press), and thus the relative similarity of its streams in terms of aquatic invertebrates, as detected in this project. Neither of these possible causes, however, explains why the Eerste linked with the Molenaars, and other explanations must be sought. Perhaps each river system functions differently, based on the underlying geology, climate or other influences, and this affects the proportions of each invertebrate species present in assemblages. Similar influences could result in similar river functioning and thus similar proportions of species. Resolving the uncertainty as to the nature and causes of catchment signatures might provide the basis for a new level of understanding of river ecosystem functioning.

Until catchment signatures are better understood, management decisions should not be based on the assumption that specific rivers can be sacrificed to developments because other similar rivers exist. At present, the only safe assumption is that rivers in different catchments are not similar. In terms of the geomorphological hierarchy, this means that it can only partially guide on river groupings at the highest ecological level within a bioregion. Geographically, it is possible to delineate each catchment on maps, but not to indicate which ones are likely to be biologically similar. This next step might be possible in the future, once catchment signatures are better understood.

Within a catchment, a further level of dissimilarity over-rides the influence of zone, and so caution should be exercised regarding any assumptions of similarity between a catchment's rivers. Bedrock rivers occur in their appropriate catchment group, but are quite different from the alluvial ones in the same catchment in terms of invertebrate assemblages. As the nature of the riverbed is a physical feature, its details can be incorporated into the geomorphological hierarchy. Such information cannot be gleaned from maps, however, and so cannot be part of a desktop classification but rather requires field identification.

The river zone, far from being the expected over-riding influence on invertebrate distributions within a bioregion, appears at the third level of differentiation, after catchment and riverbed substratum. This level already forms part of the geomorphological hierarchy, and the delineation of zones along the river can easily be done, using maps in a desktop exercise. The zones should be defined using ecological data, however. This appears to be necessary, as the geomorphological analyses of such variables as zone class and valley form (Chapter 6), did not reflect the biological zones revealed by the riverine biota in this study. The relevant ecological data for delineating zones can be gleaned, for any bioregion, from ecological studies within that region. These will provide a first estimate of the slope and altitude ranges of each biological zone along a river, and the ranges can be refined with time as additional data accumulate. Such an exercise was completed in this study, when first estimates of slope and altitude ranges (Tables 5.1 and 10.6), taken from the literature, were used to initially guide the study, and later refined using the study's results (Table 15.5).

In summary, the overall ecological natures of the studied headwater streams appear to be dictated by three main factors: the catchment; the riverbed substratum; and the longitudinal zone. The top levels of the geomorphological hierarchy partially incorporate some of these factors, but not sufficiently accurately or comprehensively to allow the hierarchy to be a surrogate for ecological aspects in research and management decisions.

20.1.2 Hydraulic biotopes

Hydraulic biotopes (HBs) sit at the lowest level of the proposed geomorphological hierarchy, and are seen as the "building blocks" for its intermediate levels. Once distributions of hydraulic conditions and the biota at this fine scale are understood, it should be possible to seek wider patterns of distribution at the level of morphological units (MUs) and reaches. HBs are at the only level of the hierarchy that incorporates a description of flow as well as of substratum. Flow was included because the ecologists felt that the micro-distribution of small aquatic animals and plants is dictated by both flow and substratum.

After discussions with ecologists, geomorphologists described a range of HBs (Rowntree & Wadeson 1999; Table 4.5) that reflected ecological understanding of faunal distributions but were defined simply by their abiotic (flow and substratum) characteristics. Their list of HBs was:

- backwater;
- slack water;
- pool;
- glide;
- run;
- riffle;
- rapid;
- cascade;
- chute;
- waterfall;
- boil.

This project revealed that in terms of assemblages of benthic invertebrate species, only four main HBs were obvious: runs, riffles, rapids and pools. The other terms bulleted above appeared within these four main groups, so that, for instance, the invertebrate samples taken from chutes and cascades were intermingled in a larger group all recognised as coming from turbulent water flowing fast over boulders, here named a rapid. A suggested grouping of the geomorphological HBs into ecological HBs is thus as follows:

Table 20.1 Geomorphological HBs grouped by ecological HBs.

Geomorphological HBs	Ecological HBs
backwaters, slack waters, pools, slow glides:	pools;
runs and fast glides:	runs;
riffles:	riffles;
rapids, cascades, chutes, waterfalls, boils:	rapids.

We may be able to ecologically distinguish features such as slack waters, chutes and cascades, however, by concentrating on the distributions of individual species. Some species may occur in select smaller micro-environments within the larger HBs, and be good indicators of these areas. *Aphrotenia* sp., for example, occurs in pool-like areas, but within them is only found on clean small gravel in quiet edge waters with hydraulic cover (Section 11.4). The pool is the HB, the environment of the species assemblage. The clean gravel in the quiet edge area is the hydraulic habitat of *Aphrotenia*, representing an hierarchical level finer than any presently in the hierarchy.

The characteristics of the four broad-ranging HBs can be summarised as follows (Table 20.2). The information is derived from Chapter 11, including from Table 11.8.

Table 20.2 Definition of each biologically-defined hydraulic biotope (HB) by depth (m), flow types, substrata, mean water column (0.6) velocity (m s^{-1}), and Froude number. Flow-type codes as per Table 2.3.

HB	Depth	Flow Description	Substrata	Mean Velocity	Froude Number	Comments
Rapid	shallow to deep: up to 0.70	turbulent, broken water: CAS, USW, BSW, CH, STR, FF, FRF, some fast RS	boulders and large cobbles	0.38 – 0.64	0.371 – 0.900	CAS is the dominant flow type; CH and FF are unique to this HB
Riffle	shallow: <0.30	fast, flickering flow: FRF, USW, BSW, CAS, some fast RS	cobbles and sometimes small boulders	0.27 – 0.39	0.332 – 0.425	FRF is the dominant flow type.
Run	shallow to moderately deep: up to 0.50	fast to moderately fast rippled flow: RS, SBT, some FRF	a range of substrata	0.05 – 0.19	0.070 – 0.200	RS is the dominant flow type.
Pool	shallow or deep: 0.03 - >1.00	slow, smooth flow: SBT, BPF, rarely NF	a range of substrata	0.00 – 0.10	<0.070	Bedrock and alluvial pools may have different species assemblages

In summary, the lowest level of the geomorphological hierarchy, which focuses on *the hydraulic biotopes of species assemblages*, distinguishes more HBs than the four that can be justified from the ecological data. Within the ecological HBs, however, another level of the hierarchy could be considered, to describe the *hydraulic habitat of individual species*. All species from one HB may well have slightly different hydraulic requirements, which in total describe the broad hydraulic character of the HB. Some of the species, however, may have requirements that are so specific that they can be used as indicator species for micro-environments within the HB, such as slack water or chutes.

The four ecological HBs could form the basis for biomonitoring programmes in headwater streams. They are reasonably easy to distinguish on the ground, and present the four main conditions found in such streams. Each HB can be distinguished visually, but this should be done by judging the overall appearance of the flow as no one HB is uniquely described by one flow type (Table 20.1). To ensure collection of the greatest possible range of species, the full range of micro-environments within each HB should be sampled. It is emphasised that this kind of broad-spectrum sampling of an HB is not suitable for species studies, because details of the specific micro-habitats will be lacking.

A last point concerns noise in distribution data for river benthic invertebrates. Data from the Intensive Sampling programme (Section 11.3.2) indicated that individual invertebrate samples were collected from an HB other than the one they represented. A "pool" species assemblage, for instance, was collected from the middle of an area that otherwise produced "run" species assemblages and had a "run" flow type. This patchiness is not yet understood, but might help to explain the well-reported "noise" in distribution data. Patch dynamics of both the hydraulic conditions and the groups of invertebrates will be further studied in Ms Schael's PhD.

20.1.3 Morphological Units

Morphological Units (MUs) are used to explain the next larger scale of arrangement of channel features, and as such have been very useful in aiding ecologists to structure their studies. The authors envisaged MUs as structures that might be more relevant to fish ecologists and riparian botanists, for instance, than to invertebrate ecologists, as fish move over larger distances, and both fish and trees inhabit larger-scale physical habitats.

In this study of invertebrates, the MUs were not particularly good predictors of the distribution of invertebrate assemblages. Some MUs, such as "step", were better predictors than ones such as "plane-bed", but none would be as useful as HBs in aiding location of specific assemblages. Step MUs, for instance, yielded mostly "rapid" species assemblages, but rarely "riffle" or "run" ones also, whilst "plane-beds" yielded all four kinds of assemblages in approximately the same proportions. Sampling by HB, using the guides listed in Table 20.1, should provide a better chance of collecting a targetted species assemblage than using the MUs as guides.

The concept of MUs is useful, however, in a preliminary assessment of a site. MUs inform on the overall nature of a studied river reach and thus provide an idea of the invertebrate assemblages likely to be present. Riffle assemblages, for instance, appear not to occur in mountain zones, even if riffle flow/substratum combinations are present, presumably because such assemblages consist of species adapted to foothill

conditions which is where riffles commonly occur. Knowing this in advance allows sampling strategies to be planned that avoid spending unnecessary effort on areas unlikely to yield different assemblages.

In summary, the concept of MUs as a level in the hierarchy remains useful for organising thoughts and data, and for overall assessment of a study site. MUs are not particularly useful, however, as indicators of where to locate specific assemblages of species. In addition, use of the terms riffle, run, rapid and pool at two levels of the hierarchy (HB and MU), is confusing, and it is suggested that alternative terms be sought that are specific to one level.

20.1.4 Reaches

Reaches form the next level up from MUs in the hierarchy. This level, nested within the zone, is used to describe a length of river with similar channel and hydrological characteristics. Reaches can be delineated from maps, based on changes in slope, geological formations, valley form and runoff, and verified in the field by the composition of MUs. Preliminary analyses of reach-level invertebrate data (Chapter 13) have not led to much insight to their ecological relevance. The two reaches studied were geomorphologically different, but the overall densities or composition of their invertebrate assemblages were not significantly different. The animals were primarily grouped, not by site, but by whether they were in fast or slow flow. However, within the groups of fast-flow and slow-flow samples, those from each site (i.e reach) tended to cluster together. It seems possible that there are differences in assemblage composition at the reach level, but any such subtleties will only be revealed with more intensive examination of the data. This will be done as part of Ms. Schael's PhD.

In terms of biomonitoring, reach type is a useful guide to the mosaic of MUs and HBs likely to be encountered, and thus helps development of a sampling strategy. Reaches within one zone that have similar MUs and HBs will probably yield much the same invertebrate fauna, whilst those with different sets of MUs and HBs, or different substrata, could yield different species. All reach types within a zone likely to add to the list of fauna present should therefore be considered for inclusion in the sampling programme.

Reach type may be important when focusing on biodiversity issues. Reach types with unusual MUs and HBs could contain rare species that would not be detected if only one reach was selected to represent the whole zone. As an example, the genus mentioned earlier has two species, *Aphrotenia barnardi* and *A. tsitsikamae*, that are Gondwanaland relics. These species occur in steep mountain zones, but their specific hydraulic requirements for quieter waters would preclude their presence from the more common reach types with their fast, turbulent flow. They would probably not be found unless rarer reach types, with well-sorted smaller substrata and a range of slower flows, were sampled.

It is envisaged that a predictive model can be formulated that would use the mosaic of different hydraulic conditions as a template upon which to predict the location of species. This will be explored in the Ph.D. thesis mentioned above.

In summary, reach types are as important as MUs in guiding overall structure of a river study, but are too coarse to guide on the exact location of individual species or species assemblages. Different reach types may yield different invertebrate species assemblages, and sampling strategies should recognise this.

20.1.5 Temporal stability of hydraulic biotopes over a range of discharges

HBs are the only part of the geomorphological hierarchy affected on a short to immediate temporal scale by a change in discharge (Frissell *et al.* 1986; Rowntree & Wadeson 1999). They can be defined by the in-stream biota and then described by hydraulic conditions (Chapter 11). A preliminary analysis of the physical stability of hydraulic biotopes over time and with changing discharges (Chapter 14) revealed that the overall wetted area and proportions of flow types persisted over a range of similar low discharges, and only changed when discharge increased substantially. Essentially, there was a 14 – 24% change in wetted area once there was a 50 – 80% increase in discharge. The associated faunal data will be analysed in Ms Schael's PhD.

20.1.6 The impact of anthropogenic disturbance

Ten rivers with a range of disturbances were studied to assess how disturbance might affect the abiotic-biotic links described for the least-disturbed rivers (Chapter 15). In this project, disturbance at the level of the total species assemblage was assessed. Studied disturbances were not rated for severity *a priori*, and instead severity was judged based on location of each river's invertebrate assemblage on MDS similarity plots. Based on the findings, the following hypothesis is suggested for further testing.

The hypothesis: Increasing disturbance gradually leads to the loss of a river's catchment signature, and eventually to loss of its bioregion character.

Suggested explanation of the data, based on invertebrate assemblages, to support this hypothesis: The most mildly disturbed rivers yield invertebrate assemblages that are similar to those of the least-disturbed rivers. In other words, they remain within their catchment clusters on the MDS plot, and so their catchment signatures remain intact. As disturbance increases, rivers become less similar to others within their catchment, moving to the edge of their catchment cluster on the MDS plot. Moderately disturbed rivers lose their catchment signature completely, moving outside their catchment grouping on the MDS plot to cluster together in the middle of the ring of catchment groups. This suggests that they have lost their individuality and become more similar, as kinds of generalised rivers of that bioregion. Possibly, by this stage, all sensitive species have disappeared and any coarser bioregion signature remaining is provided by hardy, opportunistic species. Highly disturbed rivers lose even this generalised signature, being located well outside all the catchment groupings. It is not known at this stage to what extent these rivers retain any kind of bioregion identity. A variation on the trend occurs for rivers receiving inter-basin transfers of water, which may take on the catchment signature of the donating catchment.

In seems important to discover exactly how different kinds of disturbances transform species assemblages, resulting in the gradual erosion of catchment signatures. At this stage we cannot say if there are likely to be profound management implications, but we suggest that simply understanding better how disturbance affects the signatures would be a critical step forward. To this end, further analysis of this project's data is recommended (Section 20.3).

20.1.7 Usefulness of the hierarchy

A major impression from this project was that geomorphological hierarchies are exceedingly useful tools to aid organisation of thinking, studies and data analysis. Before such hierarchies were suggested, the country's ecologists were using a spatial hierarchy of sorts (Table 2.2), but ones like that tested here enabled a giant step forward in the way ecologists viewed rivers. As a result, the study of physical-biotic links in rivers has gradually taken its place alongside studies of chemical-biotic links, providing a much more rounded perspective on river functioning, to the benefit of both fields of study.

Geomorphological studies based on a spatial hierarchy now form part of every environmental flow assessment done in South Africa (King *et al.* 2000), as well as contributing to the National River Health biomonitoring programme. We feel this involvement is essential, but suggest that discussions should be held with the geomorphologists on whether it is necessary for their approaches to accommodate the findings from this project. Specifically, discussions should be held on the following:

- the significance of catchment signatures;
- use of biologically relevant zones, as opposed to geomorphologically derived ones;
- reduction in the number of HBs to the four ecologically relevant ones;
- re-naming HBs and/or MUs, so that each level of the hierarchy has unique names;
- studying further the role of changing physical conditions in the disturbance levels suggested in the above hypothesis.

Much of this discussion could well reflect the traditional contrast between "top-down" and "bottom-up" classifications. The "top-down" approach in this case is the geomorphological one of grouping similar rivers and parts of rivers based on easily measured abiotic and landscape features. The "bottom-up" approach in this case is the use of aquatic invertebrates to indicate which rivers or parts of rivers are similar. This project was, in essence, a "bottom-up" testing of a "top-down" approach. Inevitably, mismatches occurred, but these where of a nature that should be amenable to resolution. This should be the main objective of the discussions suggested above.

20.2 Additional applications of the project's techniques and data

Chapters 16-19 illustrate further applications of the data collected in this project. In Chapter 16, use of the data for biogeographical and biodiversity studies is illustrated. Information on the hydraulic conditions in which each species was found is also available in the database, and examples are given in Chapter 17. A preliminary investigation of the hydraulic nature of flow types is reported on in Chapter 18, and use of the mapping techniques in Environmental Flow Assessments is illustrated in Chapter 19. The analyses in Chapters 16 and 17, at least, could be taken much further, but this was not possible in this project. Together with the data on catchment and river signatures, yet to be analysed, the database represents a considerable resource that could enhance understanding of the nature and functioning of the region's rivers. For this reason, further analyses of the data are recommended (Section 20.3).

20.3 The value of species data

In invertebrate studies it is becoming increasingly common to work only to family-level identifications, because of the time and other costs entailed in species identifications. If we had done that in this project, catchment and river signatures would not have been detected. There is no intention here to detract from the use of family-level data, for such data are well established and of great use, particularly for biomonitoring purposes. A deep understanding of ecosystem functioning and biogeographical trends, however, can only be obtained when working at the level of species. Here, we record our view that, to improve the quality of advice offered by ecologists on management practices for the sustainable use of our rivers, the collection of biological data on invertebrate species, their behaviour and their life-cycle requirements must continue to have a place in research programmes.

In this project, apart from the results described, the species data revealed higher numbers of species, and higher numbers of unique species, in some catchments than in others. The results might be partly due to sampling strategies, but they might not. Either way, they trigger some new questions and potential insights on these rivers. For instance, why did the Eerste and Molenaars Rivers consistently group as very similar when they are not in the same catchment and not in contiguous catchments? And why, between them, did they have by far the highest number of species (99 – next highest catchment had 71 species) and the highest number of unique species (31 – next highest 17) (Section 16.3)? Could these rivers be located within some centre of biodiversity? Or were the data simply reflecting our sampling strategy? Further analyses of the dataset might provide answers to these questions (Section 20.4).

20.4 Recommendations

This project has produced a very comprehensive data set. The data have extra value because they cover many similar rivers, within one bioregion, and were collected by a single team in a standardised way. Because of the geographical spread of the data, previously unimagined characteristics of Cape rivers have been revealed. Region-wide patterns of river type have been detected, as well as trends in how human disturbance affects these patterns. Specifically, the invertebrate data clearly show that all rivers and catchments have their own signatures.

The management implications could be profound. Without an understanding of the detected signatures, we can no longer assume that all rivers within a region are ecologically similar, or that knowledge from one can be extrapolated to the rest, or that they will respond to disturbance in a common way. There may be other, presently unknown, factors that need to be considered before assuming, for instance, that some rivers can be sacrificed to development because we have many more like them.

It is therefore recommended that further analysis of the database be undertaken. Some of this will be done in the PhD thesis of one of the authors, as detailed elsewhere in this report. The following additional aims will still need to be addressed.

- Ascertain the proximal cause of the signatures. Two possible explanations are that they are due to unique species in each catchment/river (i.e. related to historical biogeographical distributions), or that there are unique combinations of common species in each catchment/river (i.e. each river is functioning slightly differently, perhaps due to climatic or geochemical influences).

- Analyse the data for all the disturbed rivers, to ascertain the influence of disturbance on catchment signatures. Rate disturbances on a severity scale. The following data need analysing: species, geomorphological, flow type and sorting of substrata.
- Convene a workshop, with selected river scientists, to reach consensus on the management implications of catchment and river signatures. Transfer the findings to the management arena.
- Allocate SASS-type scores to all 380 invertebrate samples in the database. Using the GIS site maps, assess how reach, MU, site and sample point selection affects the SASS score. These kinds of scores are now used at national level for management of river health, and so it is important to continue assessment of their strengths and weaknesses. Transfer the findings to the management arena.
- Ascertain if it is likely to be true that some of the studied catchments had far higher numbers of species and higher numbers of unique species, than others.
- Refine and upgrade the interface and query centre of the database created in this project, and complete a quality-control assessment of the data housed in it. This should a) make the database accessible as a research tool, and b) allow other researchers to add their data to the database, thereby initiating a national database of biological and physical links in rivers. The database created in this project database is compatible with BIOBASE, developed by the Freshwater Research Unit at the University of Cape Town, which links biological and chemical data for South African rivers.

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Appendix E.1. Questionnaire to assess present methods used by scientists too choose sampling sites and sampling areas within sites.

This was originally referred to as Attachment A in WRC Steering Committee Progress Report 2 submitted in January 1997

E1.1 Overview

The purpose of the field portion of the project is to enhance understanding of correlations between the geomorphological structure of Western Cape rivers and distribution of aquatic macroinvertebrate (and to a lesser extent, riparian vegetation) taxa. If the correlations are strong, easily measured geomorphological surrogates could be used to provide a framework that would help river ecologists choose sampling sites and sampling points within those sites in a structured way, and interpret the data collected. With such a framework in place, different kinds of data sets could be brought together for the same river or same river type, in order to contribute to a regional knowledge of river types using a common language and compatible scales.

A questionnaire was compiled to determine the ways in which South African river scientists presently decide on site and sampling-point selection, and how well their selections would enable their data to be linked to those of others researching the same river or river type. Thus, in the questionnaire, scientists were asked how they knew where they were in a stream at differing levels of resolution from catchment to microhabitat; how they presently made decisions on where to sample; and whether or not they were identifying their sampling areas in a way that others could understand and duplicate. The questionnaire also presented an opportunity to find out how data were stored and interpreted and what sorts of data were being collected. No attempt was made to interview all river scientists in the country; rather, those available during the normal course of other work were interviewed.

E1.2 Participants

Twelve river scientists in the country were interviewed (Table A.1). Every province was not represented but scientists in the Western Cape, Eastern Cape and KwaZulu-Natal were interviewed. Scientists across different disciplines with a wide range of perspectives were contacted.

Table E1.1 The participants in the questionnaires, region of the country and institution at which they work and their primary expertise.

Scientist	Province	Institution	Speciality
Mr. J. Alletson	KwaZulu-Natal	Natal Parks Board	macroinvertebrates and fish
Dr. C. Boucher	Western Cape	University of Stellenbosch	riparian vegetation
Dr. J. Boelhouwers	Western Cape	University of the Western Cape	geomorphology
Ms. C. Brown	Western Cape	Southern Waters	macroinvertebrates
Dr. J. Cambray	Eastern Cape	Albany Museum	fish
Dr. A. Channing	Western Cape	University of the Western Cape	amphibians
Dr. M. Coke	KwaZulu-Natal	Natal Parks Board	fish
Ms. H. Dallas	Western Cape	Freshwater Research Unit	macroinvertebrates
Dr. C. Dickens	KwaZulu-Natal	Umgeni Water Board	macroinvertebrates
Mr. B. Fowles	KwaZulu-Natal	CSIR- Durban	macroinvertebrates
Mr. D. Impson	Western Cape	Cape Nature Conservation	fish
Ms. G. Ractliffe	Western Cape	Southern Waters	macroinvertebrates

E1.3 SCIENTIFIC AND MANAGEMENT ISSUES ADDRESSED

As a reflection of the needs of the country, common themes occurred in the scientific and management issues that the scientists were addressing. Most of those interviewed were interested in some aspect of biomonitoring, such as water quality issues, species conservation, habitat preservation or the determination of conservation status of rivers. These issues were being addressed in two ways: through direct monitoring of systems, using available biomonitoring techniques; or through researching ways to change or upgrade current techniques and procedures. Data were also being collected for studies on species distributions and behaviour and on river rehabilitation. The researchers were conducting applied rather than traditional research programmes.

E1.4 RECOGNITION AND CHOICE OF SAMPLING SITES

According to Rowntree and Wadeson (1996), there are several possible scales for site selection: catchment, segment, reach, (site,) geomorphological unit and hydraulic biotope. The extent to which researchers within the country had already recognised these or similar hierarchical scales and used them for site selection was investigated.

The largest scale, at a regional level, was almost always recognised and recorded by researchers, and communicated well from one researcher to another. Regional designations and catchment information can be gained from well established maps. It is at the next hierarchical level, of segment (Rowntree and Wadeson, 1996) or zone (Eckhout *et al*, 1996), that site selection begins to be less well organised and recorded by researchers.

For the most part, researchers with strict management goals selected sampling areas where their management issues would be addressed. For example, such scientists responded to the question "How do you select your sampling sites?" with the answer that sites were selected upstream and downstream from a

disturbance in order to monitor its effect. This is understandable, but leads to the next question "Was the segment/zone/reach in which the sites occurred recorded and, if so, how?". Most scientists did not formally record where they were, but when asked were able to give an answer, such as "lower river". When asked how they had reached that particular conclusion, the answer was almost always "intuition", "gestalt" or "just know". Other than one person who used a reach-break analysis, there was no structured attempt to identify the location of the site within an hierarchical framework, either geomorphological or ecological. Some people did have an intuitive feel for the slope of the area, but had not translated this into calculated gradients.

Selection of a sampling site was also overwhelming based on accessibility. Concern was expressed over the representativeness of such sites, but few people made any attempt to establish if their chosen sites were representative. Representativeness of a site was most commonly determined by the fact that it "looked as if it had the right sort of habitats". However, no-one could provide data on what combination of physical conditions would be within the range of normal for any chosen site. Thus, there seems to be a great body of intuitive knowledge on sites around the country, but little attempt by most scientists to place their sites in context.

E1.5 *CHOICE OF* SAMPLING POINTS WITHIN SITES

The choice of where to sample within a particular site was done in a similar way to that of choosing a site. Researchers using the SASS approach to pollution assessment followed Dr M. Chutter's lead by sampling macroinvertebrates in "stones-in-current" and "stones-out-of-current". Others, especially fish scientists, sampled areas that they knew from past experiences or from intuitive feel would contain the animals they sought. Researchers with a primary goal of finding a certain species tended to sample where they felt that species would be found, in part to save time, hence money; they did not usually choose or describe such areas in any structured, measurable way. Mostly, where different combinations of hydraulics and substrata were sampled, each area was given a name, such as riffle, run, or pool. However, usually, no clear definitions of these terms were given or, if they were, these tended to be descriptive rather than including measurable characteristics. Thus, knowledge of sampling areas could not easily be transferred between scientists, misunderstandings could arise and opportunities for linking data sets were reduced.

