# A RIVER HEALTH ASSESSMENT OF SELECTED SOUTH-WESTERN CAPE RIVERS: INDEX OF HABITAT INTEGRITY, WATER QUALITY AND THE INFLUENCE OF SURROUNDING LAND USE

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**DECLARATION**

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

Signature___________________________ Date___________________

## EXECUTIVE SUMMARY

The River Health Programme (RHP) is an assessment tool for monitoring the ecological state of rivers to ensure that they remain fit for use by present and future generations. This study, forming part of a RHP assessment conducted on the south-western Cape Hout Bay, Lourens and Palmiet Rivers, has the aim to (1) zone the rivers for representative site selection, (2) assess their habitat integrity (HI), (3) determine the influence of land use on riverine HI and (4) assess the river water quality at the time of the RHP assessments.

(1) The desktop geomorphological zonation method used in RHP assessments has not been sufficiently previously tested on short rivers draining the Western Cape Mountains. The Lowland River Zone of the rivers studied, as well as the Hout Bay River's Upper Foothill Zone, were found to have steeper gradients than expected, probably due to these rivers being shorter and consequently steeper than any on which the method was previously tested. The notion of one gradient river classification system being applicable throughout South Africa, with its diverse geology and climate, is unlikely. Rather a classification system modified for various physiographic features regions or by a factor based on river length is more realistic.

(2) Although there is a general longitudinal decrease in HI downstream along the Hout Bay and Lourens Rivers, coinciding with increased anthropogenic activities, HI improves in the Palmiet River's lower reaches through the Kogelberg Nature Reserve. Surrounding land use thus seems to be a major determinant of HI. Although the Index of Habitat Integrity (IHI) used appears to achieve its aim, it was found to be subjective. Categorisation of the IHI scoring is suggested.

(3) The amount of natural versus disturbed land use occurring upstream of a site at a regional and local scale, is a good predictor of riverine HI. Regional alien forestry and local urbanisation have significantly strong negative effects on instream ($r^2$ = -0.80, $r^2$ = 0.80, $p<0.05$) and riparian ($r^2$ = -0.81, $r^2$ = -0.83, $p<0.05$) HI. Different land use types therefore appear to affect riverine HI at differing scales and thus managers must not only think on a local but also a catchment scale.

(4) In the Hout Bay River, a filtering system (e.g. wetland) appears to improve the water quality between the middle and lower reaches. Along the Lourens River, high total dissolved salts, conductivity and inorganic nitrogen concentrations in the middle reaches are cause for concern. Along the Palmiet River there appeared to be insufficient oxygen to support most aquatic life forms at Grabouw. Impoundments in the middle reaches act as sinks for nutrients and salts, but the Huis and Krom tributaries downstream then appear to degrade the water quality of the Palmiet River's lower reaches within the Kogelberg Nature Reserve.

Together with the results of simultaneous biotic assessments, these results should be used to develop management actions to improve the ecological health of these rivers. The results have been used in a State-of-Rivers Report for the south-western Cape.

## UITVOERENDE OPSOMMING


Die Riviergesondheidsprogram (RGP) is 'n asseseringsinstrument wat die ekologiese stand van riviere monitor om te verseker dat hulle steeds bruikbaar bly vir huidige en toekomstige geslagte. Hierdie studie maak deel uit van 'n RGP-assessering van die Lourens-, Houtbaai- en Palmietrivier in die Suidwes-Kaap en het ten doel om (1) die riviere te soneer vir verteenwoordigende terreinseleksie, (2) die habitat-integriteit (HI) te assesseer, (3) die invloed van grondgebruik op rivier-HI te bepaal en (4) die kwaliteit van rivierwater tydens die RGP-assesserings te bepaal.

(1) Die geomorfologiese-soneringsmetode wat in RGP-assesserings gebruik word, is nog nie voorheen genoegsaam vir die kort riviere wat die Wes-Kaapse berge dreineer, getoets nie. Daar is bevind dat die studiegebied riviere in die laagland-sones skerper gradiënte het as verwag, gehad het. Dit kan moontlik toegeskryf word aan die riviere wat korter en dus steiler is as enige van dié wat voorheen met die metode getoets is. Die moontlikheid dat een gradiëntklassifikasiestelsel vir riviere regdeur Suid-Afrika met sy diverse geologie en klimaat toegepas kan word, is onwaarskynlik. 'n Klassifikasiestelsel aangepas vir verskillende fisiografiese streke of met 'n faktor gebaseer op rivierlengte, is meer realisties.

(2) Alhoewel HI stroomaf langs die Lourens- en Houtbaairivier in die algemeen longitudinaal saam met die toename in antropogeniese aktiwiteite afneem, verbeter die Palmietrivier se HI waar dit laer af deur die Kogelbergnatuurreservaat vloei. Die gebruike van aanliggende grond blyk dus 'n belangrike bepaler van HI te wees. Die Indeks van Habitatintegriteit (IHI) bereik klaarblyklik die vereiste doel, maar is te subjektief. Kategorisering van die IHI-waardes word voorgestel.

(3) 'n Goeie voorspeller van rivier-HI is die hoeveelheid natuurlike teenoor versteurde grondgebruik stroomop van 'n terrein op 'n streeks- en lokale skaal. Die sterk negatiewe effek van uitheemse plantegroei in die omgewing en lokale verstedeliking op stroom- ($r^2 = -0.80$, $r^2 = 0.80$, $p<0.05$ ) en oewer-HI ($r^2 = -0.81$, $r^2 = -0.83$, $p<0.05$) is beduidend. Verskille in tipe grondgebruik beïnvloed rivier-HI op verskillende vlakke; bestuurders moet dus plaaslik en aan die opvanggebied dink.

(4) In die Houtbaairivier lyk dit asof 'n filtreringstelsel (bv. vleigrond) die waterkwaliteit tussen die middel- en lae gedeeltes verbeter. In die loop van die Lourensrivier is hoë totale opgeloste soute, geleidingsvermoë en anorganiese stikstofkonsentrasies in die middelgedeelte 'n rede tot kommer. In die Palmietrivier by Grabouw was die suurstof te min om die meeste akwatiese lewensvorme te onderhou. Opgedamde water in die middel gedeeltes dien as 'n sink vir voedingstowwe en soute, maar dit lyk asof die Huis- en Kromrivier die waterkwaliteit van die Palmietrivier stroomaf in die Kogelbergnatuurreservaat degradeer.

Saam met die resultate van gelyktydige biotiese assesserings, kan hierdie resultate gebruik word vir die ontwikkeling van bestuursaksies om die ekologiese toestand van hierdie riviere te verbeter. Die resultate is gebruik in 'n toestand-van-riviere-verslag vir die Suidwes-Kaap.

# DEDICATION

To Mum and Dad, for your love, support, understanding and encouragement;

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**FOREWORD**

This thesis is structured with the first chapter being a general introduction, where the study area, study aims and literature consulted is presented. Chapters 2 to 5 are then presented as a series of papers, each designed as individual papers prepared for the South African Journal of Aquatic Sciences. Each chapter deals with a specific aim laid out in the introductory Chapter 1. The thesis then ends with Chapter 6 which deals with the general conclusions of the thesis.

A summary of the work performed in this thesis is presently in press in the form of a State-of-Rivers Report published by the River Health Programme.

*CHAPTER 1*

# GENERAL INTRODUCTION

## 1.1 THE IMPORTANCE OF WATER MANAGEMENT

Water is a vital resource to man, firstly, because it is essential for life; secondly, it is important economically in agriculture and industry; thirdly, it has an important recreational and aesthetic function and finally, it also provides vital ecological functions in nutrient recycling and diverse habitat creation (Moore and Seckler 1993; DWAF 1996; Tharme *et al.* 1997; Davies and Day 1998; CSIR 2002; Gleick 2002; WRC 2002; RHP 2003).

However, fresh water resources in South Africa are limited (WRC 2001; RHP 2003). Average annual rainfall for South Africa is 452 mm $yr^{-1}$ (Davies and Day 1998), which is below the world's average and is combined with high evaporation rates (DWAF 1996). Under normal rainfall conditions, perennial rivers occur only over 25% of South Africa's surface (Van der Merwe 1994). The rivers in the entire western interior of South Africa are episodic, flowing only after infrequent storms and in the absence of lakes and permanent snow-caps to stabilise the flow, even the perennial rivers flow irregularly and are often strongly seasonal (Van der Merwe 1994). Added to this, is the fact that, like rivers throughout the world, South African rivers are increasingly suffering disturbance from water resource development (Rowntree *et al*. 2000), with several, if not all South African rivers, having some major form of alteration or deterioration (Kleynhans 1996). Therefore, the importance of sustainable water use in South Africa for long term economic, social and environmental security cannot be over emphasised.