E1.6 FATE OF SAMPLES AND DATA

When samples of plants and animals are collected, the majority of researchers send voucher specimens/catalogue specimens to the relevant museums around the country, and so all common species as well as new species are catalogued in the national archives. In a few instances, samples remain in the possession of individual researchers for the duration of the project and for a set time period after the completion of the project for future validation purposes. National respositories do exist for fish, vegetation and invertebrates.

Data storage, or the transfer of data from sheets to some sort of permanent storage record, varies from scientist to scientist. A fair number of projects still have their data on data sheets and have not transferred the information to either a spreadsheet or database. Of those who have transferred their data to an electronic medium, packaged database programs seem to be the primary storage method, although

spreadsheets are also in use. Overall, there is not a consistent method of storing data and, for the most part, the use of these data collections is set up for personal use in each individual project.

None of the studies surveyed have been submitted out for journal publication, although some are in preparation and could very well be submitted to a refereed journal. Primarily, data have been analysed and written up either in internal reports or for reports to a particular funding agency. In a few instances data collected have been incorporated in the relevant national Red Data Book for rare and endangered species.

E1.7 CONCLUSIONS

The main finding, based on these questionnaires, is that there is a need and a desire for the development of guidelines on where to sample in a structured way. All but two of the scientists interviewed felt that a geomorphological template that was ecologically relevant, or something similar, would be very helpful to them in their work. Use of this kind of physical template can enhance understanding of relationships between biological communities and their environment, and give researchers clues as to how communities could change with anthropogenic disturbances of a river's physical structure. Most researchers are presently using an intuitive rather than explicit rationale for choosing sampling sites and sampling points within a site.

There thus seems a need for a framework and a common language to guide such selections. With these in place, data collected in different ways by different specialists can be linked to create a growing body of knowledge on specific rivers or river types. Thus far there is not such a system in use in the country. The geomorphological template proposed by Rowntree and Wadeson is a recent development and requires validation as to its ecological relevance. Once the validation process has been completed for Western Cape rivers and if the template is found to be valid, this could be used for development of guidelines that will aid Cape researchers in site selection, and production of a protocol for undertaking the same process in other regions of the country.

Appendix E2. Liaison with the Kruger National Park Rivers Research Programme, through its abiotic-biotic links project

This was originally referred to as Attachment B in WRC Steering Committee Progress Report 2 submitted in January 1997

E2.1 Introduction

Meeting objective 3.2(a), JMK and DMS participated in meetings of Phase II of the Kruger National Park Rivers Research Programme (KNPRRP). The KNPRRP was one of the principle influences in the design of this project (as cited in the explanatory memorandum of May 1996) and continues to influence it. The last year of Phase II was a project to model abiotic conditions within the Sabie River and use the results to predict biotic responses. After several years of research on the Sabie River, the project is operating in a relatively data-rich environment. The project reported on here is designed to develop a framework for organising and interpreting scientific data on rivers, which can be used in data-poor situations. The main purposes of project staff attending workshops on the KNPRRP Abiotic-biotic links project were a) to learn the KNPRRP methodologies being developed and to assess the potential for their application in data-poor situations, and b) to contribute to model development where expertise allowed. The complexities of linking geomorphological data to biological/ecological data were evident, as were the differing time scale factors at work. It became clear that data collection needed to be done with the appropriate abiotic-biotic linkages in mind, something that had not always been possible in the KNPRRP because of the lack of co-ordination of projects in the early stages.

E2.2 Activities

The specific activities in which JMK and DMS participated are outlined below. Appendices referred to are not attached, but are available on request.

- April 1996. Attended KNPRRP workshop, where the model which would link hydrology, geomorphology and fish community composition was presented. The core group that developed the model were G. Jewitt, A. van Niekerk, G. Heritage and D. Weeks.
- JMK and DMS, together with R. Tharme of the Freshwater Research Unit, communicated with the core group by email and eventually wrote a feedback document (Appendix 1) to the group. This expressed some concerns with the modelling process and with some of the assumptions made in the model itself. The main concerns were:
- Confusion as to how the suitability indices (SI) were calculated, used and interpreted. Channel index appeared to have been used to create SI curves, but with no explicit inclusion of hydraulic processes. The codes could thus code different habitats similarly, although the areas would be preceived differently by instream biotas.
- The calculation used to to produce the "fishy index of niceness" or FIN seemed to be an inappropriate use of the SIs calculated by the fish specialist. The mis-use of the SI was queried by JMK and R. Tharme, through their experience with a similar mis-use of data in the instream flow incremental methodology (IFIM).

The feedback document was sent out May 1996, email dialogue continued April-June 1996.

- May - July 1996. A paper, authored by Heritage, van Niekerk and Weeks, on the KNPRRP abiotic-biotic links research had been submitted to the Ecohydraulics 2000 conference held in

Canada. Project staff and R. Tharme compiled a five-page informal review of the manuscript, upon request from the core group (Appendix 2).

- June 1996. A written response to the feedback document was received from the core group, (Appendix 3). Project staff met with Messrs. Weeks and Jewitt in Stellenbosch to discuss development of the abiotic-biotic links models. One of the main issues discussed was the codes used for describing the abiotic environment, which still seemed to exclude appropriate information on hydraulic conditions. JMK and DMS agreed to design another set of codes that could help solve this problem.
- June 1996. An alternative set of cover codes was developed by project staff and sent to the core group.
- July 1996. Continued email dialogue between DMS/JMK and the core group.
- August 1996. A meeting between the core group, JMK, DMS and R. Tharme was set up to find solutions to outstanding points still in contention. FIN and FIN2 (a second version by Dr Heritage) were still seen by JMK, DMS and Ms Tharme as taking the data further than was valid. Project staff suggested an alternative way of linking the geomorphological and fish data, that was similar to that used to link the hydrological and fish data. The core group agreed to consider this approach, and also decided not to use the alternative set of cover codes suggested by project staff due to the work load involved in new analyses. JMK and DMS left the core group to continue model development and conclude the project, which was nearing its end.
- December 1996. JMK and DMS attended the final workshop of the KNPRRP abiotic-biotic links project. In this, the last meeting of Phase II, the contributors to the modelling process presented the up-dated form of their models and demonstrated how the models linked. It was discussed that these were prototype models and that there was still much development needed to finalise them and test their applicability outside the Sabie River. A proposal to refine and advance these models was discussed.

E2.3 Conclusions

There were few direct similarities between the KNPRRP abiotic-biotic links project and the WRC-funded Western Cape one. However, as both groups are focussed on essentially the same problem, there is much to be gained by continued strong collaboration between them and it is hoped that this will continue. It is clear from the KNPRRP project that a geomorphological template for biological data organisation for rivers can work, although there can be problems with this if the details are not thought out fully before data collection begins. For instance, when the abiotic model outputs are to be linked to **instream** biota, as opposed to **riparian** biota, it is still felt that there needs to be an explicit hydrological component in the linkage rather than an implied one through the presence of different geomorphological units. The geomorphological units can still be there, implying (say) a riffle, long after all water has disappeared from a river, with obvious consequences for instream biotas.

We were also able to see, through this exercise, the benefits of having a conceptual and practical framework in place to facilitate link-ups of data on a regional basis and national basis. Without such a framework, at this stage, there is no procedure for extrapolating the Sabie River data and models to other areas.

Appendix E3 Capacity Building

This was originally in WRC Steering Committee Progress Report 5 submitted in June 2000

Capacity Building

The following university theses are linked to this project:

- There has been close contact with Prof André Görgens and Prof Albert Rooseboom of the Civil Engineering Department, Stellenbosch University, throughout the project, particularly with regard to possible research projects with an environmental slant for engineering students. The engineering students used the study sites from this project, or data collected, as one or more of the foci of their theses:
    - Ralph Canto completed a fourth-year engineering thesis ***Channel maintenance flows for pristine Western Cape rivers.*** This project won the Departmental and Faculty awards at the University of Stellenbosch.
    - A. P. Zeeman completed a fourth-year engineering thesis ***Investigation of the depth-discharge relations of Western Cape cobble-bed streams.***
    - Verno Jonkers is presently writing a PhD thesis within the linked WRC project ***Hydraulic characteristics of ecological flow requirement components in winter rainfall rivers.***
- There is also close liaison with Mr Neil Armitage at the Civil Engineering Department at the University of Cape Town. As a result one fourth-year engineering project has been completed based on the hydraulic data from this project:
    - Sonja Karassellos: B.Sc (Eng.) thesis project ***Exploring the links between ecological flow types in rivers and local hydraulics***, completed 1999.
- In the Zoology Department at the University of Town, JMK supervised the following postgraduate students directly linked to this project:
    - Jennifer Botha: BSc (Hons.) project ***Indentifying hydraulic biotopes in a mountain stream using the community structure of benthic macroinverthrates***, completed 1997.
    - Carryn Manicom: BSc. (Hons.) project ***Effect of the Black Wattle Acacia mearnsii on a Cedarberg river ecosystem*** completed 1999.
    - Denise Schael: PhD thesis ***Distributions of physical habitats and benthic invertebrates in Cape headwater streams at multiple temporal and spatial scales,*** due for submission in 2002.
    - Bruce Paxton: BSc. (Hons) project ***Distribution and biodiversity patterns of invertebrates in a Cape foothill river,*** completed 2000.
- In addition, during the course of this project JMK acted as supervisor or co-supervisor to the following postgraduates:
    - Cate Brown: PhD thesis ***Modelling and managing the effects of trout farms on Cape rivers.*** Completed 1997.
    - Sharon Pollard: PhD thesis ***Instream flow requirements for the Marite River based on a habitat-assessment approach***, completed 2001.
    - Rebecca Tharme: PhD thesis ***Towards the incorporation of low flow requirements of riverine benthic macroinvertebrates in environmental flow methodologies***, due for submission 2002.
    - Geordie Ractliffe: MSc thesis, ***Changes in macroinvertebrate assemblages in the Molenaars River, du Toits Kloof, during bridge construction***, due for completion in 2001, but now upgraded to Ph.D. for completion in 2002.

University of Cape Town undergraduate students employed part-time on this project, who received scientific training from project staff:

- Helen Syfret
- Belinda Day
- Brett Macey
- Tim Corver
- Glen Malherbe

- Bruce Paxton
- Allistair McMaster
- Peta Binedell (GIS)

Technology transfer

1996/97

- JMK acted as scientific consultant to the Institute of Water Quality Studies for the design phase of the National Aquatic Ecosystem Biomonitoring Programme, and sat as scientific advisor on its National Co-ordinating Committee until mid 1997.
- JMK was the senior planner and organizer of the IWQS-funded Spatial Framework workshop in Cape Town in January 1996, she co-authored the report on Technical Considerations and Protocols for the Selection of Reference and Monitoring Sites (Eekhout *et al.* (1996), and acted as facilitator at the National Biomonitoring Programme consultation planning meeting in September 1996.
- JMK attended the Third National River Bioassessment workshop of the Australian National River Health Programme in Canberra, October 1996, and wrote a report for the Water Research Commission and IWQS.
- JMK and DMS liaised with the Kruger National Park Rivers Research Programme's (KNPRRP) Abiotic-biotic Links project, to provide input to the fish-habitat modeling component.
- JMK served on the KNPRRP's Programme Development and Management Committee.

1997/98

- The habitat-mapping techniques developed in the project were applied by consultants advising on environmental flows from the newly-built on the Koekoedouw River, Ceres. Mapping of downstream reaches was used to assess the success of flood releases in re-establishing appropriate aquatic habitat in the heavily silted-up river.
- The habitat-mapping techniques developed allowed Australian taxonomists specializing in the Gondwanaland links between Australia, southern Africa and South America, to visit, re-locate and collect rare and relevant species recorded during the project.
- The habitat-mapping techniques were used in the major international consultancy on environmental flows for the Lesotho Highlands Water Project. The maps were used as guides when setting flows for the rivers, and will provide the base-line description of habitat and channel conditions for future monitoring programmes. There is no doubt that contact with the international team employed on the Lesotho Project, and particularly with Prof Angela Arthington of Brisbane, greatly benefited the mapping techniques being developed within this WRC project.
- JMK was invited to a joint Australian/Great Britain workshop on river biomonitoring at Oxford University. Report submitted to IWQS(DWAF).
- JMK presented a paper ***Exploring the links between geomorphological and biological river data, at scales from catchment to hydraulic biotope***, co-authored by Ms Schael and Prof. Rowntree of Rhodes University, at the annual congress of the South African Society of Aquatic Scientists, Mtunzini, June 1997.
- JMK lectured on ***Physical conditions in aquatic*** systems to the third-year Zoology course on Inland Aquatic Ecosystems and, with DMS, ran the associated Hydrology-hydraulics practical sessions.
- JMK organized the three-week section on Conservation and Management in the same course, and lectured on ***Managing river flow.***
- JMK lectured on ***Inland Water Systems*** in the professional IEM course rune by the Environmental Evaluation Unit at UCT.
- DMS participated in the Western Cape testing of field data sheets for the development of a geomorphological index for Prof. Rowntree.
- DMS attended a KNPRRP workshop on future development of the Biotic-abiotic Links programme within the Kruger Park.
- JMK contributed to the review of the Water Law, including writing the discussion document ***Quantifying the amount of water required for the maintenance of aquatic ecosystems.***

- JMK became an inaugural member of the international Advisory Panel for the journal Marine and Freshwater Research.

1998/99

- JMK delivered a paper at the Third International Ecohydraulics Symposium in Salt Lake City ***Mosaics of flow types: an ecologist's perspective of local hydraulics***. Paper co-authored by DMS. As a result of this visit, JMK was approached to organise the Fourth International Ecohydraulics Symposium in Cape Town in March 2002.
- JMK visited the World Bank in Washington at their invitation and gave a presentation ***Environmental flow assessments for the Lesotho Highlands Water Project.***
- JMK visited Taiwan at the invitation of the Commissioner of the Taiwanese Provincial Government. She ran a two-day workshop for river engineers ***Sustainable Use of Rivers***, and visited water-resource projects.
- JMK visited Portugal, at the invitation of the Instituto da Agua, Lisbon, to run an introductory workshop on ***Environmental Flow Assessment Techniques.***
- JMK joined the International Aquatic Modelling Group, to exchange information and ideas with (mostly) American and European modellers.
- JMK lectured on ***Physical conditions in aquatic systems*** to the third-year Zoology course on Inland aquatic ecosystems and ran the associated Hydrology-hydraulics practical sessions.
- JMK organized the three-week section on Conservation and Management in the same course, and lectured on ***Managing river flow.***
- JMK refereed papers in Biodiversity and Conservation, the Australian Journal of Ecology, Water SA and the Southern African Journal of Geography. She acted as Evaluator of Research Outputs for the Foundation of Research Development for two senior scientists, Assessor for one institutional application for funding and UCT Internal Examiner for one MSc thesis.
- JMK served on six Steering Committees for the Water Research Commission.
- JMK attended the SASAQS conference on the National Rivers Initiative, Pietermaritzburg, and a two-day Planning Workshop for defining research issues related to assessment of the Ecological Reserve for rivers.

1999/2000

- JMK attended a regional SADC workshop on Water Resources in Southern Africa: Enhancing Environmental Sustainability in Harare, Zimbabwe, November 1999, and co-authored a chapter ***Environmental flow assessments and requirements*** in the resulting World Bank/IUCN publication.
- JMK taught at a ***Training Workshop for Undertaking Research to Assess the Socio-economic Benefits off Improved Water Resources Management in the Lower Zambezi Valley*** as the specialist on environmental flows. Organised by CalTech (USA) and funded by IUCN. Held in Mozambique, March 2000.
- JMK was one of four international specialists invited to make a presentation at the World Bank's Water Week, Washington April 2000.
- JMK lectured on ***Physical conditions in aquatic*** systems to the third-year UCT Zoology course on Inland aquatic ecosystems and ran the associated Hydrology-hydraulics practical sessions. She also lectured on ***Managing river flow*** in the section on Conservation and Management.

Planned technology transfer

It is hoped that the mapping techniques can be developed into a model for predicting discharge-linked changes in river physical habitat. This process was begun in this project, and will form a component of Ms Schael's PhD thesis. It was also pursued in the Lesotho project and developed further in the Breede River Basin Study by the consultants Southern Waters. A similar idea appears in a new WRC project at the University of the Witwatersrand, for which JMK serves on the steering committee.

Implications of the findings of the project regarding river typing need further thought and data analysis, before presentation to the national community of water scientists and managers.

Additional publications

During the course of the project, JMK also co-authored the following publications:

- King, J.M. and D. Louw. 1998. Instream flow assessments for regulated rivers in South Africa using the Building Block Methodology. Aquatic Ecosystem Health and Management 1:109-124.
- Cambray, J.A., J.M. King and C. Bruwer. 1997. Spawning behaviour and early development of the Clanwilliam yellowfish (*Barbus capensis*: Cyprinidae), linked to experimental dam releases in the Olifants River, South Africa. Regulated Rivers: Research and Managament 13: 579-602.
- King, J., J.A. Cambray and N.D. Impson. 1998. Linked effetes of dam-released floods and water temperature on spawning of the Clanwilliam yellowfish *Barbus capensis*. Hydrobiologia 384: 245-265.
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Appendix 4.1 **Part of the record of photographs collected at each site over the 1996-98 field seasons.** Film spool number (Spool #), picture number (Pict. #), river and details of photograph are given. All slides are catalogued and kept with Dr. JM King.

Spool #	Pict. #	River	Description
1	1	Window	Upstream from mid-point of site
1	2	Window	Downstream from mid-point of site
1	3	Window	Step-pool #2, mid-channel bar
1	4	Window	Step-pool morphological unit
1	5	Window	Mini cascade-chute at 14 m
1	6	Window	Chute with Simuliidae at 10 m
1	7	Disa	Upstream from 10 m mark
1	8	Disa	Downstream from 10 m mark
1	9	Disa	Upstream from 15 m mark (at fallen tree)
1	10	Disa	Sample sorting and ID at table
1	11	Newlands	Upstream from bottom of site
1	12	Newlands	Downstream from mid-point of site
1	13	Newlands	Island with main stream on left, temp stream on right, by fallen tree
1	14	Newlands	Step-pool morphological unit at 10 m
1	15	Newlands	Step-pool morphological unit at 10 m
1	16	Cecilia	*Populus canescens* in Cecilia Stream
1	17	Cecilia	*Populus canescens* in Cecilia Stream
1	18	Swartboskloof	Upstream from 5 m
1	19	Swartboskloof	Upstream from 15 m
1	20	Swartboskloof	Downstream from 15 m
1	21	Swartboskloof	Flow types: stream and chute
1	22	Swartboskloof	Upstream at 26 m
1	23	Eerste	Upstream from mid-point of site
1	24	Eerste	Upstream from 0 m point
2	1	Eerste	Metrociderous at 15 m bar
2	2	Eerste	Metrociderous at 15 m bar
2	3	Eerste	Waterfall
2	4	Eerste	Waterfall mood shot
2	5	Eerste	Downstream from 25 m
2	6	Eerste	Deep pool polarised at 22 m
2	7	Lang	Upstream from 20 m (mid-point)
2	8	Lang	Upstream from 20 m (mid-point)
2	9	Lang	Downstream from 20 m
2	10	Lang	Brabejum root at 20 m
2	11	Lang	Denise Schael taking hydraulic readings
2	12	Lang	Flow meter probe in water
2	13	Lang	Sorting table
2	17	Molenaars	Upstream from 0 m over slow area (left bank)
2	18	Molenaars	Upstream from 0 m over fast area (right bank)
2	19	Molenaars	"Sideways riffle" at 15-20 m
2	20	Molenaars	Clear water clean to stones at 30 m
2	21	Molenaars	Downstream from 30 m
2	22	Molenaars	Water in pool, went murky ~13h00
2	23	Molenaars	Water in pool, went murky ~13h00
2	24	Molenaars	Source of pollution: RH Stream and not Elands or tunnel
2	25	Molenaars	Source of pollution: RH Stream and not Elands or tunnel
3	1	Elandspad	Scirpus seeps on access road between David Susmans house and trout farm
3	2	Elandspad	Protea
3	3	Elandspad	Denise Schael laying out cross tape at 5 m
3	4	Elandspad	Downstream from 15 m point
3	5	Elandspad	Scirpus fall and long pool downstream at 5 m (cataract MU)
3	6	Elandspad	Scirpus waterfall at 10-11 m
3	7	Elandspad	Upstream from 25 m with fallen tree
3	8	Elandspad	Denise Schael sampling with kicknet at 20 m

Appendix 6.1 Data sheets used in the baseline survey of site geomorphology

REACH CHARACTERISATION

Recorder		**Date**		**River**	
Reach no.		**Contour range**		**Lat.**	
				Long.	

Delete one

Channel gradient **(measured from topographic map scale: 1: 50 000/1:10 000)**

Tick presence of any of the following features

1. Valley floor		*2. Lateral mobility or entrenchment*		*3. Channel pattern*	
Flood plain		Confined: channel laterally confined by valley side walls		**Single thread**	
Erosional bench				i) low sinuosity (SI<1.5)	
Terrace		Moderately confined: channel course determined by macro-scale features, but some lateral migration is possible		ii) high sinuosity (meandering) (SI>1.5)	
Valley side bench				a) stable-sinuous	
				b) laterally mobile	
Pediment		Non-confined: channel free to migrate laterally over the valley floor (associated with flood plain)		**Multiple thread**	
				braided *(unstable)*	
Valley floor absent		Entrenched: channel confined by steep banks and/or terraces		anastomosing / anabranching	

Channel type

Tick dominant type(s)

Bedrock			Comments
Mixed (note dominant alluvial type(s) below)			
Alluvial	sand		
	gravel		
	cobble		
	boulder		

REACH CLASSICATION

RIVER: _____ *REACH No:* _____ *SITE No.* _____ *DATE:*

(Tick appropriate box)

Reach Type	Description	Tick
ALLUVIAL CHANNELS		
Step-Pool	Characterised by large clasts which are organised into discrete channel spanning accumulations that form a series of steps separating pools containing finer material.	
Plane-Bed	Characterised by plane bed morphologies in cobble or small boulder channels lacking well defined bedforms.	
Pool-Riffle	Characterised by an undulating bed that defines a sequence of bars (riffles) and pools.	
Regime	Occur in either sand or gravel. The channel exhibits a succession of bedforms with increasing flow velocity. The channel is characterised by low relative roughness. Plane bed morphology, sand waves, mid channel bars or braid bars may all be characteristic.	
BEDROCK CHANNELS		
Bedrock Fall	A steep channel where water flows directly on bedrock with falls and plunge pools.	
Cascade	High gradient streams dominated by waterfalls, cataracts, plunge pools and bedrock pools. May include bedrock core step-pool features.	
Pool-Rapid	Channels are characterised by long pools backed up behind channel spanning bedrock intrusions forming rapids.	
Bedrock rib	Formed in steeply dipping bedrock; alluvial areas separate rock ribs which span the channel, significant pools, rapids or falls absent.	
Planar Bedrock	Predominantly bedrock channel with a relatively smooth bed. Significant pools, rapids or falls absent.	

CATCHMENT AND RIPARIAN ZONE CONDITION (REACH)
(can be applied at either the reach or site scale)

RIVER: _____ ***REACH No:*** _____ ***DATE:***

Riparian conditions

Riparian land use	aerial extent			Riparian / channel disturbance	degree of impact		
	local	freq-uent	wide-spread		low	mod	high
natural veld				surface erosion			
natural forest				gully erosion			
grazed veld				borrow pit			
pasture				clearance of riparian vegetation			
arable				roads			
orchards				bridge			
forestry plantation				drift / causeway			
rural residential				weirs			
urban residential				channelisation			
urban industrial				gabions			
				large woody debris			
				water abstraction			
				storm discharge			
other				other			

Local catchment disturbance

erosion	low	mod	severe	probable cause(s)
upsteam impoundment	yes	no		
			distance downstream from dam wall (km)	
other (specify)				

CATCHMENT AND RIPARIAN ZONE CONDITION (SITE)

RIVER: _____ ***REACH No:*** _____ ***SITE No.*** _____ ***DATE:*** _____ ***LATITUDE:*** ***LONGITUDE:***

Riparian conditions

Riparian land use	aerial extent			Riparian / channel disturbance	degree of impact		
	local	freq-uent	wide-spread		low	mod	high
natural veld				surface erosion			
natural forest				gully erosion			
grazed veld				borrow pit			
pasture				clearance of riparian vegetation			
arable				roads			
orchards				bridge			
forestry plantation				drift / causeway			
rural residential				weirs			
urban residential				channelisation			
urban industrial				gabions			
				large woody debris			
				water abstraction			
				storm discharge			
other				other			

Local catchment disturbance

erosion	low	mod	severe	probable cause(s)
upsteam impoundment	yes	no		
			distance downstream from dam wall (km)	
other (specify)				

SITE MORPHOLOGY

RIVER: _____ **REACH No:**_____ **SITE No.**_____ ***DATE:***

Morphological units

ALLUVIAL		
Morphological unit	**Description**	**% aerial cover**
pool	Topographical low point in an alluvial channel caused by scour; characterised by relatively finer bed material.	
backwater	Morphologically detached side channel which is connected at lower end to the main flow	
rip channel	High flow distributary channel on the inside of point bars or lateral bars; may form a backwater at low flows.	
plane bed	Topographically uniform bed formed in coarse alluvium, lacking well-defined scour or depositional features.	
lateral bar or channel side bar	Accumulation of sediment attached to the channel margins, often alternating from one side to the other so as to induce a sinuous thalweg channel	
point bar	A bar formed on the inside of meander bends in association with pools. Lateral growth into the channel is associated with erosion on the opposite bank and migration of meander loops across the flood plain.	
transverse or diagonal bar	The bar forms across the entire channel at an angle to the main flow direction.	
riffle	A transverse bar formed of gravel or cobble, commonly separating pools up stream and downstream.	
rapid	Steep transverse bar formed from boulders.	
step	Step-like features formed by large clasts (cobble and boulder) organized into discrete channel spanning accumulations; steep gradient.	
channel junction bar	Forms immediately downstream of a tributary junction due to the input of coarse material into a lower gradient channel.	
lee bar	Accumulation of sediment in the lee of a flow obstruction	
mid-channel bar	Single bars formed within the middle of the channel; strong flow on either side.	
braid bar	Multiple mid-channel bars forming a complex system of diverging and converging thalweg channels.	
sand waves or lingoid bars	A large mobile feature formed in sand bed rivers which has a steep front edge spanning the channel and which extends for some distance upstream. Surface composed of smaller mobile dunes.	
bench	Narrow terrace-like feature formed at edge of active channel abutting on to macro-channel bank.	
islands	Mid-channel bars which have become stabilised due to vegetation growth and which are submerged at high flows due to flooding	

RIVER: _____ *REACH No:* _____ *SITE No.* _____ *DATE:*

BEDROCK		
Morphological unit	**Description**	**% aerial cover**
Bedrock pool	Area of deeper flow forming behind resistant strata lying across the channel.	
Plunge pool	Erosional feature below a waterfall	
Bedrock backwater	Morphologically detached side channel which is connected at lower end to the main flow	
Waterfall	Abrupt continuity in channel slope; water falls vertically; never drowned out at high flows. Height of fall significantly greater than the channel depth.	
Cataract	Step like succession of small waterfalls drowned out at bankfull flows, height of fall less than channel depth.	
Rapid	Local steepening of the channel long profile over bedrock, local roughness elements drowned out at intermediate to high flows.	
Bedrock pavement	Horizontal or near horizontal area of exposed bedrock.	
Bedrock core bar	Accumulation of finer sediment on top of bedrock.	

Perimeter conditions

note approximate percentage in bank and bed; indicate stratified banks with a /		% silt + clay	% sand	% gravel	% cobble	% boulder	% bedrock
Bank composition Right bank	macro-channel						
	active channel						
Bank composition Left bank	macro-channel						
	active channel						
Bed composition (Use data from form S4 if available. Note type of hydraulic control and bar(s) if present)	pools						
	hydraulic controls						
	bars 1						
	2						
Note relative **density** (d = dense; m = moderate; s = sparse or scattered) and **frequency** (w - widespread, f - frequent, l - local)			trees	shrubs	grass	reeds	herbs
Bank vegetation - Right bank							
Bank vegetation - Left bank							
Instream vegetation							
Indicate main species if known							

BED MATERIAL SIZE DISTRIBUTION ***OBSERVER***

RIVER: _____ ***SITE No.*** _____ ***DATE:***

Tally occurences for a sample of 100 randomly selected clasts for each morphological unit
N.B. class limits for clast sizes adapted from Gordon et al. (1992) after Brakensiek et al. (1979)

	Hydraulic control		***Pool***		***Bar 1***		***Bar 2***	
MORPHOLOGICAL UNIT								
Clast size (mm)	***Tally***	***F***	***Tally***	***F***	***Tally***	***F***	***Tally***	***F***
v. fine sand/silt <0.125								
fine / medium sand 0.125-0.0.5								
coarse/v. coarse sand 0.5 - 2.0								
v.fine / fine gravel 2 – 8								
medium gravel 8 – 16								
coarse/ v.coarse gravel 16 – 64								
small cobble 64 – 128								
large cobble 128 – 250								
small boulder 250 – 500								
medium boulder 500 – 1000								
large / very large boulder 1000 - 4000								
bedrock								

CHANNEL CONDITION

RIVER: _____ REACH No: _____ SITE No. _____ DATE:

Bank condition

	macro-channel						**active channel**					
	Right bank			**Left bank**			**Right bank**			**Left bank**		
	wide-spread	freq-uent	local	wide-spread	freq-uent	local	wide-spread	freq-uent	local	wide-spread	freq-uent	local
stable banks												
active basal erosion												
subaerial erosion												
active basal erosion	vertical banks, undercutting, slumping											
subaerial erosion	sloping bank, sparsely vegetated, active rilling, livestock trampling, etc.											

RIVER _____ SITE

OBSERVER _____ DATE

BED STRUCTURE	**MORPHOLOGICAL UNIT**			
general bed condition				
imbrication: 1. Loosely packed or no packing 3. Moderate packing - some effort required to move material 5. Strongly imbricated- material difficult to move				
armouring 1. No armour 2. Moderate armouring 3. Well developed armour				
Median particle size of armour				
bed clusters 1. No clusters evident 2. Ill defined clusters 3. Clearly developed clusters				

HYDRAULIC BIOTOPES **OBSERVER**

RIVER: **SITE** **DATE**

Flow level at time of sampling (tick box)	**dry**	**isolated pools**	**low**	**medium**	**high**	**flood**	**% aerial cover**	

Hydraulic biotope	**General description**	**Flow type (see table below)**	**pools**	**HCs[2]**
Backwater	a morphologically defined area along-side but physically separated from the channel, connected to it at its downstream end; occur over any substrate	Barely perceptible or zero flow		
Slackwater	an area of no perceptible flow which is hydraulically detached from the main flow but is within the main channel; occur over any substrate	Barely perceptible or zero flow		
Pool	Has direct hydraulic contact with upstream and downstream water; occur over any substrate	Barely perceptible flow		
Glide	Occur over any substrate as long as the depth is sufficient to minimise relative roughness. Glides exhibit uniform flow with no significant convergence or divergence.	Smooth boundary turbulent flow: clearly perceptible flow without any surface disturbance		
Chute	Typically occur in boulder or bedrock channels where flow is being funnelled between macro bed elements. Chutes are generally short and exhibit flow acceleration, often due to flow convergence.	Smooth boundary turbulent flow exhibiting flow acceleration		
Run	Occur over any substrate apart from silt; relative roughness low. They often occur in the transition zone between riffles and the downstream pool;.	Rippled flow or surging flow		
Riffle	Occur over coarse alluvial substrates from gravel to cobble; relative bed roughness high.	Undular standing waves or breaking standing waves		
Rapid	Rapids occur over a fixed substrate such as boulder or bedrock.	Undular standing waves or breaking standing waves		
Cascade	Occurs over a substrate of boulder or bedrock. Small cascades may occur in cobble where the bed has a stepped structure due to cobble accumulations.	Free-falling flow		

[2] HC hydraulic control (riffle / rapid/ etc)

Definition of flow types used in Table 1

No flow.	no water movement
Barely perceptible flow	smooth surface, flow only perceptible through the movement of floating objects.
Smooth boundary turbulent	the water surface remains smooth; streaming flow takes place throughout the water profile; turbulence can be seen as the upward movement of fine suspended particles or as 'boils' on the surface in stronger flow
Rippled surface	the water surface has regular disturbances which form low transverse ripples across the direction of flow
Surging flow	undular waves forming on the surface, but move down stream, breaking up
Undular standing waves	standing waves form at the surface but there is no broken water
Broken standing waves	standing waves present which break at the crest (white water)
Free falling	water falls vertically without obstruction

TRANSECT DATA: CROSS SECTION FORM

RIVER: _____ ***REACH No:*** _____ ***SITE No.*** _____ ***DATE:***

MORPHOLOGICAL UNIT 1										
Cross section channel form (insert measured values)										
		macro -channel		active channel						
channel width (m)										
distance from LHB (m)										
channel depth		max.								
form ratio										

Bank Characteristics (tick appropriate box)										
bank shape		macro-		active		bank	macro-		active	
		RB	LB	RB	LB		RB	LB	RB	LB
vertical						< 10°				
concave						10° - 30°				
convex						30° -60°				
undercut						60° - 80°				
stepped						> 80°				

MORPHOLOGICAL UNIT 2										
Cross section channel form (insert measured values)										
		macro -channel		active channel						
channel width (m)										
distance from LHB (m)										
channel depth		max.								
form ratio										

Bank Characteristics (tick appropriate box)										
bank shape		macro-		active		bank	macro-		active	
		RB	LB	RB	LB		RB	LB	RB	LB
vertical						< 10°				
concave						10° - 30°				
convex						30° -60°				
undercut						60° - 80°				
stepped						> 80°				

TRANSECT DATA: FLOW MEASUREMENTS

RIVER: ___________________REACH No:___________ SITE No.________DATE:

remarks	*distance (m)*	*flow depth (m)*	*velocity ($m\ s^{-1}$)*	*velocity ($m\ s^{-1}$)*	*velocity ($m\ s^{-1}$)*	*flow type*	*substrate*	*hydraulic biotope*
			d =	*d =*	*d =*			

State depth of velocity measurement from surface as a ratio of the depth. Use 0.6 if only one measurement; bottom, 0.8 & 0.2 to give a velocity profile.

CHANNEL PLAN RIVER: _____REACH No:_____ SITE No._____DATE:

CHANNEL CROSS SECTIONS ***RIVER:*** _____ ***REACH No:*** _____ ***SITE No.*** _____ ***DATE:***
(indicate shape of channel and banks, position and type of vegetation, bank composition, benches, bars, flood levels present water levels, bank full level)

left handbank Right hand bank

Hydraulic control (specify _____)
Pool

SUMMARY OF SITE CHARACTERISTICS

RIVER _____ SITE

REACH GRADIENT _____ RIVER ZONE

CHANNEL DIMENSIONS (M)

	WIDTH	DEPTH	XS AREA
MACRO-CHANNEL			
ACTIVE CHANNEL ('bank-full')			
OTHER SIGNIFICANT FEATURE -			

CHANNEL TYPE

CONFINEMENT	
CHANNEL PLAN	
DOMINANT BED MATERIAL	
DOMINANT BANK MATERIAL	
REACH TYPE	
ROUGHNESS	

COMMENTS

Appendix 6.2 Geomorphological classification of study sites. BR = bedrock.

			DESK TOP CLASSIFICATION				FIELD CLASSIFICATION			
No.	Catchment	River	Valley Type	Valley Form (field)	Valley Gradient	Zone	Channel Pattern	Channel Type	Bed Material	Reach Type
1	Olifants	JanDissels	V4	unconfined FP	0.012	D	single	bedrock	BR/ boulder	pool-rapid
2	Olifants, Doring	Rondgat	V2	confined	0.032	C	single	mixed	boulder	plain-bed
3	Olifants	Noordhoek	V4	unconfined FP	0.015	D	single	alluvial	mixed/ boulder	plain-bed
4	Olifants, Doring	Middeldeur	V4	mod. confined	0.013	D	single	bedrock	BR	cascade
5	Olifants, Doring	Groot	V8	mod. confined	0.005	D	multiple	alluvial	mixed/ boulder	pool-riffle
6	Breede	Steenbok	V2	mod. confined	0.035	C	single	mixed	BR/ cobble	plain-bed
7	Breede	Wolvekloof	V1	mod. confined	0.060	B	single	mixed	cobble	step-pool
8	Breede	Wit	V2	confined	0.0184	D	single	mixed	BR/ boulder	plain-bed + pool-rapid
9	Molenaars	Molenaars	V1	confined	0.006	D	multiple	alluvial	boulder	pool-riffle
10	Molenaars	Elands	V1	confined			multiple	fixed boulder	boulder	pool-rapid
11	Molenaars	Elandspad	V2	confined	0.029	C	single	bedrock	BR	pool-rapid
12	Breede	Holsloot	V4	mod. confined	0.0139	D	multiple	alluvial	mixed/ boulder	pool-riffle
13	Breede	DuToits	V1	confined	0.090	B	single	alluvial	cobble	plain-bed
14	Berg	Bakkerskloof	V1	confined	0.230	A	multiple	bedrock	BR	cascade
15	Berg	Zachariashoek	V1	confined	0.174	A	multiple	mixed	BR/ boulder	step-pool
16	Berg	Wemmershoek	V8	unconfined FP	0.010	D	single, wandering	alluvial	sand/ cobble/ boulder	?????
17	Berg	Berg	V4	mod. confined	0.023	C	single	alluvial	cobble	pool-riffle
18	Eerste	Eerste 1	V1	confined	0.055	B	single	fixed boulder	boulder	step-pool + plain-bed
19	Eerste	Langrivier	V1	confined	0.139	A	single	fixed boulder	boulder/ cobble	step-pool
20	Eerste	Swartboskloof	V2	confined	0.139	A	single	fixed boulder	boulder	step-pool
21	Eerste	Eerste 2	V4	confined	0.024	C	single	fixed boulder	boulder	pool-rapid
22	Lourens	Lourens	V8	unconfined FP	0.018	D	single, wandering	alluvial	boulder	pool-riffle
23	Palmiet	Palmiet	V1	confined	0.062	B	single	bedrock	BR	cascade
24	Palmiet	Dwars	V2	confined	0.032	C	single	mixed	BR/ cobble	pool-rapid
25	Davidskraal	Davidskraal	V1	confined	0.064	B	single	alluvial	gravel	pool-riffle
26	Liesbeek	Window		mod. confined			multiple	fixed boulder	boulder/ cobble	step-pool + plain-bed
27	Liesbeek	Newlands	V2	entrenched	0.200	A	single	fixed boulder	boulder	step-pool + plain-bed
28	Sand	Cecilia	V1	confined	0.523	A	single	fixed boulder	boulder	step-pool
29	Disa	Disa	V1	confined			single	fixed boulder	boulder	step-pool

Appendix 7.1 Proportions of substrata x flow type divided by total wetted area of each map of 18 "least disturbed" rivers.

Substrata	Flow Type	B14#	B17$	B15#	R13#	R06#	R08$	R07#	T29#	E18#	E19#	E20#	T27#	M11#	M10#	M09$	O01$	O02$	P24#
BR	BOIL	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	BPF	14.6	0.0	1.7	0.0	2.6	10.6	2.2	0.0	0.03	0.0	0.0	0.0	7.7	0.04	0.0	1.1	3.4	3.7
	BSW	0.0	0.0	0.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0	3.5	0.0	0.0
	CAS	2.2	0.0	3.9	0.0	5.9	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	1.0	0.2
	CH	0.0	0.0	0.1	0.0	0.2	0.0	0.0	0.0	0.03	0.0	0.0	0.0	0.2	0.0	0.0	0.6	0.05	0.1
	FF	0.2	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0
	FRF	0.0	0.0	0.2	0.0	0.7	0.4	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.8	0.0	0.2
	NF	3.7	0.0	0.0	0.0	0.7	0.8	0.0	0.0	0.0	0.0	0.0	0.0	5.5	0.0	0.0	0.8	0.9	0.7
	RS	2.6	0.0	4.0	0.0	11.6	1.0	6.9	0.0	5.9	0.0	1.4	0.0	0.9	0.1	0.0	18.4	0.7	0.5
	SBT	12.2	0.7	4.7	0.0	10.2	0.4	10.4	0.0	0.2	0.0	0.0	0.0	4.3	0.4	0.0	9.6	0.1	3.5
	STR	1.3	0.0	3.5	0.0	0.9	0.0	4.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.03	0.0
	TR	0.7	0.0	3.1	0.0	2.5	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.05	0.7
	USW	0.5	0.0	2.7	0.0	1.7	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	6.8	0.0	0.0
BR/SA	BPF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
	CAS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.05	0.0	0.0
	FRF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3	0.0	0.0
	RS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0
	SBT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.4	0.0	0.0
BR/SI	BPF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.6	0.0	0.0
	FRF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
	NF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.7	0.0	0.0
	RS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
	SBT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	0.0	0.0
	SRF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	0.0	0.0
	TR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0
BR/MOSS	BPF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
	NF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.02	0.0	0.0
	SBT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
	RS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.12	0.0	0.0
	STR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.05	0.0	0.0
	USW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
BR/PALMIET	BPF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.7	0.0	0.0	0.0	0.0	0.8
	NF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.9	0.0	0.0	0.0	0.0	4.9

Substrata	Flow Type	B14#	B17$	B15#	R13#	R06#	R08$	R07#	T29#	E18#	E19#	E20#	T27#	M11#	M10#	M09$	O01$	O02$	P24#
BR/PALMIET	SBT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
BR/SCIRPUS	BPF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.8	0.0	0.0	0.0	0.0	7.4
	BSW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.3
	CAS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.0	0.0	0.0	0.0	2.3
	CH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.04
	FF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
	FRF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.0	0.0	0.0	0.0	0.9
	NF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.7
	RS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.8	0.0	0.0	0.0	0.0	29.3
	SBT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.8	0.0	0.0	0.0	0.0	26.0
	SRF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8	0.0	0.0	0.0	0.0	0.0
	STR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.8	0.0	0.0	0.0	0.0	0.0
	TR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
	USW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.0	0.0	0.0	0.0	2.5
B	BOIL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	4.1	0.0	0.3	0.0	0.2	0.0	0.0	0.0	0.0
	BPF	7.6	2.0	0.0	0.2	5.7	41.5	2.0	16.3	3.5	0.3	0.7	2.2	11.8	4.6	1.5	0.0	0.4	0.3
	BSW	0.0	0.4	0.0	0.6	0.7	0.0	0.2	0.0	6.6	10.7	6.5	0.0	0.3	1.1	0.3	0.05	0.0	0.0
	CAS	1.0	0.6	2.7	1.4	0.3	0.0	0.6	1.6	0.4	9.9	13.6	6.6	0.2	6.6	0.01	0.1	1.9	0.1
	CH	0.0	0.0	0.1	0.03	0.2	0.0	0.0	0.0	0.9	0.1	1.3	0.0	0.0	0.02	0.0	0.0	0.0	0.0
	FF	0.03	0.0	0.0	0.0	0.0	0.0	0.2	0.0	1.7	1.6	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0
	FRF	0.0	0.5	1.7	1.4	0.8	1.0	2.2	8.9	0.9	1.4	0.6	2.7	0.0	3.0	1.7	0.5	0.3	0.1
	NF	1.2	0.1	0.0	0.03	0.0	8.7	0.0	1.6	0.8	0.4	0.2	0.0	0.2	1.7	1.4	0.0	0.1	0.0
	RS	1.0	10.8	2.4	13.5	8.4	0.5	7.4	7.8	18.2	17.2	26.1	15.5	3.0	34.5	12.7	2.2	3.4	1.8
	SBT	3.2	9.1	2.3	1.5	8.1	1.4	7.7	10.9	6.2	4.7	0.0	2.1	0.4	12.9	9.7	0.3	2.9	0.8
	SPILL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SRF	0.0	0.2	0.3	0.03	0.0	0.3	0.0	0.0	0.1	0.0	0.03	0.0	0.0	0.1	0.2	0.0	0.1	0.0
	STR	0.0	0.1	0.4	0.0	0.5	0.0	0.0	0.0	0.6	0.2	2.4	0.0	0.0	0.0	0.0	0.02	0.5	0.0
	TR	0.7	0.0	0.0	0.1	0.0	0.9	0.05	0.8	0.3	0.0	0.0	0.4	0.0	0.1	0.1	0.02	0.0	0.0
	USW	0.03	1.9	1.1	4.1	1.2	0.0	0.1	0.0	9.1	5.7	6.4	1.2	0.8	2.4	0.5	0.3	0.5	0.1
B/LC	BPF	0.0	9.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	BSW	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	CAS	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	FRF	0.0	3.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	NF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	RS	0.0	6.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SBT	0.0	17.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Appendix 7.1

Substrata	Flow Type	B14#	B17$	B15#	R13#	R06#	R08$	R07#	T29#	E18#	E19#	E20#	T27#	M11#	M10#	M09$	O01$	O02$	P24#
B/LC	SRF	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	STR	0.0	0.02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	TR	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	USW	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B/SI	BPF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
	RS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SBT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LC	BO/L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.4	0.0	0.02	0.0	0.0	0.0	0.0
	BPF	5.9	0.8	0.4	1.9	0.4	23.2	2.0	1.9	1.6	0.7	0.7	2.5	0.8	1.1	0.0	0.0	3.0	0.0
	BSW	0.0	0.02	0.0	0.1	0.0	0.0	0.0	0.0	4.2	1.5	0.4	0.0	0.0	0.5	0.0	0.0	0.2	0.1
	CAS	0.7	0.1	0.7	1.2	0.1	0.4	0.4	0.2	0.6	1.0	0.9	3.0	0.0	0.02	0.0	0.0	0.4	0.0
	CH	0.0	0.0	0.3	0.0	0.1	0.0	0.05	0.0	0.5	0.1	0.2	0.3	0.0	0.0	0.0	0.0	0.1	0.0
	FF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.04	0.2	0.04	0.0	0.0	0.0	0.0	0.0	0.0
	FRF	0.0	0.03	1.5	6.4	8.6	1.1	3.6	0.5	2.3	1.6	1.7	13.1	0.0	0.6	0.05	0.0	2.8	0.2
	NF	1.7	0.0	0.0	0.5	0.0	0.9	0.0	0.3	0.5	0.3	0.1	0.0	0.7	0.2	0.0	0.0	0.0	0.0
	RS	1.1	0.5	6.9	33.7	6.7	1.5	9.0	1.9	16.3	11.7	11.0	15.0	0.0	4.4	8.6	0.4	22.3	4.1
	SBT	3.3	7.1	4.3	4.0	1.1	0.3	8.1	3.4	2.7	4.0	0.4	7.8	0.4	5.7	0.01	0.0	9.6	0.3
	SPILL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SRF	0.0	0.0	0.5	0.7	0.0	0.2	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.7	0.0
	STR	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.03	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	TR	0.0	0.0	0.0	0.2	0.1	0.0	0.0	0.0	0.8	0.0	0.0	5.2	0.0	0.0	0.0	0.0	0.03	0.0
	USW	0.1	0.1	0.5	7.2	0.5	0.0	0.3	0.0	6.4	5.2	1.4	1.3	0.0	0.0	0.4	0.0	1.2	0.0
LC/B	BPF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.8	0.0	0.0	0.0
	BSW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
	CAS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0
	FRF	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	4.2	0.0	0.03	0.0
	NF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.1	0.0
	RS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	29.3	0.0	0.25	0.0
	SBT	0.0	2.4	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	9.1	5.9	0.0	0.0	0.0
	SRF	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.1	0.0
	TR	0.0	0.03	0.0	0.0	0.0	0.0	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
	USW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
LC/SC	BPF	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	CAS	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	RS	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SBT	0.0	1.1	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Appendix 7.1

Substrata	Flow Type	B14#	B17$	B15#	R13#	R06#	R08$	R07#	T29#	E18#	E19#	E20#	T27#	M11#	M10#	M09$	O01$	O02$	P24#
LC/SC/SI	BPF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.7	0.0
LC/SA	NF	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	RS	0.0	0.0	0.0	1.23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SBT	0.0	0.0	0.0	0.03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	USW	0.0	0.0	0.0	0.03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LC/SI	BPF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.4	0.0	0.0	0.0	7.8	0.0	0.0	0.0	0.0	0.0	0.0
	CAS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.04	0.0	0.0	0.0	0.0	0.0	0.0
	NF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.5	0.0	0.0	0.0	0.0	0.0	0.0
	RS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SBT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SC	BPF	2.5	2.6	0.2	0.8	0.4	1.9	3.8	1.8	0.0	2.5	0.1	0.4	0.0	1.8	0.2	0.0	2.7	0.0
	BSW	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.03	0.1	0.1	0.0	0.0	0.0	0.1	0.0	0.03	0.0
	CAS	0.0	0.1	0.0	0.3	0.1	0.0	0.1	0.1	0.0	1.1	0.2	0.4	0.0	0.0	0.02	0.0	0.8	0.0
	CH	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.05	0.0
	FRF	0.0	0.7	0.6	0.8	2.5	0.0	2.5	2.3	0.1	1.8	0.4	0.0	0.0	0.3	0.1	0.0	5.1	0.0
	NF	1.1	0.02	0.0	0.1	0.2	0.6	0.0	0.2	0.0	0.9	1.4	0.1	0.03	0.4	0.0	0.0	0.2	0.0
	RS	0.03	3.9	0.7	8.3	4.2	0.0	3.3	0.6	0.0	0.9	2.1	0.8	0.0	0.3	0.4	0.0	6.2	0.1
	SBT	1.7	5.4	1.3	1.5	0.3	0.1	5.8	1.4	0.1	3.5	0.5	2.7	0.0	3.2	0.8	0.0	4.2	0.0
	SPILL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SRF	0.0	0.2	0.0	0.1	0.0	0.05	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.0	4.8	0.0
	STR	0.0	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.03	0.0	0.1	0.0	0.0	0.0	0.0	0.0
	TR	0.0	0.0	0.0	0.03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.8	0.0
	USW	0.0	0.5	0.0	0.9	0.0	0.0	0.6	0.0	0.5	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0
SC/B	BPF	0.0	1.5	0.0	0.0	0.0	0.0	0.05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.03	0.0	0.0	0.0
	BSW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0
	FRF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	1.3	0.0	0.0	0.0
	NF	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	RS	0.0	0.0	0.0	0.0	0.0	0.0	1.45	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0	0.0	0.0	0.0
	SBT	0.0	0.2	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
	SRF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
	USW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
SC/LC	FRF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	0.0	0.0	0.0
	RS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.01	0.0	0.0	0.0
SC/LC/B	BPF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.03	0.0
	FRF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
	SRF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.05	0.0

Appendix 7.1

Substrata	Flow Type	B14#	B17$	B15#	R13#	R06#	R08$	R07#	T29#	E18#	E19#	E20#	T27#	M11#	M10#	M09$	O01$	O02$	P24#
SC/LC/B	TR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.03	0.0
SC/SG	BPF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	RS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SC/SA	BPF	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	CAS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	NF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	3.2
	RS	0.0	0.0	0.0	0.03	0.0	0.0	0.0	0.0	0.0	0.0	7.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	TR	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SC/SI	BPF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.4	0.0
	FRF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
	NF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0
LG	BPF	4.3	1.4	1.5	0.6	0.5	0.9	0.1	0.0	1.3	0.2	0.0	0.0	0.4	0.5	0.1	0.0	0.6	0.5
	BSW	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	CAS	0.0	0.0	0.6	0.03	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.04
	CH	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	FF	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	FRF	0.0	0.1	7.7	0.4	1.2	0.0	0.0	0.0	0.3	0.6	0.0	0.0	0.0	0.2	0.05	0.0	0.2	0.4
	NF	0.9	0.03	0.5	0.0	0.3	0.4	0.0	0.0	0.4	0.0	0.0	0.04	0.0	0.04	0.1	0.0	0.0	0.0
	RS	0.4	0.25	6.9	0.9	4.6	0.1	0.0	0.0	0.4	0.9	0.0	0.3	0.0	0.02	0.0	0.0	1.2	0.2
	SBT	4.7	0.7	8.9	0.6	0.4	0.0	0.1	0.0	1.2	1.4	0.0	0.3	0.0	0.2	0.0	0.0	0.7	0.0
	SRF	0.0	0.03	3.4	0.1	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
	STR	0.0	0.03	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	TR	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
	USW	0.0	0.0	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.04
LG/B	BPF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0
	BSW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0
	CAS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.04	0.0	0.0	0.0
	FRF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0
	NF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
LG/SG	BPF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	RS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LG/SI	FRF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	NF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	RS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SRF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SG	BPF	13.2	1.1	0.1	0.2	0.0	0.4	0.5	0.0	0.0	0.0	0.0	0.1	0.0	0.3	0.0	0.0	0.0	0.0

Appendix 7.1

Substrata	Flow Type	B14#	B17$	B15#	R13#	R06#	R08$	R07#	T29#	E18#	E19#	E20#	T27#	M11#	M10#	M09$	O01$	O02$	P24#
SG	CAS	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	FRF	0.0	0.05	0.1	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.04	0.0	0.02	0.0	0.0	0.0	0.2
	NF	2.5	0.3	0.0	0.0	0.0	0.0	0.0	0.3	0.2	0.0	0.0	0.0	0.0	0.02	0.1	0.0	0.0	0.3
	RS	0.0	0.0	0.1	0.63	1.1	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.02	0.05	0.0	0.0	0.2
	SBT	0.2	0.2	0.5	0.2	0.3	0.0	0.9	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0
	SRF	0.0	0.0	0.1	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
	TR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.6	0.0
SG/SI	BPF	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	NF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0
	SBT	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SA	BPF	1.2	0.3	1.6	0.4	2.6	0.4	1.1	1.3	0.0	0.3	0.0	0.0	0.0	0.04	0.0	4.7	0.3	1.1
	BSW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	CAS	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.04	0.0	0.0	0.0	0.0	0.05	0.0
	FRF	0.0	0.0	0.3	0.1	0.0	0.0	0.1	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0
	NF	0.0	0.2	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	1.5	0.0	0.1	0.0	0.3	0.4	0.0
	RS	0.5	0.05	0.1	0.6	0.0	0.0	0.0	1.4	0.0	0.8	0.3	0.0	0.0	0.0	0.0	12.8	0.2	0.0
	SBT	1.3	0.1	2.9	0.03	0.2	0.0	0.4	0.2	0.0	0.1	0.0	0.5	0.0	0.0	0.0	3.6	0.4	0.1
	SRF	0.0	0.0	0.3	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.03	0.0
	TR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	USW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
SA/LC	BPF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SA/SG	BPF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	CAS	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.03	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	CH	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	FRF	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	NF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	RS	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SBT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SRF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SA/SI	BPF	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SBT	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	BPF	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.2	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.2	0.2	0.0
	FRF	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	NF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	1.1	0.2	0.0
	RS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.4	0.0	0.0
	SBT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0

Appendix 7.1

Substrate	Flow Type	B14#	B17$	B15#	R13#	R08#	R08$	R07#	T29#	E18#	E19#	E20#	T27#	M11#	M10#	M09$	O01$	O02$	P24#
SI	TR	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RF	BPF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0
	BSW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.02	0.0	0.0	0.0	0.0
	FRF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
	NF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
	RS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
	SBT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
	USW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.02	0.0	0.0	0.0	0.0
WOOD	BOIL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	FF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	RS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

APPENDIX 8.1 **Species list for all sites sampled for testing the geomorphological hierarchy.** A "+" denotes species presence and a "-" denotes absence.

ORDER / SUB-ORDER	FAMILY / SUB-FAMILY	TAXON	O01$	O02$	O03$	O04$	O05$	R06#	R07#	R08#	M09$	M10#	M11#	R12#	R13#	B14#
Acariformes	Anisitsellidae	Anisitsellidae spp.	-	-	+	-	-	+	-	-	-	-	-	-	-	-
		Anisitsellidae sp. 1	-	-	+	-	-	-	-	-	-	-	-	-	-	-
		Anisitsellidae sp. 2	-	-	+	-	-	+	+	-	+	+	-	-	-	-
		Anisitsellidae sp. 3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Anisitsellidae sp. 4	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Anisitsellidae sp. 5	-	-	-	-	-	-	-	-	-	-	-	-	+	-
		Anisitsellidae sp. 6	-	-	-	-	-	-	+	-	-	-	-	-	-	-
		Anisitsellidae sp. 7	-	-	-	-	-	-	-	-	+	-	-	-	-	-
		Anisitsellidae sp. 8	-	-	-	-	-	+	-	-	-	-	-	-	-	-
	Arrenuridae	Arrenuridae sp. 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Arrenuridae sp. 2	-	-	-	-	-	-	-	-	+	-	-	-	-	-
		Arrenuridae sp. 3	-	-	-	-	-	-	-	-	-	+	-	-	-	-
		Arrenuridae sp. 4	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Arrenuridae sp. 5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Hydrachnellae	Hydracarina spp.	+	+	-	-	+	+	-	-	-	-	-	-	-	-
		Hydracarina morph A	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Hydracarina morph B	-	-	-	-	-	+	-	+	+	-	-	-	-	-
		Hydracarina morph D	-	-	-	-	-	-	-	+	-	-	-	-	-	-
		Hydracarina morph E	-	-	+	+	-	+	-	-	+	+	+	-	-	-
		Hydracarina morph F	-	-	-	-	-	-	+	-	+	-	-	-	-	-
		Hydracarina morph H	-	-	-	-	-	+	-	-	-	-	-	-	-	-
		Hydracarina morph K	-	-	+	-	-	+	+	+	+	+	-	-	-	-
		Hydracarina morph M	-	-	-	-	-	-	-	-	+	-	+	-	-	-
		Hydracarina morph N	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Hydracarina morph O	-	-	+	-	-	-	-	+	+	-	-	-	-	-
		Hydracarina morph P	-	-	-	-	-	-	-	-	+	-	+	-	-	-
		Hydracarina morph Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Hydracarina morph S	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Hydracarina morph T	-	-	-	-	-	-	-	-	+	-	+	-	-	-
		Hydracarina morph W	-	-	-	-	-	-	-	-	+	+	-	-	-	-
		Hydracarina morph X	-	-	-	-	-	-	-	-	+	+	-	-	-	-
		Hydracarina morph Y	-	-	+	-	-	-	+	+	+	+	+	-	-	-
		Hydracarina morph Z	-	-	-	-	-	-	-	-	+	-	-	-	-	-
		Hydracarina morph AA	-	-	+	-	-	-	-	-	+	-	-	-	-	-
		Hydracarina morph AB	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix 8.1

ORDER / SUB-ORDER	FAMILY / SUB-FAMILY	TAXON	O01$	O02$	O03$	O04$	O05$	R06#	R07#	R08#	M09$	M10#	M11#	R12#	R13#	B14#
Acariformes	Hydrachnellae	Hydracarina morph AD	-	-	-	-	-	-	-	-	+	+	-	-	-	-
		Hydracarina morph AE	-	-	-	-	-	-	-	-	+	+	-	-	-	-
		Hydracarina morph AF	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Hydracarina morph AH	-	-	-	-	-	+	+	+	-	-	-	-	+	-
		Hydracarina morph AJ	-	-	-	-	-	+	-	-	-	-	-	-	-	-
		Hydracarina morph AK	-	-	-	-	-	+	-	-	-	-	-	-	+	-
		Hydracarina morph AL	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Hydracarina morph AP	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Hydracarina morph AT	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Oribatidae	Oribatidae sp. 1	-	-	-	-	-	-	-	-	-	+	+	-	-	-
		Oribatidae sp. 2	-	-	-	-	-	-	-	-	-	+	+	-	-	-
		Oribatidae sp. 3	-	-	-	-	-	-	-	-	-	+	-	-	-	-
		Oribatidae sp. 4	-	-	-	-	-	-	-	-	-	-	+	-	-	-
		Oribatidae sp. 5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Oxidae	Oxidae sp. 1	-	-	-	-	-	-	-	+	-	-	-	-	-	-
Amphipoda	unspecified	Amphipoda sp.	+	-	-	+	-	-	-	-	-	-	-	-	-	-
	Paramelitidae	*Paramelita sp.*	-	-	-	-	-	-	-	-	-	-	-	+	-	-
		Paramelita nigroculus	-	-	-	+	-	+	-	-	-	-	-	-	-	-
Anomopoda	Daphniidae	*Daphniopsis sp.*	-	-	-	-	-	-	-	-	-	-	-	+	-	-
Basommatophora	Ancylidae	*Burnupia sp.*	-	-	-	-	+	-	-	-	-	-	-	-	-	-
Branchiobdellidae	unspecified	Branchiobdellidae spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cladocera	Chydoridae	*Chydoridae sp.*	-	-	-	-	-	-	-	-	+	+	-	+	-	-
Coleoptera	unspecified	Coleoptera spp.	-	-	+	+	-	-	+	-	+	-	+	-	-	-
		Coleoptera sp. 4	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Curculionidae	Curculionidae spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Dytiscidae	Dytiscidae spp.	-	-	+	-	+	-	-	-	+	-	-	-	-	+
		Dytiscidae sp. 1	-	-	-	-	-	-	-	-	-	-	-	+	-	-
		Dytiscidae sp. 2	-	-	-	-	-	-	-	-	-	-	-	+	-	-
		Potamonectes capensis	-	-	-	-	-	-	-	-	-	-	-	-	-	+
		Yola inopinata	+	-	-	-	-	-	-	-	-	-	-	-	-	-
		Laccophilus concisus	-	-	-	-	+	-	-	-	-	-	-	-	-	-
	Dryopidae	Dryopidae spp.	-	-	+	-	-	+	+	-	-	-	-	-	+	-
		Dryopidae sp. 1	-	-	-	-	-	-	+	-	+	-	+	-	-	-
		Dryopidae sp. 2	-	-	-	-	-	-	-	-	-	+	+	-	-	-
		Strina sp.	-	-	-	-	+	-	-	-	-	-	-	-	-	-
		Strina sp. 1	-	-	-	+	-	+	+	+	+	+	+	-	-	-
		Strina sp. 2	-	-	-	-	-	-	-	-	+	-	-	-	-	-
	Elmidae	Elmidae spp.	+	-	-	-	+	-	-	-	+	+	+	-	-	-
		Elmidae sp. 1	-	-	-	-	-	-	-	-	+	+	+	-	-	-

Appendix 8.1

ORDER / SUB-ORDER	FAMILY / SUB-FAMILY	TAXON	O01$	O02$	O03$	O04$	O05$	R06#	R07#	R08#	M09$	M10#	M11#	R12#	R13#	B14#
Coleoptera	Elmidae	Elmidae sp. 2	-	-	-	+	-	-	-	-	+	+	-	-	-	-
		Elmidae sp. 3	-	-	-	-	-	-	-	-	+	+	-	-	-	-
		Ctenelmis harrisoni	+	-	-	-	-	-	-	-	-	-	-	-	-	-
		Elpidelmis sp.	+	+	+	+	+	-	-	-	-	-	-	-	-	+
		Elpidelmis sp. 1	-	-	-	-	-	+	+	+	+	+	+	-	+	-
		Elpidelmis sp. 2	-	-	-	-	-	-	-	-	+	+	+	-	-	-
		Elpidelmis sp. A	-	-	+	+	-	+	+	+	+	+	+	-	+	-
		Elpidelmis sp. B	-	-	-	+	-	+	+	+	-	+	+	-	-	-
		Elpidelmis capensis	+	+	-	-	-	-	-	-	-	-	-	-	-	-
		Haplelmis sp.	-	-	+	-	-	-	-	-	-	-	-	-	-	-
		Haplelmis mixta	-	+	-	-	-	-	-	-	-	-	-	-	-	-
		Peloriolus sp.	+	+	+	+	+	+	+	+	+	+	+	-	+	+
		Peloriolus sp. 1	-	-	-	-	-	+	+	+	-	+	+	-	+	-
		Peloriolus sp. 2	-	-	-	-	-	+	-	+	-	+	+	-	+	-
		Peloriolus sp. nov.	+	+	-	-	+	-	-	-	-	-	-	-	-	-
		Peloriolus granulosus	+	+	-	-	+	-	-	-	-	-	-	-	-	-
		Peloriolus parvulus	-	+	-	-	-	-	-	-	-	-	-	-	-	-
		Peloriolus pilosellus	+	+	-	-	-	-	-	-	-	-	-	-	-	+
		Tropidelmus sp.	-	-	-	+	-	-	-	-	-	-	-	-	-	-
		Tropidelmus hintoni	+	-	-	-	-	-	-	-	-	-	-	-	-	-
	Gyrinidae	Gyrinidae spp.	-	-	+	+	-	+	-	-	+	+	-	-	+	-
		Aulonogyrus sp.	-	+	-	-	-	-	-	-	-	-	-	-	-	-
		Aulonogyrus caffer	+	-	-	-	-	-	-	-	-	-	-	-	-	-
		Orectogyrus sp.	+	-	-	-	-	-	-	-	-	-	-	-	-	-
	Helodidae	Helodidae spp.	+	-	-	+	+	-	-	-	+	-	-	-	-	+
		Helodidae sp. 1	-	-	+	+	-	-	+	+	+	+	+	+	+	-
		Helodidae sp. 2	-	-	-	-	-	-	+	+	-	-	-	-	-	-
		Helodidae sp. 4	-	+	+	-	-	-	-	-	-	-	-	-	-	-
		Helodidae sp. 5	-	-	-	-	-	-	-	-	+	+	+	-	-	-
		Helodidae sp. 6	+	+	+	+	+	+	+	-	+	+	-	-	+	+
		Helodidae sp. 7	+	+	-	+	+	+	-	-	-	-	+	-	-	+
		Helodidae sp. 8	-	+	-	-	-	-	-	-	-	-	-	-	-	-
	Hydraenidae	Hydraenidae spp.	+	-	-	-	+	+	-	+	+	-	-	+	+	+
		Coelonefopas sp.	-	+	-	-	-	-	-	-	-	-	-	-	-	-
		Hydraena sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Hydraena sp. 1	-	-	-	-	-	+	+	+	-	+	+	+	-	-
		Hydraena sp. 2	-	-	-	-	-	-	+	-	-	-	+	-	-	-
		Hydraena sp. 3	-	-	-	-	-	-	-	-	+	-	-	-	-	-
		Mesoceration sp.	-	-	+	+	-	-	-	-	+	+	-	-	-	-

ORDER / SUB-ORDER	FAMILY / SUB-FAMILY	TAXON	O01§	O02§	O03§	O04§	O05§	R06#	R07#	R08#	M09§	M10#	M11#	R12#	R13#	B14#
Coleoptera	Hydraenidae	*Mesoceration ?pollidum*	-	-	-	-	+	-	-	-	-	-	-	-	-	-
		Mesoceration dissonum	-	+	-	-	-	-	-	-	-	-	-	-	-	-
		Mesoceration distinctum	-	+	-	-	+	-	-	-	-	-	-	-	-	-
		Mesoceration endroedyi	+	+	-	-	+	-	-	-	-	-	-	-	-	-
		Mesoceration jucundum	-	-	-	-	+	-	-	-	-	-	-	-	-	-
		Mesoceration jusciceps	+	-	-	-	+	-	-	-	-	-	-	-	-	-
		Mesoceration languidum	+	+	+	-	+	-	-	-	-	-	-	-	-	-
		Mesoceration splendorum	-	+	-	-	-	-	-	-	-	-	-	-	-	-
		Mesoceration truncatum	-	-	-	-	+	-	-	-	-	-	-	-	-	+
		Parahydraena sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	+
		Parasthetops nigritus	-	+	-	-	-	-	-	-	-	-	-	-	-	+
	Hydrophilidae	Hydrophilidae spp.	-	-	-	-	-	-	+	-	-	-	-	+	-	-
		Hydrophilidae sp. 1	-	-	-	-	-	-	-	-	-	-	-	+	-	-
		Limnebius sp.	-	+	-	-	-	-	-	-	-	-	-	-	-	-
	Limnichidae	Limnichidae spp.	+	+	+	-	+	+	+	+	-	-	-	-	+	-
		Limnichidae sp. 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Limnichidae sp. 2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Noteridae	Noteridae spp.	-	-	-	-	-	+	-	-	-	-	-	-	-	-
	Torridincolidae	Torridincolidae spp.	-	-	-	-	-	+	-	-	-	-	-	-	-	-
Collembola	unspecified	Collembola spp.	-	-	+	-	-	-	-	-	-	-	-	-	-	-
	Sminthuridae	Sminthuridae spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Copepoda	unspecified	Copepoda spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cyclopoida	unspecified	Cyclopoida spp.	-	-	+	+	-	-	-	+	-	+	+	+	-	+
		Cyclopoida sp. 1	-	-	-	-	-	-	-	+	-	-	-	-	-	-
		Cyclopoida sp. 2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Cyclopoida sp. 3	-	-	-	-	-	-	-	-	+	-	+	-	-	-
Decapoda	Potamonautidae	*Potamonautes sp.*	+	+	-	+	+	-	+	-	-	+	-	-	-	-
Diptera	unspecified	Diptera spp.	-	-	-	-	-	-	+	-	+	-	-	-	+	-
	Anthomyiidae	Limnophora spp.	+	-	-	-	-	-	-	-	-	-	-	-	-	-
	Athericidae	Athericidae spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Atherix sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Atherix sp. 1	-	-	+	-	-	-	-	-	+	+	-	-	-	-
		Atherix sp. 2	-	-	+	-	-	+	+	+	+	+	-	-	+	-
		Atherix sp. 3	-	-	-	-	-	+	+	+	+	-	-	-	-	-
		Atherix sp. 4	-	+	+	-	+	+	-	+	+	-	-	+	+	-
	Blephariceridae	Blephariceridae spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Elporia barnardi	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Elporia capensis	-	-	-	-	-	-	-	-	+	+	-	-	-	-
		Elporia uniradius	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix 8.1

ORDER	SUB-ORDER	FAMILY	SUB-FAMILY	TAXON	O01$	O02$	O03$	O04$	O05$	R06#	R07#	R08#	M09$	M10#	M11#	R12#	R13#	B14#
Diptera		Ceratopogonidae		Ceratopogonidae spp.	+	+	-	-	+	-	-	-	-	-	-	+	-	-
				Ceratopogonid (Bezzia TYPE)	-	-	-	-	+	-	-	-	-	-	-	-	-	-
			Ceratopogoninae	*Bezzia sp.*	-	-	-	-	-	+	-	-	-	-	-	+	-	-
				Bezzia sp. 1	-	-	+	+	-	-	-	-	-	-	-	-	-	-
				Bezzia sp. 2	-	-	+	-	+	-	-	-	-	-	-	+	-	+
			Dasyheleinae	*Dasyhelea spp.*	-	-	+	-	-	-	-	-	-	-	-	-	-	-
			Forcipomyinae	*Atrichopogon spp.*	-	+	-	-	-	+	-	-	-	+	-	-	-	+
				Atrichopogon sp. 1	-	-	-	-	-	+	-	-	-	-	-	-	+	-
			Forcipomyinae	*Atrichopogon sp. 2*	-	-	-	-	-	+	-	-	-	-	-	-	+	-
				Forcipomyia spp.	-	-	+	-	-	-	-	-	-	+	-	+	-	-
				Forcipomyia sp. 1	-	-	-	-	-	-	-	-	-	-	-	-	+	-
				Forcipomyia sp. 2	-	-	+	-	-	+	+	-	+	-	-	-	+	-
		Chironomidae		Chironomidae spp.	+	-	-	-	+	+	+	-	-	-	-	-	+	-
			Aphroteniinae	*Aphrotenia barnardi*	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				Aphrotenia tsitsikamae	-	-	-	-	-	-	-	-	-	-	+	-	-	-
			Chironominae	*Chironomus sp.*	-	-	+	-	-	-	-	-	-	-	-	+	-	+
				Cladotanytarsus near linearis	-	-	-	+	-	-	-	-	-	-	-	-	-	-
				Cladotanytarsus near reductus	-	-	-	+	-	-	-	-	-	-	-	-	-	-
				Cladotanytarsus reductus	-	-	-	+	-	-	-	-	-	-	-	-	-	-
				Cladotanytarsus sp.	-	+	+	+	-	-	+	-	-	-	-	-	-	-
				Cryptochironomus sp.	+	-	-	-	+	-	+	-	-	-	-	-	-	-
				Microtendipes sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				Parachironomus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				Polypedilum dewulfi	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				Polypedilum E sp.	-	-	+	+	-	+	+	+	+	+	+	+	-	-
				Polypedilum sp.	-	+	+	-	-	-	-	-	+	-	-	+	+	-
				Polypedilum U sp.	+	+	+	+	+	+	+	+	+	+	-	+	+	+
				Rheotanytarsus fuscus	+	+	+	+	+	+	+	+	+	+	+	+	+	+
				Stenochironomus sp.	-	+	-	-	+	-	-	-	-	-	-	-	-	-
				Stictochironomus sp.	-	-	-	-	-	+	-	-	-	-	-	-	+	-
				Tanytarsus sp.	+	-	+	-	-	+	+	-	-	-	-	-	-	-
				Tanytarsus sp. 1	+	+	+	+	+	+	-	-	+	-	+	+	+	+
				Tanytarsus sp. 2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				Tanytarsus sp. 3	-	-	-	+	-	-	-	-	-	-	-	-	-	-
				Virgatanytarsus nigricornis	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				Virgatanytarsus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			Orthocladinae	Orthocladiinae spp.	-	-	-	-	-	+	-	-	-	-	-	-	-	-
				Orthocladius sp.	-	-	-	-	-	-	-	-	-	-	+	-	-	-
				Orthocladius sp. 2	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix 8.1

ORDER / SUB-ORDER	FAMILY / SUB-FAMILY	TAXON	O01$	O02$	O03$	O04$	O05$	R06#	R07#	R08#	M09$	M10#	M11#	R12#	R13#	B14#
Diptera	Orthocladinae	Orthocladinae gen. nov.	-	-	-	-	-	-	-	-	-	-	+	-	-	-
		Hairy Orthocladinae	+	-	-	-	-	-	-	+	-	-	-	-	-	-
		Bryophaenocladius sp.	-	-	-	-	-	-	-	-	-	-	-	+	-	-
		Cardiocladius sp.	+	+	-	+	+	-	+	+	+	+	-	-	+	-
		Cardiocladius hessei	-	-	-	-	-	-	+	-	-	-	-	-	-	-
		Corynoneura dewulfi	-	-	-	-	-	-	-	-	+	-	-	-	-	-
		Corynoneura sp. 1	+	+	-	+	+	+	+	-	+	+	+	-	+	+
		Corynoneura sp. 2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Corynoneura sp. 3	-	-	-	+	-	-	-	-	-	-	-	-	-	-
		Cricotopus sp.	-	-	+	-	-	+	-	-	-	+	-	+	-	-
		Cricotopus sp. 1	+	+	+	-	+	+	+	-	-	+	+	+	+	+
		Cricotopus sp. 2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Cricotopus sp. 3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Cricotopus sp. 4	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Cricotopus sp. 5	-	-	-	-	+	-	-	-	-	-	-	+	-	-
		Cricotopus sp. 6	-	-	-	-	-	+	-	-	-	-	-	-	-	-
		Cricotopus albitibia	-	-	-	-	-	-	+	-	-	-	-	-	-	-
		Cricotopus dibalteatus	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Cricotopus flavozonatus	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Cricotopus kisantuensis	-	+	-	-	-	+	+	-	-	-	-	+	-	-
		Cricotopus obscurus	-	-	+	+	-	-	-	-	-	-	-	+	-	-
		Cricotopus scottae	-	-	-	-	-	-	-	-	-	-	-	+	-	-
		Eukiefferiella calviger	+	-	-	-	+	-	-	-	-	-	-	-	+	-
		Eurycnemus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Nanocladius brunneus	-	-	-	-	-	-	-	-	-	-	-	+	-	-
		Nanocladius sp.	-	-	+	+	-	-	-	-	-	-	-	+	+	-
		Notocladius capicola	+	+	+	+	+	+	+	+	+	+	+	-	+	+
		Paracladopelma sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Paradoxocladius mangoldi	-	-	+	+	+	-	-	-	-	-	-	-	-	-
		Parakiefferiella biloba	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Parakiefferiella sp.	-	-	-	-	-	+	-	-	-	-	-	-	-	-
		Parametriocnemus scotti	-	+	+	+	-	+	-	-	-	-	+	-	-	+
		Paraphaenocladius sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Psectrocladius sp.	-	-	-	-	-	-	-	-	-	-	-	+	-	-
		Pseudosmittia sp.	-	-	-	-	-	-	-	+	-	-	-	-	-	-
		Rheocricotopus capensis	+	+	+	+	+	+	+	-	+	+	+	+	+	+
		Thienemanniella sp.	-	-	+	-	-	+	-	-	+	-	-	-	-	-
		Thienemanniella sp. 1	+	+	+	-	-	+	+	-	+	+	+	+	-	+
		Thienemanniella sp. 2	-	-	-	-	-	+	-	-	-	-	-	-	-	-

Appendix 8.1

ORDER	SUB-ORDER	FAMILY	SUB-FAMILY	TAXON	O01$	O02$	O03$	O04$	O05$	R06#	R07#	R08#	M09$	M10#	M11#	R12#	R13#	B14#
Diptera			Tanypodinae	*Thienemanniella sp. 3*	+	-	-	-	-	+	+	-	-	-	-	-	-	-
				Thienemanniella sp. 4	-	+	+	-	-	-	-	-	-	-	-	-	-	-
				Thienemanniella trivittata	-	-	-	-	-	-	-	-	-	+	-	-	-	-
				Tvetenia calvescens	+	+	+	+	+	+	+	+	+	+	+	+	+	+
				Ablabesmyia sp.	+	-	+	+	+	+	-	+	+	-	-	+	+	+
				Clinotanypus sp.	-	-	-	-	+	-	-	-	-	-	-	-	-	-
				Conchapelopia sp.	+	+	+	+	+	+	+	+	+	+	+	+	+	+
				Conchapelopia trifascia	-	-	+	-	-	-	-	-	-	-	-	-	-	-
				Larsia sp.	+	+	+	+	+	+	+	+	+	+	+	-	+	+
				Macropelopia marmorata	-	-	-	-	-	-	+	-	-	-	-	-	-	-
				Nilotanypus sp.	-	-	+	+	-	-	-	-	-	-	-	+	-	-
				Nilotanypus sp. 1	+	-	-	-	+	-	+	-	+	+	+	-	-	-
				Nilotanypus sp. 2	-	-	-	-	-	+	-	-	-	-	-	-	-	-
				Nilotanypus sp. 3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				Paramerina sp.	+	+	+	+	+	+	+	+	+	+	+	+	+	+
				Paramerina sp. 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				Paramerina sp. 2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				Procladius sp.	+	+	+	+	+	+	-	+	-	-	-	+	+	+
			Tanytarsini	*Constempellina sp.*	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				Stempellina sp.	+	-	+	+	+	+	+	+	-	-	-	-	+	-
				Stempellinella sp.	-	-	-	-	-	-	-	-	-	-	+	-	-	-
				Stempellinella truncata	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				Zavreliella marmorata	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Culicidae		Culicidae spp.	-	-	+	-	-	-	-	-	+	+	+	-	+	+
				Anopheles sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	+
		Dolichopodidae		Dolichopodidae spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Empididae		Empididae spp.	+	-	-	+	+	-	-	-	-	+	+	-	-	-
				Clinocera sp.	+	+	-	-	-	+	+	+	-	+	+	-	-	+
				Hemerodromia sp.	+	+	-	+	+	+	+	+	-	-	-	+	-	+
				Trichina sp.	-	-	-	-	-	-	-	-	-	+	-	-	-	-
		Dixidae		Dixidae spp.	-	-	-	+	-	+	-	-	-	-	-	-	+	-
		Ephydridae		Ephydridae spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Muscidae		Muscidae spp.	+	-	-	-	+	-	-	-	-	-	-	-	-	-
		Psychodidae		Psychodidae spp.	-	-	-	-	-	+	-	-	-	-	-	-	-	-
				Pericoma sp.	-	-	-	-	-	-	-	-	-	-	-	+	-	-
				Pericoma sp. 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				Pericoma sp. 2	-	-	-	-	-	-	-	-	-	-	-	+	-	-
		Sciomyzidae		Sciomyzidae spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Simuliidae		Simuliidae spp.	+	+	+	+	+	+	+	+	+	+	+	+	+	+

Appendix 8.1

ORDER / SUB-ORDER	FAMILY / SUB-FAMILY	TAXON	O01$	O02$	O03$	O04$	O05$	R06#	R07#	R08#	M09$	M10#	M11#	R12#	R13#	B14#
Diptera	Simulidae	*Simulium spp.*	-	+	-	+	+	-	-	-	-	+	-	-	-	+
		Simulium alcocki	-	-	-	-	-	-	-	-	-	-	-	-	-	+
		Simulium bequaerti	+	-	-	-	-	-	-	-	+	+	-	-	-	-
		Simulium bovis	-	-	-	-	-	-	-	+	-	-	-	-	-	-
		Simulium dentulosum	-	-	-	-	-	-	-	-	-	-	-	-	-	+
		Simulium harrisoni	+	+	-	-	-	-	-	-	-	+	-	-	-	-
		Simulium impukane	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Simulium medusaeforme	+	+	-	+	+	-	+	-	+	+	+	-	-	+
		Simulium m. hargreavesi	-	-	-	-	+	-	-	-	-	-	-	-	-	-
		Simulium merops	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Simulium metamphallus	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Simulium nevermania	-	-	-	+	-	-	-	-	-	-	-	-	-	-
		Simulium nigritarse	+	+	-	-	-	-	-	-	-	-	+	-	-	-
		Simulium nigritarsi/brachium	-	-	-	-	-	-	-	-	-	+	+	-	-	-
		Simulium rutherfoordi	-	-	-	-	-	-	-	-	-	-	+	-	-	+
		Simulium unicornutum	-	-	-	-	+	-	-	-	-	-	-	-	-	-
		Simulium vorax	+	-	-	-	-	-	-	-	-	-	-	-	-	-
	Stratiomyiidae	Stratiomyiidae spp.	-	-	-	-	-	-	+	-	-	-	-	+	-	-
	Tabanidae	Tabanidae spp.	-	-	-	-	+	-	+	-	-	-	+	-	-	-
		Tabanus sp.	-	-	+	-	-	-	-	-	-	-	-	-	-	-
	Tipulidae	Tipulidae spp.	-	-	-	-	-	-	-	-	+	-	-	+	+	-
	Limoniinae	*Antocha sp.*	+	+	-	-	-	-	-	-	-	-	-	-	-	-
		Limnophila sp.	-	+	-	-	-	+	-	+	-	+	-	-	+	-
		Limnophila sp. 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Limnophila sp. 2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Limnophila nox	-	-	-	-	-	+	+	+	-	-	-	+	+	+
		Limonia sp.	-	-	-	-	-	+	+	+	-	-	-	+	-	-
		Limonia sp. 1	-	-	-	-	-	-	+	-	-	-	-	-	-	-
		Limonia sp. 2	-	-	-	-	-	-	-	-	-	+	+	-	-	-
		Limonia sp. 3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ephemeroptera	unspecified	Ephemeroptera spp.	-	-	-	-	-	-	-	-	+	+	-	-	+	-
	Baetidae	Baetidae spp.	+	+	+	+	+	+	+	+	+	+	+	+	+	+
		Gen. nov. sp. nov. 1	-	-	-	-	-	-	-	-	-	-	+	-	-	-
		Afroptilum parvum	+	-	-	-	-	-	-	-	-	-	-	-	-	-
		Afroptilum sudafricanum	+	+	+	+	+	-	+	-	+	+	+	-	-	-
		Baetis sp.	-	-	-	-	-	-	+	-	-	-	-	-	-	-
		Baetis harrisoni	+	+	+	+	+	+	+	+	+	+	-	+	+	+
		Baetis latus	-	-	-	-	+	-	-	-	-	-	-	-	-	-
		Bugilliesia sp. nov.	+	+	-	-	-	-	-	-	-	-	-	-	-	-

ORDER / SUB-ORDER	FAMILY / SUB-FAMILY	TAXON	O01$	O02$	O03$	O04$	O05$	R06#	R07#	R08#	M09$	M10#	M11#	R12#	R13#	B14#
Ephemeroptera	Baetidae	*Cheleocloeon sp.*	-	-	-	-	-	-	-	-	-	-	-	-	-	+
		Cheleocloeon excisum	+	+	+	+	+	+	+	-	+	-	-	+	+	+
		Cloeodes sp.	-	-	-	-	+	-	-	-	-	+	-	-	-	-
		Cloeodes sp. nov. 1	-	-	+	-	-	-	-	+	+	+	+	-	-	-
		Cloeodes inzingae	-	+	-	-	-	-	-	-	-	-	-	-	-	+
		Cloeon sp.	+	-	-	-	-	-	-	-	-	-	-	-	-	-
		Dabulamanzia sp. nov.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Demoreptus capensis	+	+	-	-	-	+	+	+	+	+	-	+	-	+
		Demoulinia crassi	-	-	-	+	-	-	-	-	-	-	-	-	-	-
		Labiobaetis sp.	+	-	-	+	+	-	+	-	-	+	+	-	-	+
		Labiobaetis sp. nov. 1	-	-	-	-	-	+	+	-	-	-	-	-	+	-
		Labiobaetis sp. nov. 2	-	-	-	-	-	-	-	-	-	-	+	+	+	-
		Pseudocloeon sp. nov.	-	-	-	+	-	-	-	-	-	-	-	-	-	-
		Pseudocloeon vinosum	+	+	+	+	-	+	+	-	-	+	-	-	-	-
		Pseudoharrisoni? sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	+
		Pseudopannota maculosa	+	-	+	+	+	-	-	-	-	-	-	-	-	-
	Caenidae	Caenidae spp.	-	-	-	-	+	-	-	-	-	-	-	-	-	-
		Caenis sp.	-	-	+	+	-	+	-	-	-	-	-	-	+	+
		Caenis sp. 2	+	-	-	-	-	-	-	-	-	-	-	-	-	-
		Caenis sp. nov.	+	-	-	-	-	-	-	-	-	-	-	-	-	-
		Caenis capensis	+	+	+	+	+	-	-	-	-	-	-	-	-	+
	Heptageniidae	Heptageniidae spp.	-	-	-	-	-	-	-	-	+	+	-	-	-	-
		Afronurus sp.	-	+	+	-	-	-	-	-	-	-	-	-	-	-
		Afronurus harrisoni	-	-	-	-	+	-	+	-	+	+	-	-	+	-
		Afronurus scotti	-	+	-	-	-	-	-	-	-	-	-	-	-	-
	Leptophlebiidae	Leptophlebiidae spp.	+	+	-	+	+	-	-	+	+	+	+	-	+	+
		Adenophlebia sp.	-	-	-	+	-	-	-	-	-	-	-	-	-	-
		Adenophlebia auriculata	+	-	-	-	-	-	-	-	-	-	-	-	-	-
		Adenophlebia peringueyella	+	+	-	-	+	-	-	-	-	-	-	-	-	-
		Aprionyx sp.	+	+	+	-	-	-	-	-	+	-	-	-	-	+
		Aprionyx peterseni	+	+	+	+	-	+	+	+	+	+	-	+	+	-
		Aprionyx rubicundus	-	-	-	-	-	-	-	-	+	+	-	-	-	-
		Aprionyx tabularis	-	-	-	+	-	-	-	-	+	+	+	-	-	-
		Castanophlebia sp.	-	-	-	+	-	-	-	-	-	-	-	-	-	-
		Castanophlebia calida	-	-	-	+	-	+	+	+	+	+	-	-	+	+
		Castenophlebia albicanda	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Choroterpes nigrescens	-	-	-	-	-	-	-	+	+	+	-	-	-	-
		Euthraulus elegans	-	-	-	-	+	-	-	-	+	+	-	-	-	-
	Teloganodidae	Teloganodidae spp.	+	-	-	-	-	+	-	-	+	-	-	-	-	-

Appendix 8.1

ORDER / SUB-ORDER	FAMILY / SUB-FAMILY	TAXON	O01$	O02$	O03$	O04$	O05$	R06#	R07#	R08#	M09$	M10#	M11#	R12#	R13#	B14#
	Teloganodidae	Teloganodidae sp. 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Ephemerellina sp.	-	-	-	+	-	+	+	-	-	-	+	-	+	-
		Ephemerellina barnardi	+	-	-	+	-	-	-	-	+	+	+	-	-	+
		Ephemerellina crassi	-	-	-	-	-	-	-	+	+	+	+	-	+	-
		Lestagella penicillata	-	+	+	-	+	+	+	+	+	+	-	-	+	+
		Lithogloea harrisoni	+	-	-	-	-	-	-	+	+	-	+	-	+	-
Haplotaxida	Enchytraeidae	Enchytraeidae spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Lumbricidae	Lumbricidae spp.	-	-	-	-	-	-	-	-	-	-	-	+	-	-
	Naididae	Naididae spp.	-	-	+	-	-	-	-	-	+	+	+	-	-	-
		Nais sp.	-	-	+	+	-	+	-	-	-	-	-	+	+	-
Haplotaxida	Naididae	*Pristina sp.*	-	-	-	-	-	-	+	-	-	-	-	-	-	-
	Tubificidae	Tubificidae spp.	-	-	-	-	-	-	-	-	+	+	-	-	-	-
Hemiptera	unspecified	Hemiptera spp.	-	-	+	-	-	+	-	-	-	-	-	+	-	-
	Corixidae	Corixidae spp.	-	-	+	-	-	-	-	-	-	-	-	-	-	+
		Corixidae sp. 1	-	-	+	-	-	-	-	-	-	+	-	-	-	-
		Micronecta sp.	-	-	+	-	-	-	-	+	+	-	-	-	-	+
	Mesoveliidae	*Mesoveliidae spp.*	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hemiptera	Mesoveliidae	*Mesovellidae sp. 1*	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Naucoridae	Naucoridae spp.	+	-	-	+	-	-	-	+	-	-	-	-	-	-
		Aphelocheimis sp.	+	-	-	-	-	-	-	-	-	-	-	-	-	-
		Laccocoris sp.	-	-	-	+	-	-	-	-	-	-	-	-	+	-
		Laccocoris limigenus	-	-	-	-	-	-	-	-	-	-	-	-	+	-
		Laccocoris spurcus	-	-	-	-	-	-	-	+	-	-	-	-	+	-
	Notonectidae	Notonectidae spp.	-	-	-	+	-	-	-	-	-	+	-	-	-	-
		Anisops letitia	-	-	-	-	-	-	-	+	-	-	-	-	-	-
	Veliidae	Veliidae spp.	-	+	-	-	-	-	-	-	-	-	-	+	-	+
		Microvelia sp.	-	-	-	-	-	+	-	-	-	-	-	-	-	-
		Microvelia major	-	-	-	-	-	+	-	+	-	+	+	-	-	-
		Rhagovelia sp.	-	-	-	-	+	-	-	-	-	-	-	-	-	-
Hymenoptera	unspecified	Hymenoptera spp.	-	-	+	-	-	+	-	-	+	-	+	-	-	-
Isopoda	Janiridae	*Protojanira prenticei*	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lepidoptera	Pyralidae	*Petrophila sp.*	+	+	+	+	+	-	+	-	-	-	+	-	-	+
Lumbriculida	Lumbriculidae	Lumbriculidae spp.	-	-	-	+	-	+	+	+	+	+	-	+	-	-
Megaloptera	Corydalidae	Corydalidae spp.	+	-	-	-	-	+	-	+	+	+	+	-	+	-
		Chloronieila peringueyi	-	+	+	-	-	+	-	-	-	+	+	-	-	-
		Taeniochauloides ochraceopennis	-	+	-	+	-	-	+	+	-	+	-	-	+	+
	Sialidae	*Leptosialis africana*	-	-	-	-	-	-	-	-	-	-	+	-	-	-
Odonata	unspecified	Odonata spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Anisoptera spp.	-	-	-	-	+	-	-	-	+	-	-	-	-	-

Appendix 8.1

ORDER	SUB-ORDER	FAMILY	SUB-FAMILY	TAXON	O01$	O02$	O03$	O04$	O05$	R06#	R07#	R08#	M09$	M10#	M11#	R12#	R13#	B14#
Odonata		unspecified		Zygoptera spp.	-	-	-	-	-	-	-	-	-	+	+	-	-	-
	Anisoptera	Aeshnidae		*Aeshna sp.*	+	+	+	-	+	-	-	-	-	-	-	-	+	-
				Anax sp.	-	-	-	+	-	-	+	-	-	-	-	-	-	-
		Cordulidae		Cordulidae spp.	-	-	-	-	+	+	-	-	-	-	-	-	-	-
				Macromia sp.	-	-	-	-	-	-	+	-	-	-	-	-	-	-
				Syncordulia sp.	+	-	-	-	+	-	-	-	-	-	-	-	-	+
		Gomphidae		Gomphidae spp.	-	+	-	-	-	+	-	-	-	+	-	-	-	-
				Ceratogomphus sp.	-	-	-	-	-	+	-	-	-	-	-	-	-	-
				Notogomphus sp.	-	-	-	+	-	-	+	-	-	-	-	-	-	-
				Notogomphus sp. 1	-	-	+	-	-	+	-	-	-	-	-	-	+	-
				Notogomphus sp. 2	-	-	-	+	-	-	-	-	-	-	-	-	-	-
	Anisoptera	Gomphidae		*Paragomphus sp.*	+	+	+	-	-	+	+	-	-	-	-	-	+	-
				Paragomphus sp. 1	-	-	+	-	-	-	-	-	-	-	-	-	-	-
		Libellulidae		Libellulidae spp.	-	+	+	+	-	-	-	-	-	-	-	-	+	-
				Libellulidae sp. 1	-	-	-	-	-	-	-	-	-	-	-	-	+	-
				Crocothemis sp.	-	-	+	+	-	-	-	-	-	-	-	-	-	-
				Diplocodes sp.	+	-	-	+	-	-	-	-	-	-	-	-	-	-
				Oipogastra sp.	-	-	-	+	-	-	-	-	-	-	-	-	-	-
				Orthetrum sp.	+	+	+	-	+	-	-	-	-	-	-	+	-	-
				Pantala sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	+
				Tetrathemis sp.	-	-	-	-	-	-	+	-	-	-	-	-	-	-
				Trithemis sp.	-	-	+	+	+	-	-	-	-	-	-	-	-	-
				Trithemis sp. 2	-	-	+	-	-	-	-	-	-	-	-	-	-	-
				Zygonyx sp.	+	-	-	+	+	-	-	-	-	-	-	-	-	-
	Zygoptera	Coenagrionidae		Coenagrionidae spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				Enallagma sp.	-	-	-	+	-	-	-	-	-	-	-	-	-	-
				Enallagma sp. 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				Pseudagrion sp.	+	-	-	-	+	-	-	-	-	-	+	-	-	-
				Pseudagrion sp. 1	-	-	-	+	-	-	-	-	-	-	+	-	+	-
				Pseudagrion sp. 2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Lestidae		*Lestes sp.*	-	-	-	-	-	-	-	+	-	-	-	-	-	-
		Platycnemididae		*Allocnemis leucosticta*	-	-	-	-	-	-	+	+	-	+	-	-	-	-
				Allocnemis sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	+
				Mesocnemus sp.	-	-	-	-	+	-	-	-	-	-	-	-	-	-
		Protoneuridae		Protoneuridae spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Synlestidae		Synlestidae spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	+
				Chlorolestes sp.	-	-	-	-	-	-	-	-	-	-	+	-	-	-
				Chlorolestes sp. 1	-	-	-	-	-	-	-	+	-	-	-	-	-	-
				Chlorolestes sp. 2	-	-	-	-	-	-	-	-	-	-	+	-	-	-

Appendix 8.1

ORDER / SUB-ORDER	FAMILY / SUB-FAMILY	TAXON	O01$	O02$	O03$	O04$	O05$	R06#	R07#	R08#	M09$	M10#	M11#	R12#	R13#	B14#
Zygoptera	Synlestidae	*Chlorolestes sp. 3*	-	-	-	-	-	-	-	-	-	-	+	-	-	-
Ostracoda	unspecified	Ostracoda spp.	-	-	-	-	+	-	-	+	-	-	-	-	-	-
Plecoptera	Notonemouridae	Notonemouridae spp.	-	+	+	-	-	-	-	-	-	+	+	+	-	-
		Aphanicerca sp.	-	+	-	-	-	+	+	+	+	+	+	-	+	-
		Aphanicerca bicornis	-	-	-	-	-	-	-	-	+	+	+	-	+	-
		Aphanicerca capensis	-	-	-	-	-	-	-	+	+	+	+	-	+	-
		Aphanicerca lyrata	-	-	-	-	-	-	-	-	+	+	+	-	+	-
		Aphanicercella sp.	+	+	+	+	+	+	+	+	+	-	+	+	+	+
		Aphanicercella barnardi	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Aphanicercella barnardi/scutata	-	-	-	-	-	-	-	-	+	+	+	-	-	-
		Aphanicercella cassida	-	-	-	-	-	-	-	-	-	-	-	+	-	-
		Aphanicercopsis sp.	+	+	-	+	-	+	+	-	-	-	-	-	-	+
Plecoptera	Notonemouridae	*Desmonemoura sp.*	+	+	-	-	+	-	-	-	-	+	+	-	-	+
		Desmonemoura pulchellum	-	+	-	-	-	-	-	-	+	+	+	-	-	-
Trichoptera	unspecified	Trichoptera spp.	-	-	-	-	-	-	+	+	+	+	+	+	-	-
		Trichoptera morph 2	-	-	-	-	-	-	-	-	+	+	+	-	-	-
		empty case	-	-	+	+	-	+	-	+	-	-	+	+	-	-
	Barbarochthonidae	*Barbarochthon brunneum*	+	-	-	-	-	-	-	+	-	+	+	-	-	-
	Ecnomidae	Ecnomidae spp.	-	-	-	-	-	-	-	+	-	-	-	-	-	-
		Ecnomus sp.	-	-	+	+	+	-	-	-	-	-	-	-	-	-
		Ecnomus sp. nov. 1	-	-	+	+	-	-	-	-	-	-	-	-	-	-
		Ecnomus kimminsi	-	-	-	+	-	-	-	-	-	-	-	-	-	-
		Parecnomina sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Parecnomina sp. 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Parecnomina resima	+	+	+	+	+	-	-	-	+	+	-	-	-	+
	Glossosomatidae	Glossosomatidae spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Agapetus sp.	-	-	-	-	-	-	-	-	+	+	-	-	-	-
	Hydropsychidae	Hydropsychidae spp.	-	+	-	-	+	+	+	+	+	+	+	-	+	+
		Diplectroninae spp.	-	-	-	-	-	-	-	-	-	-	+	-	-	-
		Cheumatopsyche sp.	+	-	-	+	-	-	-	-	+	-	-	-	-	-
		Cheumatopsyche sp. 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Cheumatopsyche sp. 2	-	-	-	-	-	-	-	-	+	+	-	-	-	-
		Cheumatopsyche sp. Type 2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Cheumatopsyche sp. Type 7	-	-	+	+	-	-	-	-	-	-	-	-	-	-
		Cheumatopsyche sp. Type 9	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Cheumatopsyche sp. Type 11	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Cheumatopsyche afra	+	+	+	-	+	-	-	-	-	-	-	-	-	-
		Cheumatopsyche maculata	+	+	-	+	-	-	-	-	+	-	-	-	-	+
		Cheumatopsyche thomasseti	+	-	-	-	+	-	-	-	-	-	-	-	-	-

Appendix 8.1

ORDER / SUB-ORDER	FAMILY / SUB-FAMILY	TAXON	O01$	O02$	O03$	O04$	O05$	R06#	R07#	R08#	M09$	M10#	M11#	R12#	R13#	B14#
Trichoptera	Hydropsychidae	*Sciadorus sp.*	-	-	-	-	-	-	-	-	-	+	-	-	-	-
		Sciadorus acutus	-	-	-	-	-	-	-	-	-	+	-	-	-	-
	Hydroptilidae	Hydroptilidae spp.	+	-	+	+	+	+	+	-	+	+	-	+	+	-
		Hydroptila sp.	-	-	+	-	-	-	-	-	-	-	-	-	-	+
		Hydroptila sp. nov.	-	+	-	-	-	-	-	-	-	-	-	-	-	-
		Hydroptila cruciata	-	-	-	+	-	-	-	-	-	-	-	-	-	-
		Orthotrichia barnardi	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Orthotrichia sp.	+	-	+	-	-	-	-	-	-	-	-	-	-	-
		Oxyethira velocipes	-	-	-	-	-	-	-	-	-	-	-	+	-	-
	Leptoceridae	Leptoceridae spp.	+	+	-	-	+	+	+	+	+	-	+	-	+	-
		Leptoceridae sp. 1	-	-	-	-	-	-	-	-	+	-	-	-	-	-
		Athripsodes sp.	-	-	+	-	+	-	-	-	-	-	+	+	-	+
		Athripsodes sp. 1	-	-	-	-	-	-	-	-	-	-	-	+	-	-
	Leptoceridae	*Athripsodes sp. 2*	-	-	+	-	-	-	-	-	-	-	-	+	-	-
		Athripsodes (Bergensis group) *sp.*	+	+	-	+	+	-	-	-	-	-	+	+	-	-
		Athripsodes bergensis	+	-	-	-	-	-	-	-	-	-	-	+	-	-
		Athripsodes (Harrisoni group) *sp.*	-	-	-	-	-	-	-	-	-	+	+	+	-	-
		Athripsodes (Harrisoni group) *sp. 1*	-	-	-	-	-	-	-	-	-	-	-	+	-	-
		Athripsodes [harrisoni type]	-	-	+	-	-	-	-	-	-	-	-	-	-	-
		Athripsodes harrisoni	-	-	-	+	-	-	-	-	-	-	+	-	-	-
		Athripsodes schoenobates	+	-	-	-	+	-	-	-	-	-	-	-	-	-
		Ceraclea sp.	+	-	-	-	-	-	-	-	-	-	-	-	-	-
		Leptecho sp.	-	-	-	-	-	-	-	-	-	+	+	-	-	-
		Leptecho sp. E	-	-	+	-	-	-	-	-	-	-	-	+	-	-
		Leptecho sp. F	-	-	+	+	-	-	-	-	-	-	-	-	-	-
		Leptecho sp. near F	-	-	+	-	-	-	-	-	-	-	-	-	-	-
		Leptecho helicotheca	+	-	+	-	-	-	-	-	-	-	-	-	-	-
		Leptecho scirpi	-	-	-	+	-	-	-	-	-	-	-	-	-	-
		Lepticho sp.	-	-	-	-	+	-	-	-	-	-	-	-	-	-
		Leptocerus ?schoenobates	-	-	-	-	-	-	-	-	-	-	+	-	-	-
		Leptocerus sp.	+	-	-	-	-	-	-	-	+	+	-	-	-	-
		Oecetis sp.	+	-	+	-	+	-	-	-	+	-	-	-	-	-
		Oecetis sp. nov.	-	-	+	-	-	-	-	-	-	-	-	-	-	-
		Oecetis sp. [near modesta]	-	-	+	-	-	-	-	-	-	-	-	-	-	-
		Oecetis modesta	-	+	-	-	-	-	-	-	-	-	-	-	-	-
		Macrostemum capense	-	-	-	+	+	-	-	-	-	-	-	-	-	-
	Petrothrincidae	*Petrothrincus sp.*	-	-	-	-	-	-	-	+	-	-	-	-	-	-
		Petrothrincus circularis	+	-	-	-	-	-	-	+	-	-	+	-	-	+
	Philopotamidae	Philopotamidae spp.	-	-	-	-	-	+	-	+	+	-	+	-	-	-

Appendix 8.1

ORDER / SUB-ORDER	FAMILY / SUB-FAMILY	TAXON	O01$	O02$	O03$	O04$	O05$	R06#	R07#	R08#	M09$	M10#	M11#	R12#	R13#	B14#
Trichoptera	Philopotamidae	Philopotamidae sp. 1	-	-	-	-	-	-	-	-	+	+	-	-	-	-
		Philopotamidae sp. 2	-	-	-	-	-	-	-	-	-	+	-	-	-	-
		Chimarra sp.	+	+	+	+	+	-	-	-	-	-	-	-	-	+
		Dolophilodes sp.	+	-	-	-	+	-	-	-	-	-	-	-	-	-
		Paranyctiophylax sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Pisulidae	*Dyschimus thrymmifer*	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Polycentropodidae	Polycentropodidae spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Rhyacophilidae	*Myspoleo agilis*	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Sericostomatidae	Sericostomatidae spp.	-	-	-	-	-	-	-	+	-	-	-	-	-	-
		Petroplax sp.	-	-	+	-	-	-	-	-	-	-	-	-	-	-
		Petroplax curvicosta	+	-	+	-	-	-	-	-	-	-	-	-	-	-
Tricladida	Planariidae	*Dugesia sp.*	-	-	-	+	+	-	-	-	+	-	+	+	-	-
Veneroida	Corbiculidae	*Corbicula sp.*	-	-	-	-	+	-	-	-	-	-	-	-	-	-
Unspecified	unspecified	eggs	-	+	-	-	-	-	-	-	+	+	+	-	+	-
Unspecified	unspecified	Gastropoda spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Mollusca spp.	-	-	-	+	-	-	-	-	-	-	-	-	-	-
		Nematoda spp.	-	-	-	+	-	+	+	-	+	+	+	+	+	-
		Nematomorpha spp.	-	-	-	-	+	-	-	-	-	-	-	-	-	-
		Nemertea spp.	+	-	-	-	-	-	-	-	-	-	-	-	-	-
		Oligochaeta spp.	+	+	-	-	+	-	-	-	-	-	-	-	-	+
		Terrestrial Arachnid	-	-	+	+	-	+	+	+	-	-	+	+	-	-
		Tadpole	-	-	-	-	-	-	-	-	-	-	+	-	-	-
		Terrestrial unidentified	-	+	+	+	+	+	+	+	+	+	+	+	+	+

ORDER / SUB-ORDER	FAMILY / SUB-FAMILY	TAXON	B15#	B16$	B17$	E18#	E19#	E20#	L22#	P23#	P24#	D25$	T26#	T27#	T28#	T29#
Acariformes	Anisitsellidae	Anisitsellidae spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Anisitsellidae sp. 1	-	-	+	-	-	-	-	-	+	-	-	-	-	-
		Anisitsellidae sp. 2	-	-	+	+	+	+	-	-	+	-	-	-	-	-
		Anisitsellidae sp. 3	-	-	-	-	-	-	-	-	+	-	-	-	-	-
		Anisitsellidae sp. 4	-	-	-	-	-	-	-	-	+	-	-	-	-	-
		Anisitsellidae sp. 5	-	-	-	-	-	-	-	-	+	-	-	-	-	-
		Anisitsellidae sp. 6	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Anisitsellidae sp. 7	-	-	-	-	+	-	-	-	-	-	-	-	-	-
		Anisitsellidae sp. 8	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Arrenuridae	Arrenuridae sp. 1	-	-	-	+	-	-	-	-	-	-	-	-	-	-
		Arrenuridae sp. 2	-	-	-	+	-	+	-	-	-	-	-	-	-	-
		Arrenuridae sp. 3	-	-	-	-	-	-	-	-	-	-	-	-	-	+
		Arrenuridae sp. 4	-	-	-	-	-	-	-	-	+	-	-	-	-	-
		Arrenuridae sp. 5	-	-	+	-	-	-	-	-	+	-	-	-	-	-
	Hydrachnellae	Hydracarina spp.	+	-	-	-	-	-	-	-	-	-	-	-	-	-
		Hydracarina morph A	-	-	-	-	-	-	-	-	-	+	-	-	-	-
		Hydracarina morph B	-	-	-	+	-	-	-	-	+	-	-	-	-	+
		Hydracarina morph D	-	-	-	+	-	-	+	-	-	-	+	+	-	+
		Hydracarina morph E	-	-	+	+	-	+	+	-	-	+	-	+	-	-
		Hydracarina morph F	-	-	-	+	-	-	-	-	-	-	-	-	+	-
		Hydracarina morph H	-	-	-	+	-	-	-	-	-	-	-	-	-	-
		Hydracarina morph K	-	-	+	+	+	+	-	-	+	+	-	-	-	-
		Hydracarina morph M	-	-	+	+	-	+	-	-	+	+	-	-	-	+
		Hydracarina morph N	-	-	-	-	-	-	-	-	-	+	-	-	-	-
		Hydracarina morph O	-	+	-	+	-	-	-	-	-	-	-	-	-	+
		Hydracarina morph P	-	-	-	+	+	-	-	-	-	-	-	-	-	-
		Hydracarina morph Q	-	-	-	+	-	-	-	-	-	-	-	-	-	-
		Hydracarina morph S	-	-	-	-	-	-	-	-	-	-	-	-	-	+
		Hydracarina morph T	-	-	+	+	-	-	-	-	-	-	-	-	-	-
		Hydracarina morph W	-	-	-	-	+	+	-	-	+	-	-	-	-	-
		Hydracarina morph X	-	-	-	+	+	+	-	-	+	-	-	-	-	-
		Hydracarina morph Y	-	-	+	+	-	+	+	-	-	-	-	+	-	-
		Hydracarina morph Z	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Hydracarina morph AA	-	-	-	+	-	-	-	-	-	-	-	-	-	-
		Hydracarina morph AB	-	-	-	-	+	+	-	-	+	-	-	-	-	-
		Hydracarina morph AD	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Hydracarina morph AE	-	-	-	-	-	-	-	-	-	+	-	-	-	-
		Hydracarina morph AF	-	-	-	-	-	-	-	-	-	+	-	-	-	+

Appendix 8.1

ORDER / SUB-ORDER	FAMILY / SUB-FAMILY	TAXON	B15#	B16$	B17$	E18#	E19#	E20#	L22#	P23#	P24#	D25$	T26#	T27#	T28#	T29#
Acariformes	Hydrachnellae	Hydracarina morph AH	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Hydracarina morph AJ	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Hydracarina morph AK	-	-	-	-	-	-	-	-	+	-	-	-	-	-
		Hydracarina morph AL	-	-	-	-	-	-	-	-	+	-	-	-	-	-
		Hydracarina morph AP	-	-	-	-	-	-	-	-	+	-	-	-	-	-
		Hydracarina morph AT	-	-	+	-	-	-	-	-	-	-	-	-	-	-
	Oribatidae	Oribatidae sp. 1	-	-	-	-	+	+	-	-	+	+	+	+	+	+
		Oribatidae sp. 2	-	-	-	-	-	-	-	+	+	+	+	-	+	+
		Oribatidae sp. 3	-	-	-	+	+	+	-	-	-	+	+	-	-	-
		Oribatidae sp. 4	-	-	-	-	-	+	-	-	-	-	-	-	-	-
		Oribatidae sp. 5	-	-	-	-	-	-	-	-	+	-	-	-	-	+
	Oxidae	Oxidae sp. 1	-	-	-	-	-	-	-	-	+	-	-	-	-	-
Amphipoda	unspecified	Amphipoda sp.	+	-	-	-	-	+	-	-	-	-	-	-	-	-
	Paramelitidae	*Paramelita sp.*	-	-	-	-	-	-	-	+	+	+	+	-	+	+
		Paramelita nigroculus	-	-	-	-	-	-	+	-	+	+	+	+	-	-
Anomopoda	Daphniidae	*Daphniopsis sp.*	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Basommatophora	Ancylidae	*Burnupia sp.*	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Branchiobdellidae	unspecified	Branchiobdellidae spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	+
Cladocera	Chydoridae	*Chydoridae sp.*	-	+	-	+	+	+	-	+	-	-	+	+	+	+
Coleoptera	unspecified	Coleoptera spp.	-	+	-	+	+	+	-	-	+	-	+	-	+	+
		Coleoptera sp. 4	-	-	-	-	-	+	-	-	-	-	-	-	-	-
	Curculionidae	Curculionidae spp.	+	-	-	-	-	-	-	-	-	-	-	-	-	-
	Dytiscidae	Dytiscidae spp.	-	+	-	-	-	-	+	-	-	-	-	+	-	-
		Dytiscidae sp. 1	-	-	-	-	-	-	-	-	-	-	-	-	+	-
		Dytiscidae sp. 2	-	+	-	-	-	-	-	-	-	-	-	-	-	-
		Potamonectes capensis	+	-	-	-	-	-	-	-	-	-	-	-	-	-
		Yola inopinata	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Laccophilus concisus	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Dryopidae	Dryopidae spp.	-	-	-	-	-	-	+	+	+	-	-	-	+	+
		Dryopidae sp. 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Dryopidae sp. 2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Strina sp.	-	-	+	-	-	-	-	-	-	-	-	-	-	-
		Strina sp. 1	-	-	-	+	-	+	+	-	-	+	-	-	+	-
		Strina sp. 2	-	-	-	-	-	-	-	-	-	-	-	-	+	-
	Elmidae	Elmidae spp.	+	-	-	+	+	+	-	-	+	+	-	-	-	-
		Elmidae sp. 1	-	-	-	+	-	+	-	-	-	+	+	+	-	-
		Elmidae sp. 2	-	-	+	+	-	+	-	-	-	-	-	+	-	-
		Elmidae sp. 3	-	-	-	+	-	+	-	-	-	+	-	-	-	-
		Ctenelmis harrisoni	-	-	-	-	-	-	-	-	-	-	-	-	-	-

ORDER / SUB-ORDER	FAMILY / SUB-FAMILY	TAXON	B15#	B16$	B17$	E18#	E19#	E20#	L22#	P23#	P24#	D25$	T26#	T27#	T28#	T29#
Coleoptera	Elmidae	*Elpidelmis sp.*	+	-	+	+	-	-	-	-	-	-	-	-	-	-
		Elpidelmis sp. 1	-	+	-	+	+	+	+	+	+	+	-	-	-	+
		Elpidelmis sp. 2	-	-	-	-	+	-	+	-	-	+	-	-	-	-
		Elpidelmis sp. A	-	+	+	+	+	+	+	+	+	+	+	+	+	+
		Elpidelmis sp. B	-	-	-	+	+	-	-	+	-	+	+	+	-	-
		Elpidelmis capensis	+	-	-	-	-	-	-	-	-	-	-	-	-	-
		Haplelmis sp.	-	-	-	-	-	-	-	-	-	+	-	-	-	-
		Haplelmis mixta	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Pelonolus sp.	+	+	+	+	+	+	+	+	-	+	-	-	+	+
		Pelonolus sp. 1	-	+	+	+	+	+	+	+	+	-	+	-	-	+
		Pelonolus sp. 2	-	-	-	+	+	-	+	+	+	+	+	-	-	-
		Pelonolus sp. nov.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Pelonolus granulosus	+	-	-	-	-	-	-	-	-	-	-	-	-	-
		Pelonolus parvulus	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Pelonolus pilosellus	+	-	-	-	-	-	-	-	-	-	-	-	-	-
		Tropidelmus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Tropidelmus hiritoni	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Gyrinidae	Gyrinidae spp.	-	+	-	+	+	+	+	-	+	+	-	-	-	-
		Aulonogyrus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Aulonogyrus caffer	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Orectogyrus sp.	+	-	-	-	-	-	-	-	-	-	-	-	-	-
	Helodidae	Helodidae spp.	+	+	+	+	-	+	-	-	+	-	+	-	+	-
		Helodidae sp. 1	-	-	+	+	+	+	+	+	-	+	+	+	+	+
		Helodidae sp. 2	-	-	+	+	-	-	+	+	-	+	+	-	-	+
		Helodidae sp. 4	-	-	+	-	-	-	-	-	-	-	+	+	-	+
		Helodidae sp. 5	-	-	-	+	+	+	-	-	+	+	+	-	-	-
		Helodidae sp. 6	-	-	+	+	+	+	+	+	+	+	-	-	-	+
		Helodidae sp. 7	-	-	-	+	-	-	-	-	+	+	+	-	-	-
		Helodidae sp. 8	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Hydraenidae	Hydraenidae spp.	-	-	-	-	-	-	-	-	+	+	-	-	+	+
		Coelonefopas sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Hydraena sp.	+	-	+	-	-	+	-	-	-	-	-	-	-	-
		Hydraena sp. 1	-	+	-	+	-	+	+	+	-	+	-	-	+	-
		Hydraena sp. 2	-	-	-	+	-	+	-	-	-	+	-	-	-	-
		Hydraena sp. 3	-	-	-	+	-	+	-	-	-	-	-	-	-	-
		Mesoceration sp.	-	-	+	+	+	-	-	-	-	+	-	-	-	-
		Mesoceration ?pollidum	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Mesoceration dissonum	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Mesoceration distinctum	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix 8.1

ORDER / SUB-ORDER	FAMILY / SUB-FAMILY	TAXON	B15#	B16$	B17$	E18#	E19#	E20#	L22#	P23#	P24#	D25$	T26#	T27#	T28#	T29#
Coleoptera	Hydraenidae	*Mesoceration endroedyi*	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Mesoceration jucundum	+	-	-	-	-	-	-	-	-	-	-	-	-	-
		Mesoceration jusciceps	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Mesoceration langurdum	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Mesoceration splendorum	+	-	-	-	-	-	-	-	-	-	-	-	-	-
		Mesoceration truncatum	+	-	-	-	-	-	-	-	-	-	-	-	-	-
		Parahydraena sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Parasthetops nigritus	+	-	-	-	-	-	-	-	-	-	-	-	-	-
	Hydrophilidae	Hydrophilidae spp.	-	+	-	-	-	-	-	-	-	-	+	-	-	+
		Hydrophilidae sp. 1	-	-	-	-	-	-	-	-	-	+	-	-	-	+
		Limnebius sp.	+	-	-	-	-	-	-	-	-	-	-	-	-	-
	Limnichidae	Limnichidae spp.	-	+	-	-	-	-	+	-	+	+	+	-	-	-
		Limnichidae sp. 1	-	-	-	-	-	-	+	-	-	+	-	-	-	-
		Limnichidae sp. 2	-	-	-	-	-	-	+	-	-	-	-	-	-	-
	Noteridae	Noteridae spp.	-	+	-	-	-	-	-	-	-	-	+	-	+	-
	Torridincolidae	Torridincolidae spp.	-	-	-	-	+	-	-	-	+	-	+	+	-	-
Collembola	unspecified	Collembola spp.	-	-	-	-	-	-	-	-	-	-	+	+	+	-
	Sminthuridae	Sminthuridae spp.	-	-	-	-	-	-	+	-	-	-	-	-	+	-
Copepoda	unspecified	Copepoda spp.	+	-	-	-	-	-	-	-	-	-	-	-	-	-
Cyclopoida	unspecified	Cyclopoida spp.	-	+	-	-	-	-	-	+	-	-	+	+	-	+
		Cyclopoida sp. 1	-	-	-	-	+	+	-	-	+	-	-	-	-	-
		Cyclopoida sp. 2	-	-	-	-	+	-	-	-	-	-	-	-	-	-
		Cyclopoida sp. 3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Decapoda	Potamonautidae	*Potamonautes sp.*	+	+	+	-	-	+	+	+	-	+	-	+	-	-
Diptera	unspecified	Diptera spp.	-	-	+	+	+	+	-	-	-	-	+	+	+	+
	Anthomyiidae	Limnophora spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Athericidae	Athericidae spp.	-	-	-	+	-	-	-	-	-	-	-	-	-	-
		Atherix sp.	-	-	-	-	-	-	-	-	-	-	+	-	-	-
		Atherix sp. 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Atherix sp. 2	-	+	+	+	-	-	+	-	+	+	-	+	+	-
		Atherix sp. 3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Atherix sp. 4	-	-	+	-	-	-	-	-	+	+	-	-	+	+
	Blephariceridae	Blephariceridae spp.	-	-	-	+	+	-	-	-	-	-	-	-	-	-
		Elporia barnardi	-	-	-	-	-	-	-	-	-	-	-	+	-	-
		Elporia capensis	-	-	-	+	+	+	-	-	-	-	-	-	-	-
		Elporia uniradius	-	-	-	+	-	-	-	-	-	-	-	-	-	-
	Ceratopogonidae	Ceratopogonidae spp.	+	-	+	-	+	-	-	+	-	+	-	-	-	-
		Ceratopogonid (Bezzia TYPE)	-	-	-	-	+	-	-	-	-	-	-	-	-	-
	Ceratopogoninae	*Bezzia sp.*	-	+	-	-	-	-	+	-	-	-	-	-	-	+

Appendix 8.1

ORDER	SUB-ORDER	FAMILY	SUB-FAMILY	TAXON	B15#	B16$	B17$	E18#	E19#	E20#	L22#	P23#	P24#	D25$	T26#	T27#	T28#	T29#
Diptera			Ceratopogoninae	*Bezzia sp. 1*	-	+	-	-	+	-	-	-	-	+	+	+	+	-
				Bezzia sp. 2	+	+	-	-	-	+	-	-	-	+	-	-	+	+
			Dasyheleinae	*Dasyhelea spp.*	-	+	-	-	-	-	+	-	-	-	-	-	-	-
			Forcipomyinae	*Atrichopogon spp.*	+	-	+	-	+	-	-	-	-	-	+	-	-	-
			Forcipomyinae	*Atrichopogon sp. 1*	-	-	-	+	-	+	-	-	-	-	-	-	-	-
				Atrichopogon sp. 2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				Forcipomyia spp.	-	-	-	-	-	-	-	+	-	-	-	-	-	-
				Forcipomyia sp. 1	-	-	+	+	+	+	-	-	-	-	-	-	+	-
				Forcipomyia sp. 2	-	-	-	+	-	+	-	-	-	-	+	-	-	-
		Chironomidae		Chironomidae spp.	-	+	-	-	-	+	-	-	-	+	-	-	-	+
			Aphroteniinae	*Aphrotenia barnardi*	-	-	-	-	-	-	-	-	-	-	-	+	-	-
				Aphrotenia tsitsikamae	-	-	-	-	-	-	-	-	+	+	-	-	-	-
			Chironominae	*Chironomus sp.*	-	-	-	-	-	-	+	-	-	-	-	-	-	-
				Cladotanytarsus near linearis	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				Cladotanytarsus near reductus	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				Cladotanytarsus reductus	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				Cladotanytarsus sp.	-	-	-	-	-	-	+	-	+	-	-	-	-	-
				Cryptochironomus sp.	+	+	-	-	-	-	+	+	-	-	+	-	+	-
				Microtendipes sp.	-	-	+	-	-	-	-	-	-	-	-	-	-	-
				Parachironomus sp.	-	-	-	-	-	-	-	-	-	-	+	-	-	-
				Polypedilum dewulfi	-	+	-	-	+	-	-	-	-	-	-	-	-	-
				Polypedilum E sp.	-	-	+	+	+	+	+	-	+	+	-	-	+	-
				Polypedilum sp.	+	+	-	-	-	+	+	-	+	-	-	-	+	-
				Polypedilum U sp.	+	+	-	-	+	+	+	+	-	+	+	-	+	+
				Rheotanytarsus fuscus	+	+	+	-	-	+	+	+	+	+	+	+	+	+
				Stenochironomus sp.	+	-	-	-	-	-	-	-	-	-	-	-	-	-
				Stictochironomus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				Tanytarsus sp.	-	-	-	+	-	-	-	-	-	-	-	-	-	-
				Tanytarsus sp. 1	+	+	+	-	+	+	+	-	+	-	+	+	-	-
				Tanytarsus sp. 2	-	-	-	-	-	+	-	-	+	-	-	-	-	-
				Tanytarsus sp. 3	-	+	-	-	-	-	-	-	-	-	-	-	-	-
				Virgatanytarsus nigricornis	-	+	-	-	-	-	-	-	-	-	-	-	-	-
				Virgatanytarsus sp.	-	+	-	-	-	-	-	-	-	-	-	-	-	-
			Orthocladinae	Orthocladiinae spp.	-	-	-	-	-	-	-	-	-	-	+	+	-	-
				Orthocladius sp.	-	-	-	-	+	-	-	-	-	-	-	+	-	-
				Orthocladius sp. 2	-	-	-	+	-	+	-	+	-	-	-	-	-	-
				Orthocladinae gen. nov.	-	-	-	-	-	-	-	-	-	-	+	-	-	-
				Hairy Orthocladinae	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				Bryophaenocladius sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix 8.1

ORDER / SUB-ORDER	FAMILY / SUB-FAMILY	TAXON	B15#	B16$	B17$	E18#	E19#	E20#	L22#	P23#	P24#	D25$	T26#	T27#	T28#	T29#
Diptera	Orthocladinae	*Cardiocladius sp.*	+	-	+	+	+	+	+	-	-	-	-	-	-	-
		Cardiocladius hessei	-	+	-	-	-	-	-	-	-	-	-	-	-	-
		Corynoneura dewulfi	-	-	-	-	+	-	-	-	-	+	+	-	+	-
		Corynoneura sp. 1	+	+	+	+	+	+	+	+	+	+	+	+	+	+
		Corynoneura sp. 2	-	-	-	-	-	-	+	+	-	-	-	-	-	-
		Corynoneura sp. 3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Cricotopus sp.	-	-	-	-	+	-	+	-	-	-	-	+	-	-
		Cricotopus sp. 1	+	-	-	+	+	+	+	+	-	-	+	+	+	-
		Cricotopus sp. 2	-	-	-	+	-	-	-	-	-	-	-	-	-	-
		Cricotopus sp. 3	-	-	-	-	-	-	-	-	-	-	-	+	-	-
		Cricotopus sp. 4	-	-	-	-	-	-	+	-	-	-	-	-	-	-
		Cricotopus sp. 5	-	-	-	-	-	-	-	+	-	-	-	-	-	-
		Cricotopus sp. 6	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Cricotopus albitibia	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Cricotopus dibalteatus	-	-	-	-	-	-	+	-	-	-	+	+	-	-
		Cricotopus flavozonatus	-	+	-	-	-	-	-	-	-	-	-	-	-	-
		Cricotopus kisantuensis	-	+	-	-	+	+	+	-	-	-	-	-	-	+
		Cricotopus obscurus	-	+	-	-	-	-	+	-	-	-	-	-	-	-
		Cricotopus scottae	-	-	-	-	-	-	+	-	-	-	-	-	-	-
		Eukiefferiella calviger	-	-	-	-	+	-	+	-	-	-	+	+	-	-
		Eurycnemus sp.	-	-	-	-	-	-	-	-	-	+	-	-	-	-
		Nanocladius brunneus	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Nanocladius sp.	-	-	-	-	+	+	-	-	-	-	+	-	-	-
		Notocladius capicola	+	+	+	+	+	+	-	+	+	+	-	-	-	-
		Paracladopelma sp.	-	-	-	-	-	-	-	-	-	+	-	-	-	-
		Paradoxocladius mangoldi	-	+	-	-	-	-	-	-	-	-	-	-	-	-
		Parakiefferiella biloba	-	-	-	-	-	-	-	-	+	-	-	+	-	-
		Parakiefferiella sp.	-	-	-	-	-	-	-	-	-	+	-	+	+	-
		Parametriocnemus scotti	-	-	-	+	+	+	+	-	-	-	+	+	+	+
		Paraphaenocladius sp.	-	-	-	-	-	-	-	-	-	+	-	-	+	+
		Psectrocladius sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Pseudosmittia sp.	-	-	-	-	-	-	-	-	+	-	-	-	-	-
		Rheocricotopus capensis	+	+	+	+	+	+	+	+	+	+	+	+	+	+
		Thienemanniella sp.	+	-	-	-	+	-	+	+	-	+	-	-	-	-
		Thienemanniella sp. 1	+	+	+	+	+	+	+	+	+	+	+	-	-	+
		Thienemanniella sp. 2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Thienemanniella sp. 3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Thienemanniella sp. 4	-	-	-	-	-	-	+	-	-	-	-	-	-	-
		Thienemanniella trivittata	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix 8.1

ORDER	SUB-ORDER	FAMILY	SUB-FAMILY	TAXON	B15#	B16$	B17$	E18#	E19#	E20#	L27#	P23#	P24#	D25$	T26#	T27#	T28#	T29#
Diptera			Tanypodinae	*Tvetenia calvescens*	+	+	+	+	+	+	+	+	+	+	+	-	+	+
				Ablabesmyia sp.	+	+	+	-	+	-	+	+	-	-	-	-	-	-
				Clinotanypus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				Conchapelopia sp.	+	+	+	+	+	+	+	+	+	+	+	-	+	+
				Conchapelopia trifascia	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				Larsia sp.	+	-	-	+	+	+	-	+	+	+	+	+	+	-
				Macropelopia marmorata	-	-	-	-	-	-	-	-	-	-	-	-	+	-
				Nilotanypus sp.	-	-	+	-	-	-	-	-	-	-	-	-	-	-
				Nilotanypus sp. 1	-	-	-	+	-	+	-	-	+	-	-	-	-	-
				Nilotanypus sp. 2	-	-	-	-	-	-	-	-	+	-	-	-	-	-
				Nilotanypus sp. 3	-	-	+	-	-	-	-	-	-	-	-	-	-	-
				Paramerina sp.	+	+	+	+	+	+	+	+	+	+	+	-	-	+
				Paramerina sp. 1	-	-	+	-	-	-	-	-	-	-	-	-	-	-
				Paramerina sp. 2	-	-	+	-	-	-	-	-	-	-	-	-	-	-
				Procladius sp.	+	+	-	+	-	-	-	+	-	-	+	-	-	-
			Tarytarsini	*Constempellina sp.*	-	-	-	-	-	-	-	-	-	+	-	-	-	+
				Stempellina sp.	+	+	-	+	-	-	-	-	+	+	-	-	+	+
				Stempellinella sp.	-	-	-	-	+	+	-	-	-	+	+	-	+	-
				Stempellinella truncata	-	-	-	-	+	-	-	-	-	-	-	-	-	-
				Zavreliella marmorata	-	-	-	-	-	-	-	-	-	+	-	-	-	-
		Culicidae		Culicidae spp.	-	+	-	-	-	-	-	-	-	-	-	-	-	-
				Anopheles sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Dolichopodidae		Dolichopodidae spp.	-	-	-	-	-	-	-	-	-	-	-	-	+	-
		Empididae		Empididae spp.	+	+	-	-	-	+	+	-	+	+	+	-	+	-
				Clinocera sp.	-	-	-	+	-	-	-	+	-	-	-	-	+	-
				Hemerodromia sp.	+	-	+	-	+	-	+	-	+	-	+	+	+	+
				Trichina sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Dixidae		Dixidae spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Ephydridae		Ephydridae spp.	+	-	-	-	-	-	-	-	-	-	-	-	-	-
		Muscidae		Muscidae spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Psychodidae		Psychodidae spp.	-	-	-	-	-	-	-	-	-	-	+	-	-	-
				Pericoma sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				Pericoma sp. 1	-	-	-	-	+	-	-	-	-	-	-	-	+	-
				Pericoma sp. 2	-	-	-	-	-	-	-	-	-	-	-	-	-	+
		Sciomyzidae		Sciomyzidae spp.	-	-	-	-	-	-	-	-	-	+	-	-	+	-
		Simulidae		Simulidae spp.	+	+	+	+	+	+	+	+	+	+	+	+	-	+
				Simulium spp.	+	-	-	+	+	-	-	+	-	-	-	-	-	-
				Simulium alcocki	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				Simulium bequaerti	-	-	-	-	-	-	-	-	-	+	-	-	-	-

Appendix 8.1

ORDER	SUB-ORDER	FAMILY	SUB-FAMILY	TAXON	B15#	B16$	B17$	E18#	E19#	E20#	L22#	P23#	P24#	D25$	T26#	T27#	T28#	T29#
Diptera		Simuliidae		*Simulium bovis*	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				Simulium dentulosum	-	-	-	-	-	-	-	-	-	-	-	+	-	-
				Simulium harrisoni	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				Simulium impukane	-	+	-	-	-	-	-	-	-	-	-	-	-	-
				Simulium medusaeforme	+	-	-	-	-	-	-	+	-	-	-	+	-	-
				Simulium m. hargreavesi	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				Simulium merops	-	-	-	-	-	-	-	-	-	+	-	-	-	-
				Simulium metomphalus	-	-	-	-	-	-	+	+	-	-	-	-	-	-
				Simulium nevermania	-	-	-	+	+	+	-	-	-	-	+	+	-	-
				Simulium nigritarse	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				Simulium nigritarsi/brachium	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				Simulium rutherfoordi	+	-	-	-	+	-	-	-	-	-	+	+	-	+
				Simulium unicornutum	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				Simulium vorax	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Stratiomyiidae		Stratiomyiidae spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Tabanidae		Tabanidae spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				Tabanus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Tipulidae		Tipulidae spp.	-	-	-	-	-	+	-	-	-	+	-	-	-	-
			Limoniinae	*Antocha sp.*	-	-	-	-	-	-	-	-	+	+	+	-	-	-
				Limnophila sp.	-	-	-	+	+	+	-	+	-	+	-	-	-	+
				Limnophila sp. 1	-	-	-	-	-	-	-	-	-	+	-	-	-	-
				Limnophila sp. 2	-	-	-	-	-	-	-	-	-	+	-	-	-	-
				Limnophila nox	+	+	+	-	-	-	+	-	+	+	-	-	-	-
				Limonia sp.	-	-	-	-	-	+	-	-	-	-	-	+	-	-
				Limonia sp. 1	-	-	-	-	+	-	-	+	-	+	-	-	+	-
				Limonia sp. 2	-	-	-	-	+	-	-	-	-	-	-	-	-	-
				Limonia sp. 3	-	-	-	-	-	-	-	+	-	-	-	-	-	-
Ephemeroptera		unspecified		Ephemeroptera spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Baetidae		Baetidae spp.	+	+	+	+	+	+	+	+	+	+	+	+	-	+
				Gen. nov. sp. nov. 1	-	-	-	+	-	-	-	+	-	-	-	-	-	-
				Afroptilum parvum	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				Afroptilum sudafricanum	-	-	+	-	-	+	-	-	+	-	-	-	-	-
				Baetis sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				Baetis harrisoni	+	+	+	+	+	+	+	+	-	-	+	+	-	+
				Baetis latus	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				Bugilliesia sp. nov.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				Chelecloeon sp.	+	-	-	-	-	-	-	-	-	-	-	-	-	-
				Chelecloeon excisum	+	+	+	-	-	-	+	-	-	-	-	-	-	-
				Cloeodes sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix 8.1

ORDER / SUB-ORDER	FAMILY / SUB-FAMILY	TAXON	B15#	B16$	B17$	E18#	E19#	E20#	L22#	P23#	P24#	D25$	T26#	T27#	T28#	T29#
Ephemeroptera	Baetidae	*Cloeodes sp. nov. 1*	-	+	+	-	+	-	-	-	-	-	-	-	-	-
		Cloeodes inzingae	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Cloeon sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Dabulamanzia sp. nov.	-	-	-	+	-	-	-	-	-	-	-	-	-	-
		Demoreptus capensis	+	-	+	+	+	+	+	-	-	-	-	-	-	-
		Demoultnia crassi	-	-	-	-	-	-	+	-	+	-	-	-	-	-
		Labiobaetis sp.	+	-	-	-	-	-	-	+	-	+	-	-	-	-
		Labiobaetis sp. nov. 1	-	-	+	-	-	-	-	-	-	+	-	-	-	-
		Labiobaetis sp. nov. 2	-	+	-	-	-	-	+	+	+	-	-	-	-	+
		Pseudocloeon sp. nov.	-	-	-	-	-	-	+	-	-	-	-	-	-	-
		Pseudocloeon vinosum	+	+	+	-	-	-	-	+	+	+	-	-	-	+
		Pseudoharrisoni? sp.	+	-	-	-	-	-	-	-	-	-	-	-	-	-
		Pseudopannota maculosa	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Caenidae	Caenidae spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Caenis sp.	-	-	-	-	-	-	-	+	-	+	-	-	-	-
		Caenis sp. 2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Caenis sp. nov.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Caenis capensis	+	+	-	-	-	-	-	-	-	-	-	-	-	-
	Heptageniidae	Heptageniidae spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Afronurus sp.	-	+	+	-	-	-	-	-	-	-	-	-	-	-
		Afronurus harrisoni	-	+	+	-	-	-	-	-	-	-	-	-	-	-
		Afronurus scotti	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Leptophlebiidae	Leptophlebiidae spp.	+	+	+	+	+	+	-	+	-	+	-	-	-	+
		Adenophlebia sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Adenophlebia auriculata	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Adenophlebia peringueyella	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Aprionyx sp.	+	+	-	-	-	-	-	-	-	-	-	-	-	-
		Aprionyx peterseni	+	+	+	+	+	+	+	+	-	+	-	-	-	-
		Aprionyx rubicundus	-	-	-	-	+	-	-	-	-	-	-	-	-	-
		Aprionyx tabularis	-	+	-	-	-	-	-	-	-	-	-	-	-	-
		Castanophlebia sp.	-	-	-	+	-	-	-	-	-	-	-	-	-	-
		Castanophlebia calida	+	+	+	+	+	+	+	-	+	+	+	+	-	+
		Castenophlebia albicanda	-	-	-	-	-	-	-	-	-	+	-	+	-	-
		Choroterpes nigrescens	-	-	+	-	-	-	-	-	-	-	-	-	-	-
		Euthraulus elegans	-	-	-	+	-	-	-	-	-	-	-	-	-	-
	Teloganodidae	Teloganodidae spp.	+	-	-	-	-	+	-	-	+	-	-	-	-	-
		Teloganodidae sp. 1	-	-	-	-	-	-	-	-	+	-	-	-	-	-
		Ephemerellina sp.	-	-	-	-	-	-	-	-	-	+	-	-	-	-
		Ephemerellina barnardi	+	-	-	-	-	+	-	+	-	+	-	-	-	-

Appendix 8.1

ORDER / SUB-ORDER	FAMILY / SUB-FAMILY	TAXON	B15#	B16$	B17$	E18#	E19#	E20#	L22#	P23#	P24#	D25$	T26#	T27#	T28#	T29#
Ephemeroptera	Teloganodidae	*Ephemerellina crassi*	-	-	-	+	-	+	-	-	+	-	-	-	-	-
		Lestagella penicillata	+	+	+	+	+	-	-	-	-	+	+	+	-	+
		Lithogloea harrisoni	-	-	+	+	-	-	-	-	-	-	+	-	-	+
Haplotaxida	Enchytraeidae	Enchytraeidae spp.	-	-	-	+	+	-	-	-	-	-	-	-	+	-
	Lumbricidae	Lumbricidae spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Naididae	Naididae spp.	-	+	-	-	+	+	+	-	+	-	-	+	-	+
		Nais sp.	+	+	+	-	+	-	+	+	+	+	+	+	+	+
		Pristina sp.	-	-	-	+	-	-	-	-	-	+	+	-	+	+
	Tubificidae	Tubificidae spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hemiptera	unspecified	Hemiptera spp.	-	+	-	-	-	-	-	-	-	-	-	-	-	-
	Corixidae	Corixidae spp.	-	+	-	-	-	-	+	+	-	-	-	-	-	+
		Corixidae sp. 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Micronecta sp.	-	+	-	-	-	-	+	-	-	-	-	-	-	-
	Mesoveliidae	*Mesoveliidae spp.*	-	-	-	-	-	-	-	-	-	-	-	+	-	-
		Mesoveliidae sp. 1	-	-	-	-	+	-	-	-	-	-	+	-	-	-
	Naucoridae	Naucoridae spp.	+	+	-	-	-	-	-	-	-	+	-	-	-	-
		Aphelocheirnis sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Laccocoris sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Laccocoris limigenus	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Laccocoris spurcus	-	-	-	-	-	-	-	-	+	-	-	-	-	-
	Notonectidae	Notonectidae spp.	-	+	-	-	-	-	-	-	-	-	-	-	-	-
		Anisops letitia	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Veliidae	Veliidae spp.	-	+	-	-	+	+	-	-	-	+	-	+	+	-
		Microvelia sp.	-	-	-	+	-	-	-	-	-	+	-	-	-	+
		Microvelia major	-	-	+	-	-	-	-	-	-	-	-	-	-	-
		Rhagovelia sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hymenoptera	unspecified	Hymenoptera spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Isopoda	Janiridae	*Protojanira prenticei*	-	-	-	-	-	-	-	+	+	-	-	-	-	+
Lepidoptera	Pyralidae	*Petrophila sp.*	-	-	-	-	-	-	-	-	+	-	-	-	+	+
Lumbriculida	Lumbriculidae	Lumbriculidae spp.	-	+	+	+	+	+	+	+	-	+	+	+	+	+
Megaloptera	Corydalidae	Corydalidae spp.	-	-	-	+	+	+	+	+	-	+	-	-	-	-
		Chloroniella peringueyi	-	+	+	-	+	-	-	-	-	+	-	-	-	-
		Taeniochauloides ochraceopennis	-	+	+	-	-	-	-	+	-	+	-	-	-	-
	Sialidae	*Leptosialis africana*	-	+	-	-	-	-	-	-	-	-	-	-	-	-
Odonata	unspecified	Odonata spp.	+	-	-	-	-	+	-	-	-	-	-	-	-	-
		Anisoptera spp.	+	-	-	+	-	-	-	-	-	-	-	-	-	-
		Zygoptera spp.	-	-	-	+	-	-	-	-	-	-	-	-	-	-
Anisoptera	Aeshnidae	*Aeshna sp.*	+	+	+	-	-	-	-	+	-	-	-	-	-	+
		Anax sp.	-	-	-	-	-	-	+	-	-	-	-	-	-	-

Appendix 8.1

ORDER / SUB-ORDER	FAMILY / SUB-FAMILY	TAXON	B15#	B16$	B17$	E18#	E19#	E20#	L22#	P23#	P24#	D25‡	T26#	T27#	T28#	T29#
Anisoptera	Corduliidae	Corduliidae spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Macromia sp.	-	-	-	-	-	-	-	-	+	-	-	-	-	-
		Syncordulia sp.	+	-	-	-	-	-	-	-	-	-	-	-	-	-
	Gomphidae	Gomphidae spp.	+	+	-	-	-	+	-	-	+	-	-	-	-	-
		Ceratogomphus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Notogomphus sp.	-	-	+	-	-	-	-	-	-	+	-	-	-	-
		Notogomphus sp. 1	-	+	-	-	-	-	+	-	+	-	-	-	-	-
		Notogomphus sp. 2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Paragomphus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Paragomphus sp. 1	-	+	+	-	-	-	+	+	-	-	-	-	-	-
	Libellulidae	Libellulidae spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Libellulidae sp. 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Crocothemis sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Diplocodes sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Olpogastra sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Orthetrum sp.	-	+	-	-	-	-	-	-	-	-	-	-	-	-
		Pantala sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Tetrathemis sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Trithemis sp.	-	+	+	-	-	-	-	-	-	-	-	-	-	-
		Trithemis sp. 2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Zygonyx sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zygoptera	Coenagrionidae	Coenagrionidae spp.	+	-	-	-	-	-	-	+	+	-	-	-	-	-
		Enallagma sp.	-	+	-	-	-	-	-	-	-	-	+	-	-	-
		Enallagma sp. 1	-	-	-	-	-	-	-	+	+	-	-	-	-	-
		Pseudagrion sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Pseudagrion sp. 1	-	+	-	-	-	-	-	-	-	-	-	-	-	-
		Pseudagrion sp. 2	-	+	-	-	-	-	-	+	+	-	-	-	-	-
	Lestidae	*Lestes sp.*	-	-	-	-	-	-	-	-	-	-	+	-	-	-
	Platycnemididae	*Allocnemis leucosticta*	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Allocnemis sp.	+	-	-	-	-	-	-	-	-	-	-	-	-	-
		Mesocnemus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Protoneuridae	Protoneuridae spp.	-	-	-	-	+	-	-	-	-	-	-	-	-	-
	Synlestidae	Synlestidae spp.	-	-	-	-	-	-	-	+	-	-	-	-	-	-
		Chlorolestes sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Chlorolestes sp. 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Chlorolestes sp. 2	-	-	-	-	-	-	-	-	-	+	-	-	-	-
		Chlorolestes sp. 3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ostracoda	unspecified	Ostracoda spp.	-	-	-	-	-	+	-	-	-	-	+	+	-	+
Plecoptera	Notonemouridae	Notonemouridae spp.	+	+	-	+	+	+	-	-	-	+	+	-	-	+

Appendix 8.1

ORDER / SUB-ORDER	FAMILY / SUB-FAMILY	TAXON	B15#	B16$	B17$	E18#	E19#	E20#	L22#	P23#	P24#	D25$	T26#	T27#	T28#	T29#
Plecoptera	Notonemouridae	*Aphanicerca sp.*	+	-	+	+	+	+	+	+	+	+	+	+	+	+
		Aphanicerca bicornis	-	-	-	+	+	+	-	-	-	+	-	-	-	-
		Aphanicerca capensis	-	-	-	+	+	+	-	-	-	+	-	+	-	+
		Aphanicerca lyrata	-	-	-	+	-	-	-	-	-	-	-	-	-	-
		Aphanicercella sp.	+	+	+	-	+	-	+	+	+	+	+	+	+	-
		Aphanicercella barnardi	-	-	-	-	-	-	-	-	-	-	-	-	+	-
		Aphanicercella barnardi/scutata	-	-	-	+	+	+	-	-	-	+	-	-	+	-
		Aphanicercella cassida	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Aphanicercopsis sp.	+	+	-	-	-	-	-	-	-	-	-	+	-	-
		Desmonemoura sp.	+	-	-	-	-	-	-	-	-	-	-	-	-	-
		Desmonemoura pulchellum	-	-	-	-	-	-	-	-	-	+	-	-	-	-
Trichoptera	unspecified	Trichoptera spp.	-	+	-	-	+	-	-	-	-	+	-	-	-	+
		Trichoptera morph 2	-	-	-	-	+	+	-	-	-	+	-	-	-	-
		empty case	-	+	+	-	-	-	+	+	-	+	-	-	-	-
	Barbarochthonidae	*Barbarochthon brunneum*	-	-	-	-	-	-	-	+	+	-	-	-	-	+
	Ecnomidae	Ecnomidae spp.	-	-	-	-	-	-	-	-	+	+	-	-	-	-
		Ecnomus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Ecnomus sp. nov. 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Ecnomus kimminsi	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Parecnomina sp.	-	-	-	-	-	-	-	-	-	+	-	-	-	-
		Parecnomina sp. 1	-	-	-	-	-	+	-	-	-	-	-	-	-	-
		Parecnomina resima	+	+	+	+	+	+	-	+	-	+	+	-	-	-
	Glossosomatidae	Glossosomatidae spp.	-	-	-	-	+	+	-	-	-	-	-	-	-	-
		Agapetus sp.	-	-	-	+	+	+	-	-	-	+	-	-	-	-
	Hydropsychidae	Hydropsychidae spp.	-	-	-	-	+	+	-	-	+	+	-	-	-	-
		Diplectroninae spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Cheumatopsyche sp.	+	+	+	+	-	-	+	-	-	-	-	-	-	-
		Cheumatopsyche sp. 1	-	-	-	-	+	-	-	-	-	-	-	-	-	-
		Cheumatopsyche sp. 2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Cheumatopsyche sp. Type 2	-	-	+	-	-	-	-	-	-	-	-	-	-	-
		Cheumatopsyche sp. Type 7	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Cheumatopsyche sp. Type 9	-	+	-	-	-	-	-	-	-	-	-	-	-	-
		Cheumatopsyche sp. Type 11	-	+	+	-	-	-	+	-	-	-	-	-	-	-
		Cheumatopsyche afra	-	+	-	-	-	-	-	-	-	-	-	-	-	-
		Cheumatopsyche maculata	+	-	-	+	-	+	-	+	-	+	-	-	-	-
		Cheumatopsyche thomasseti	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Sciadorus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Sciadorus acutus	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Hydroptilidae	Hydroptilidae spp.	-	-	-	-	-	+	-	-	-	+	-	-	-	-

ORDER / SUB-ORDER	FAMILY / SUB-FAMILY	TAXON	B15#	B16$	B17$	E18#	E19#	E20#	L22#	P23#	P24#	D25$	T26#	T27#	T28#	T29#
Trichoptera	Hydroptilidae	*Hydroptila sp.*	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Hydroptila sp. nov.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Hydroptila cruciata	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Orthotrichia barnardi	-	-	-	+	-	-	-	-	-	-	-	-	-	-
		Orthotrichia sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Oxyethira velocipes	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Leptoceridae	Leptoceridae spp.	+	-	+	-	+	+	-	+	+	+	-	-	-	-
		Leptoceridae sp. 1	-	-	-	+	-	-	-	-	-	-	-	-	-	-
		Athripsodes sp.	-	+	-	-	+	-	-	-	-	+	-	-	+	-
		Athripsodes sp. 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Athripsodes sp. 2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Athripsodes (Bergensis group) *sp.*	+	+	-	+	-	-	+	+	-	+	+	+	+	+
		Athripsodes bergensis	+	-	-	-	-	-	-	-	-	-	-	-	-	-
		Athripsodes (Harrisoni group) *sp.*	-	-	-	-	-	-	-	+	-	-	-	-	-	-
		Athripsodes (Harrisoni group) *sp. 1*	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Athripsodes [harrisoni type]	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Athripsodes harrisoni	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Athripsodes schoenobates	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Ceraclea sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Leptecho sp.	-	-	+	+	-	+	-	-	-	-	-	+	-	+
		Leptecho sp. E	-	-	-	+	+	-	+	-	-	-	-	-	-	-
		Leptecho sp. F	-	-	-	-	-	-	+	+	-	-	-	-	-	-
		Leptecho sp. near F	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Leptecho helicotheca	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Leptecho scirpi	-	-	-	-	-	-	-	+	+	+	-	-	-	-
		Lepticho sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Leptocerus ?schoenobates	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Leptocerus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Oecetis sp.	-	+	+	+	-	-	+	-	-	+	-	-	-	+
		Oecetis sp. nov.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Oecetis sp. [near modesta]	-	+	-	-	-	-	-	-	-	-	-	-	-	-
		Oecetis modesta	-	+	-	-	-	-	-	-	-	-	-	-	-	-
		Macrostemum capense	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Petrothrincidae	*Petrothrincus sp.*	-	-	-	-	-	-	-	-	+	-	-	-	-	-
		Petrothrincus circularis	+	-	-	+	+	-	+	-	+	-	-	-	-	-
	Philopotamidae	Philopotamidae spp.	-	-	-	-	-	-	-	-	+	-	-	-	-	-
		Philopotamidae sp. 1	-	-	-	-	+	-	-	-	-	-	-	+	-	-
		Philopotamidae sp. 2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Chimarra sp.	+	-	-	-	-	+	-	-	-	-	-	-	-	-

Appendix 8.1

ORDER / SUB-ORDER	FAMILY / SUB-FAMILY	TAXON	B15#	B16$	B17$	E18#	E19#	E20#	L22#	P23#	P24#	D25$	T26#	T27#	T28#	T29#
Trichoptera	Philopotamidae	*Dolophilodes sp.*	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Paranyctiophylax sp.	-	-	+	-	-	-	-	-	-	-	-	-	-	-
	Psulidae	*Dyschimus thrymmifer*	-	-	-	-	-	-	-	-	-	-	-	-	+	-
	Polycentropodidae	Polycentropodidae spp.	-	+	-	-	-	-	-	-	-	-	-	-	-	-
	Rhyacophilidae	*Myspoleo agilis*	-	+	-	-	-	-	-	-	-	-	-	-	-	-
	Sericostomatidae	Sericostomatidae spp.	-	+	-	-	-	-	-	-	+	+	-	-	-	-
		Petroplax sp.	-	+	+	-	-	-	+	-	-	+	-	+	+	-
		Petroplax curvicosta	-	+	-	-	-	-	-	-	-	-	-	-	-	-
Tricladida	Planariidae	*Dugesia sp.*	-	+	-	-	+	+	+	-	+	+	+	+	+	+
Veneroida	Corbiculidae	*Corbicula sp.*	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unspecified	unspecified	eggs	-	-	-	-	-	-	-	-	+	+	+	+	+	-
		Gastropoda spp.	-	-	-	-	-	-	-	-	-	-	-	-	+	+
		Mollusca spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unspecified	unspecified	Nematoda spp.	-	+	-	+	+	+	+	+	+	+	-	+	+	+
		Nematomorpha spp.	+	-	-	-	-	-	-	-	-	-	-	-	-	-
		Nemertea spp.	+	-	-	-	-	-	-	-	-	-	-	-	-	-
		Oligochaeta spp.	+	-	-	-	-	-	-	-	-	-	-	-	-	+
		Terrestrial Arachnid	-	+	+	-	-	+	-	-	-	-	-	+	+	+
		Tadpole	-	+	-	-	-	-	-	+	+	+	+	+	+	-
		Terrestrial unidentified	+	+	+	+	+	+	-	+	+	+	+	+	-	+

Appendix 12.1 Number of each morphological unit and total percent (in parentheses) to total area for each of the least disturbed rivers sampled. PB = plane-bed and MCB = mid-channel bar.

Morphological Unit	O01$	O02$	R06#	R07#	R08$	M09$	M10#	M11#	R13$	B14#	B15#	B17#	E18#	E19#	E20#	P24#	T27#	T29#
Pool	2 (18.2)	2 (5.3)		5 (18.9)	1 (2.2)	1 (11.3)	3 (36.4)	2 (64.1)		2 (13.5)	7 (15.6)		2 (18.7)	5 (33.9)	2 (40.8)	3 (48.8)	1 (4.2)	6 (67.9)
Step				5 (11.4)	1 (7.6)		1 (7.8)			2 (4.1)	6 (12.0)		1 (4.6)	8 (37.1)	4 (33.8)		3 (51.3)	5 (28.6)
Plane Bed		1 (58.1)	2 (41.5)	2 (17.7)	2 (17.6)	1 (26.6)			2 (78.8)				3 (34.4)	1 (7.0)	1 (25.4)		2 (36.5)	
Rapid	3 (26.5)		1 (12.1)	2 (14.1)		1 (0.5)	1 (1.8)	3 (25.2)		7 (17.3)				1 (7.1)		1 (7.3)		
Riffle											1 (2.0)	1 (21.4)		2 (7.7)				
Run						2 (27.7)			1 (21.2)		1 (2.2)	2 (42.2)						
Lateral Bar		1 (13.9)		5 (26.4)	2 (42.6)		2 (13.9)					1 (36.4)	1 (23.5)	2 (7.3)				
Lateral Channel							1 (3.1)						1 (10.0)					
Backwater	2 (2.3)	1 (0.7)			1 (3.2)													
Bar										1 (3.9)								
Bedrock Core Bar																1 (4.6)		
Bedrock Pavement	3 (26.9)		1 (23.2)															
Bedrock Pool	1 (7.0)		2 (12.4)	1 (5.4)	1 (26.9)													
Bedrock Rapid											1 (52.4)							
Bedrock Step																4 (15.7)		
Boulder Bank				1 (6.0)														
Boulder Bar																	1 (8.0)	
Boulder Rapid							1 (17.1)											1 (3.5)
Canal																5 (22.6)		
Cataract								1 (10.8)										
Flood Bench		1 (12.5)																
Flood Channel										1 (5.3)								
Island	1 (17.5)					1 (3.0)												
Lateral Channel/ PB						1 (10.9)												
Lee Bar							2 (20.0)			2 (2.6)	1 (3.4)					1 (1.0)		
Mid-Channel Bar						1 (11.8)					1 (1.9)		1 (8.9)					
MCB Remnant						1 (8.2)												
Plunge Pool										5 (22.7)								
Proto Step										1 (0.8)	1 (9.2)							
Sandy Lee Bar											1 (1.3)							
Sculptured Bedrock										1 (25.5)								
Secondary Channel	1 (1.6)	1 (9.5)																
Slump			3 (10.7)															
Waterfall										1 (4.2)								

Appendix 13.1 **Species (or nearest taxonomic level) list used for analyses in Chapters 13 and 14.** 1 = Eerste Rivers site 1, 2 = Eerste River site 2, C = sampling period 3 (29 and 28 October 1997 for sites 1 and 2 respectively) and D = sampling period 4 (28 and 30 November 1997 for sites 1 and 2 respectively).

Order: sub-order	Family: sub-family	Taxon	1C	1D	2C	2D
Acariformes	Anisitsellidae	Anisitsellidae sp.	40	16	12	12
	Hydrachnellae	Hydracarina	356	128	164	76
	Oribatidae	Oribatidae sp.	20	8	4	4
Amphipoda	Paramelitidae	*Paramelita nigroculus*	0	4	0	8
		Paramelita sp.	0	8	0	0
Coleptera	Curculionidae	Curculionidae	0	4	0	8
	Dryopidae	Dryopidae sp.	4	0	16	0
		Strina sp.	8	8	0	8
	Elmidae	Elmidae sp. 3	16	4	0	8
		Elpidelmis sp.	16	0	0	0
		Elpidelmis sp. 1	168	68	128	60
		Elpidelmis sp. 2	0	8	8	8
		Elpidelmis sp. A	372	388	488	296
		Elpidelmis sp. B	12	8	16	4
		Peloriolus sp.	1372	292	1096	264
		Peloriolus sp. 1	424	80	244	100
		Peloriolus sp. 2	348	20	680	92
		Peloriolus sp. 3	68	68	132	56
	Gyrinidae	Gyrinidae	8	4	0	0
	Haliplidae	Haliplidae	0	0	4	0
	Helodidae	Helodidae sp. (adult)	8	8	0	12
		Helodidae sp. 1	6220	1860	4240	1096
		Helodidae sp. 2	0	4	0	0
		Helodidae sp. 6	16	24	16	40
		Helodidae sp. 9	8	0	0	0
	Hydraenidae	*Hydraena* sp.	4	0	0	0
		Mesoceration sp.	0	12	0	0
		Mesoceration sp. (adult)	388	64	424	72
	Limnichidae	*Limnichidae sp.*	452	32	292	52
Collembola	Unspecified	Collembola	0	28	0	24
Cyclopoida	Cyclopidae	Cyclopoida sp.	0	0	4	0
Diptera	Athericidae	*Atherix* sp. 4	120	16	232	8
	Blephariceridae	*Elporia barnardi*	0	0	20	0
		Elporia capra	556	28	1216	52
		Elporia spp. (adult)	24	0	32	0
		Elporia spp. (juv.)	0	0	12	0
		Elporia spp. (pupa)	0	4	0	0
		Elporia uniradius	96	0	384	0
		Elporia uniradius (pupa)	152	0	588	0
	Ceratopogonidae	*Atrichopogon* sp.	0	4	0	0
		Atrichopogon sp. 1	0	8	0	0
		Bezzia sp.	0	0	0	4
		Forcipomyia sp. 1	4	44	0	0
		Forcipomyia sp. 2	0	0	4	0
	Chironomidae: Aphroteniinae	*Aphrotenia* sp. nov. 1	0	12	0	8
	Chironomidae: Chironominae	*Cladotanytarsus* sp.	0	0	4	4
		Cryptochironomus sp.	4	0	0	0
		Microtendipes sp.	4	0	12	0
		Polypedilum E sp.	76	0	100	0
		Polypedilum sp. (adult)	0	0	0	4
		Polypedilum sp. (juv.)	24	40	4	40

Order: sub-order	Family: sub-family	Taxon	1C	1D	2C	2D
Diptera	Chironomidae: Chironominae	*Polypedilum* U sp.	12	0	168	0
		Rheotanytarsus fuscus	0	0	8	12
		Stempellina sp.	56	16	0	0
		Tanytarsus sp.	4	12	0	0
		Tanytarsus sp. 1	204	8	12	0
		Tanytarsus sp. nov.	0	0	8	0
	Chironomidae: Orthocladinae	*Cardiocladius* sp.	212	4	140	32
		Corynoneura dewulfi (adult)	0	20	8	4
		Corynoneura dewulfi (pupa)	8	0	4	0
		Corynoneura sp.	96	0	60	0
		Corynoneura sp. (adult)	4	0	12	0
		Corynoneura sp. (pupa)	16	4	0	4
		Cricotopus dibalteatus	16	0	4	0
		Cricotopus kisantuensis	20	4	96	8
		Cricotopus sp. (adult)	0	0	4	4
		Cricotopus sp. (pupa)	0	4	0	8
		Cricotopus sp. 1	4	0	12	0
		Cricotopus sp. 3	0	4	8	4
		Cricotopus sp. 4	40	0	0	0
		Eukiefferiella calviger	0	4	8	0
		Eukiefferiella calviger (pupa)	0	0	4	0
		Nanocladius vitellinus (adult)	0	8	0	0
		Notocladius capicola	556	52	288	32
		Notocladius capicola (adult)	0	0	4	0
		Notocladius capicola (pupa)	4	0	0	0
		Orthoclad gen. nov.	8	0	0	0
		Orthoclad gen. nov. (adult)	0	0	4	0
		Orthocladiinae (adult)	0	8	0	8
		Paradoxocladius mangoldi	12	0	0	0
		Parakiefferiella biloba (pupa)	0	4	0	0
		Parametriocnemus scotti (adult)	0	0	0	4
		Pseudorthocladius similis (adult)	0	12	0	0
		Pseudosmittia sp.	4	0	0	0
		Rheocricotopus capensis	12	0	40	20
		Rheocricotopus capensis (pupa)	4	8	0	4
		Thienemanniella sp. (adult)	0	8	0	0
		Thienemanniella sp. (pupa)	0	4	4	0
		Thienemanniella sp. 1	32	4	16	0
		Thienemanniella sp. 2	0	8	0	0
		Thienemanniella sp. 3	8	0	12	4
		Thienemanniella sp. 4	36	0	32	0
		Thienemanniella sp. 6	0	16	0	0
		Thienemanniella trivittata (adult)	12	4	0	0
		Tvetenia calvescens	40	16	216	36
		Tvetenia calvescens (pupa)	0	0	8	0
	Chironomidae: Tanypodinae	*Ablabesmyia* sp.	4	4	0	0
		Conchapelopia sp.	216	112	204	68
		Conchapelopia sp. (pupa)	0	0	16	0
		Conchapelopia sp. 2	84	0	0	4
		Larsia sp.	60	28	84	8
		Nilotanypus sp. (pupa)	36	20	4	8
		Nilotanypus sp. 1	44	8	84	0
		Nilotanypus sp. 1 (pupa)	0	0	40	0
		Paramerina sp.	516	16	176	32
		Paramerina sp. 1 (pupa)	4	0	0	0

Order: sub-order	Family: sub-family	Taxon	1C	1D	2C	2D
Diptera	Chironomidae: Tanypodinae	*Paramerina* sp. 2 (pupa)	4	0	4	0
		Procladius sp.	12	0	4	0
	Culicidae	Culicidae sp.	0	4	4	0
	Dolichopodidae	Dolichopodidae sp.	0	0	4	0
	Dytiscidae	Dytiscidae sp.	0	4	0	0
		Dytiscidae sp. (adult)	44	8	16	0
	Empididae	*Hemerodromia* sp.	12	0	12	4
	Simuliidae	Simuliidae	1380	2124	688	1520
		Simuliidae (adult)	4	8	0	0
		Simuliidae (pupa)	0	0	0	4
		Simulium alcocki (pupa)	0	12	0	4
		Simulium freemanellum (pupa)	0	0	4	0
		Simulium medusaeforme (pupa)	4	0	0	0
		Simulium nevermania (pupa)	20	0	20	12
		Simulium sp. (adult)	4	0	0	0
	Tipulidae	*Limnophila nox*	92	16	12	8
		Limnophila sp.	176	176	16	24
		Limnophila sp. (pupa)	8	0	0	0
Ephemeroptera	Baetidae	Baetidae sp.	15124	4188	21924	2488
	Heptageniidae	*Afronurus harrisoni*	0	0	4	0
	Leptophlebiidae	*Adenophlebia auriculata*	0	0	24	0
		Adenophlebia peringueyella	0	0	0	4
		Aprionyx peterseni	1340	252	964	256
		Castanophlebia calida	3056	1812	1884	920
		Euthraulus elegans	320	60	1024	176
		Leptophlebiidae (juv.)	552	128	672	52
	Teloganodidae	*Ephemerellina barnardi*	124	4	40	32
		Lestagella penicillata	4448	1436	4408	744
		Lestagella penicillata (adult)	0	0	4	0
		Lithogloea harrisoni	1420	376	1288	540
		Nadinetella crassi	20	4	8	0
Haplotaxida	Lumbriculidae	Lumbriculidae	72	32	72	48
	Naididae	*Nais* sp.	64	0	84	12
		Pristina sp.	0	0	0	4
Hemiptera	Corixidae	*Micronecta piccanin*	0	0	8	4
		Micronecta scutellaris	12	0	0	4
	Noteridae	Noteridae sp.	0	4	0	0
	Veliidae	*Microvelia major*	0	0	0	4
		Microvelia major (adult)	48	0	0	8
		Microvelia sp. (adult)	4	4	0	0
		Rhagovelia sp.	0	8	0	0
Lepidoptera	Pyralidae	Pyralidae	0	12	4	12
Megaloptera	Corydalidae	*Chloroniella peringueyi*	4	4	12	8
		Taeniochauloides ochraceopennis	12	4	4	4
Nemata (Phylum)	Unspecified	Nematoda	8	4	4	0
Odonata: Zygoptera	Coenagrionidae	*Enallagma* sp.	0	4	0	0
		Pseudagrion sp.	8	0	0	0
	Platycnemididae	*Allocnemis* sp.	0	0	4	0
Plecoptera	Notonemouridae	*Aphanicerca* sp.	2092	1768	2284	1140
		Aphanicercella sp.	64	40	8	40
		Aphanicercopsis sp.	0	0	0	4
		Desmonemoura sp.	776	0	112	0
Trichoptera	Barbarochthonidae	*Barbarochthon brunneum*	16	0	0	0
	Ecnomidae	*Parecnomina resima*	360	8	192	28
	Glossosomatidae	*Agapetus* sp.	48	32	56	36

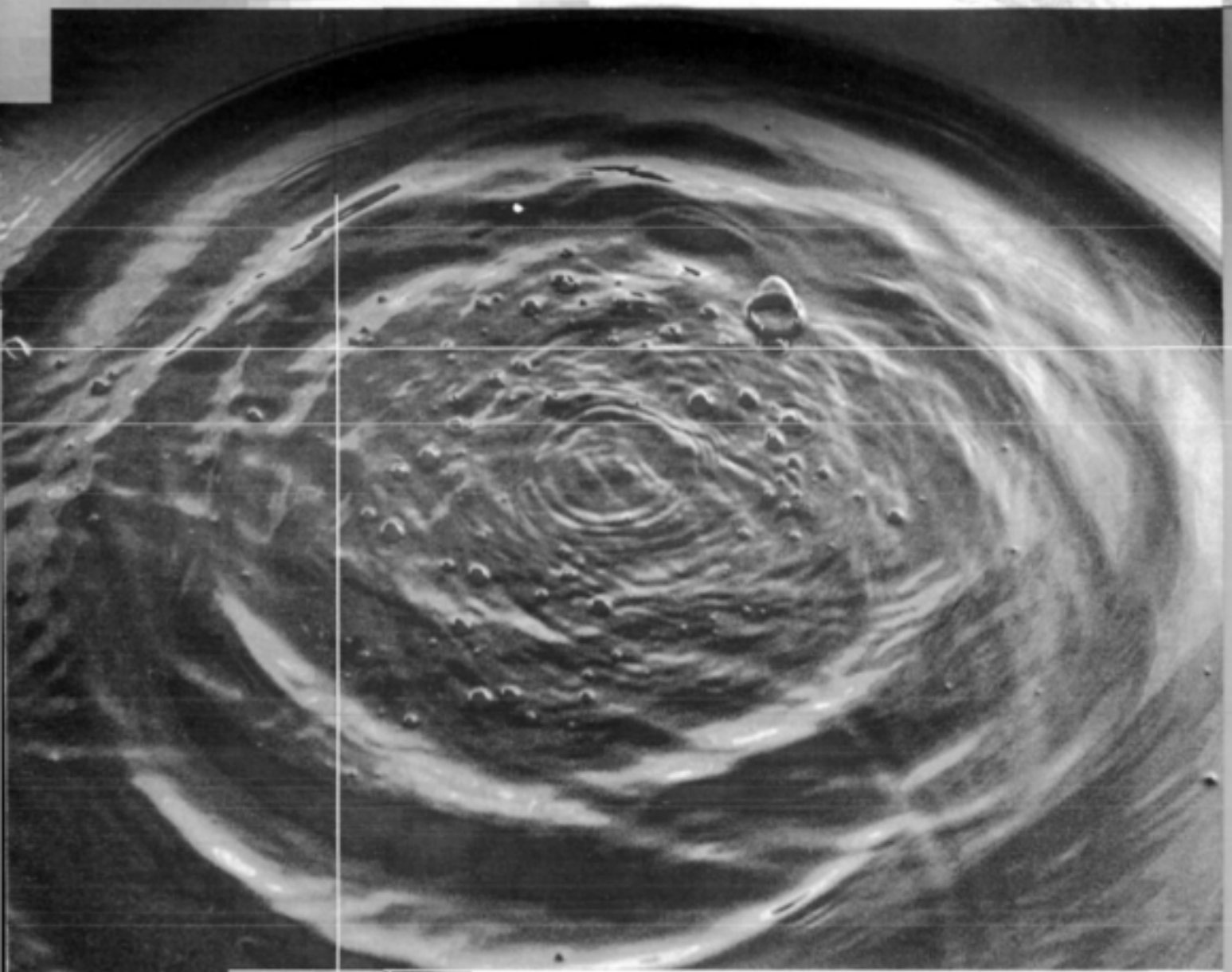
Order: sub-order	Family: sub-family	Taxon	1C	1D	2C	2D
Trichoptera	Goeridae	*Goera* sp.	0	0	0	4
	Hydropsychidae	*Cheumatopsyche maculata*	52	12	56	20
		Hydropsyche sp.	8	0	0	4
	Hydroptilidae	*Orthotrichia barnardi*	8	0	0	0
	Leptoceridae	*Athripsodes* (Bergensis group) sp.	40	24	60	16
		Athripsodes sp.	64	0	0	0
		Ceraclea sp.	12	0	16	16
		Leptecho sp.	760	144	328	204
		Leptecho sp. 1	16	4	8	36
		near *Leptecho* sp.	0	24	0	0
		Oecetis sp.	4	4	16	4
	Petrothrincidae	*Petrothrincus circularis*	436	168	472	220
	Philopotamidae	*Chimarra* sp.	0	0	4	4
	Sericostomatidae	*Petroplax curvicosta*	0	4	4	8
		Petroplax sp.	8	16	24	4
Tricladida	Planariidae	*Dugesia* sp.	36	8	16	20

Appendix 16.1 Comparison of abundances of species in the Breede and Olifants-Berg catchment groups. Average abundance rating for each group, average, ratio, percent contribution and cumulative percentage between groups given.

No.	Species	Breede Average Abundance	Olifants-Berg Average Abundance	Average Term	Ratio	Percent	Cumulative Percentage
11	*Elpidelmis* sp. A	0.00	2.46	1.86	6.45	3.04	3.04
129	*Cheumatopsyche maculata*	2.28	0.00	1.70	5.95	2.76	5.80
79	*Labiobaetis* sp. nov. 1	0.00	2.21	1.67	3.15	2.71	8.51
23	*Atherix* sp. 2	0.00	2.04	1.55	2.34	2.52	11.03
25	*Atherix* sp. 4	0.47	2.00	1.40	1.26	2.28	13.31
53	*Polypedilum* E sp.	0.00	1.72	1.27	1.46	2.08	15.39
99	*Ephemerellina barnardi*	1.65	0.00	1.25	1.32	2.04	17.43
88	*Afronurus harrisoni*	0.00	1.63	1.24	1.60	2.03	19.45
13	Helodidae sp. 2	0.00	1.63	1.24	1.47	2.02	21.47
84	*Caenis capensis*	1.63	0.00	1.23	2.46	2.00	23.47
4	*Stnia* sp. 1	0.00	1.63	1.15	0.95	1.88	25.35
70	*Baetis harrisoni*	2.11	3.43	1.15	1.40	1.87	27.22
136	*Athripsodes* (Bergensis group) sp.	1.56	0.00	1.13	1.61	1.83	29.06
77	*Demoreptus capensis*	2.07	1.50	1.04	1.27	1.69	30.74
33	*Forcipomyia* sp. 2	0.00	1.36	1.01	1.63	1.64	32.39
128	*Cheumatopsyche afra*	1.46	0.00	0.98	0.96	1.60	33.99
16	Helodidae sp. 6	1.37	2.38	0.95	1.19	1.55	35.54
69	*Afroptilum sudafricanum*	1.33	0.75	0.95	1.26	1.55	37.09
85	*Caenis* sp. 1	0.25	1.25	0.95	1.08	1.54	38.63
127	*Parecnomina resima*	1.58	0.38	0.94	2.27	1.53	40.16
24	*Athrix* sp. 3	0.00	1.25	0.89	0.91	1.45	41.61
147	*Petrothrincus circularis*	1.09	0.00	0.84	1.61	1.37	42.99
91	*Aprionyx perterseni*	1.25	2.18	0.81	1.15	1.33	44.31
17	Helodidae sp. 7	1.19	0.50	0.81	1.25	1.33	45.64
114	*Notogomphus* sp. 1	0.00	1.04	0.80	0.91	1.31	46.95
94	*Castanophlebia calida*	1.00	1.99	0.80	1.39	1.31	48.26
82	*Pseudocloeon vinosum*	1.34	1.34	0.79	1.39	1.29	49.55
102	*Lithogloea harrisoni*	0.25	0.97	0.78	1.03	1.27	50.82
101	*Lestagella penicillata*	1.71	1.77	0.78	1.54	1.26	52.09
13	Helodidae sp. 2	0.00	1.00	0.75	0.95	1.23	53.31
12	*Elpidelmis* sp. B	0.00	1.04	0.74	0.96	1.20	54.51
40	*Cricotopus kisantuensis*	0.25	1.02	0.74	1.06	1.20	55.72
66	*Limnophila nox*	0.75	1.58	0.74	1.62	1.20	56.92
62	*Thienemanniella* sp. 3	0.25	1.00	0.72	1.07	1.17	58.09
109	*Taeniochaufoides ochraceopennis*	0.75	1.10	0.71	1.30	1.16	59.25
67	*Limonia* sp. 1	0.00	1.00	0.69	0.55	1.13	60.38
90	*Adenophlebia peringueyella*	1.02	0.00	0.68	0.88	1.10	61.48
108	*Chloroniella peringueyi*	0.25	0.88	0.68	1.02	1.10	62.59
54	*Polypedilum* U sp.	1.69	1.70	0.68	1.34	1.10	63.69
74	*Cloeodes inzingae*	0.88	0.00	0.64	0.86	1.05	64.73
41	*Cricotopus* sp. 1	1.48	1.57	0.64	1.77	1.04	65.77
33	*Forcipomyia* sp. 2	0.00	0.75	0.57	0.89	0.92	66.70
30	*Bezzia* sp. 1	0.00	0.75	0.57	0.89	0.92	67.62
86	*Caenis* sp. 2	0.88	0.00	0.56	0.56	0.92	68.54
47	*Notocladius capicola*	1.90	2.38	0.56	1.42	0.91	69.45
63	*Tvetenia calvescens*	1.58	1.77	0.51	1.29	0.84	70.28
56	*Rheocricotopus capensis*	1.58	1.98	0.50	1.72	0.82	71.10
72	*Bugiliesia* sp. nov.	0.75	0.00	0.50	0.89	0.81	71.91
58	*Tanytarsus* sp. 1	1.50	1.34	0.50	1.22	0.81	72.72
83	*Pseudopannota maculosa*	0.75	0.00	0.48	0.56	0.79	73.51
132	*Cheumatopsyche thomasseti*	0.75	0.00	0.48	0.56	0.79	74.30
56	*Rheotanytarsus fuscus*	1.46	2.11	0.47	2.05	0.77	75.07
52	*Parametriocnemus scotti*	0.56	0.33	0.46	1.03	0.75	75.83

Appendix 16.1

No.	Species	Breede	Olifants-Berg				
		Average Abundance	Average Abundance	Average Term	Ratio	Percent	Cumulative Percentage
121	*Aphanicerca bicornis*	0.00	0.56	0.46	0.55	0.74	76.57
138	*Athripsodes bergensis*	0.58	0.00	0.45	0.89	0.74	77.31
60	*Thienomanniella* sp. 1	1.16	1.00	0.45	1.14	0.73	78.04
64	*Pericoma* sp. 1	0.25	0.50	0.43	0.75	0.71	78.74
31	*Bezzia* sp. 2	0.50	0.00	0.42	0.96	0.69	79.43
5	*Strina* sp. 2	0.50	0.00	0.42	0.96	0.69	80.12
14	Helodidae sp. 4	0.44	0.25	0.42	0.81	0.68	80.80
61	*Thienemanniella* sp. 2	0.00	0.56	0.41	0.55	0.67	81.47
123	*Aphanicerca lyrata*	0.00	0.50	0.41	0.55	0.66	82.13
104	*Laccocoris limigenus*	0.00	0.50	0.41	0.55	0.66	82.79
105	*Laccocoris spurcus*	0.00	0.50	0.41	0.55	0.66	83.45
122	*Aphanicerca capensis*	0.00	0.50	0.41	0.55	0.66	84.11
32	*Forcipomyia* sp. 1	0.00	0.50	0.41	0.95	0.66	84.77



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