## 1.2 WATER LEGISLATION IN SOUTH AFRICA

With environmental problems escalating due to intense pressure on water resources from population growth and economic development world-wide, many nations have established legislative, regulatory and institutional frameworks to protect and improve their natural resources (Deason 1992). Gorgens *et al*. (1998) observe that the significant transformations that have occurred in the field of water resources management in South Africa during the past decade, have been spurred on by two sets of events in particular; namely, a growing awareness that there is an increasing exploitation of water resources to meet the rising water demands in South African catchments, and the intensification of concomitant impacts on water quality. These have necessitated fresh applications to water management. The new South African National Water Act (Act No. 36 of

1998), recognises and protects a basic human need and ecological reserve in rivers and legislates the monitoring of river health (Republic of South Africa 1998). Rowntree *et al.* (2000) observe that this law brings South Africa in line with other countries like Australia, where the Council for Australian Governments promotes the legal protection of environmental flows, and England and Wales where the National Rivers Authority (Petts 1996) gives explicit recognition to the ecological needs within water resource management.

## 1.3 THE RIVER HEALTH PROGRAMME (RHP)

As custodian of water resources in South Africa, the Department of Water Affairs and Forestry (DWAF) is responsible for the protection of aquatic ecosystem health, thereby ensuring the ability of these systems to meet utilisation requirements of present and future generations (DWAF 1996; WRC 2001 and 2002; RHP 2003 and *in prep.*). For this purpose, DWAF initiated the River Health Programme in 1994 (Roux *et al.* 1999; WRC 2001, 2002; RHP 2003, *in prep.*).

The RHP is in compliance with the National Water Act (Act No. 36 of 1998) legislation of monitoring the health of the nation's rivers (Rowntree *et al.* 2000; WRC 2001, 2002; RHP 2003, *in prep.*) and is essentially a tool for monitoring the ecological state of rivers in South Africa (Roux *et al.* 1999; WRC 2001, 2002). Its objectives, according to Roux *et al.* (1999) are to:

1. Measure, assess and report on the ecological state of riverine ecosystems;
2. Detect and report on spatial and temporal trends in this ecological state; and
3. Identify and report on emerging problems regarding this ecological state.

The results of the RHP should then be incorporated into a water resource management system (Roux *et al.* 1999).

## 1.4 THE DEFINITION OF 'RIVER HEALTH'

Roux *et al.* (1999) state that the term 'river health' simply refers to the ecological condition of a river. An ideally healthy river is one that is in, or very close to, its natural (undisturbed) state (Uys 1994). The natural state of the river is the baseline against which the deterioration of its health is measured (Uys 1994; Roux *et al.* 1999). However, probably no completely natural river remains today and so any river, in which the majority of the characteristics are relatively unmodified, is considered and termed 'healthy' (Uys 1994).

### 1.4.1 Ecological health versus ecological integrity

Karr (1993) defines ecological health (i.e. ecological condition) as "the condition when a system's inherent potential is realised, its condition is stable, its capacity for self repair, when perturbed, is preserved, and minimal external support for management is needed". Reiger (1993) explains that "a living system exhibits integrity if, when subjected to disturbance, it sustains an organising, self correcting capability to recover toward an end-state that is normal or 'good' for that system. End states other than pristine or naturally whole may be taken to be 'normal and good". It, therefore, can be concluded from these definitions that ecological health can be defined as ecological integrity.

## 1.5 'MEASURING' RIVER HEALTH

River health measures conditions that are necessary for proper ecosystem functioning and for the ability to supply good water quality and other services, like food, flood and erosion control and grazing (WRC 2001, CSIR 2002). A multitude of factors determines these conditions, but to measure all of these is impractical (Townsend and Riley 1999; WRC 2001, 2002; RHP 2003, *in prep.*). Therefore, to determine river health the RHP uses a set of scientifically derived indices to assess the condition of selected ecological indicators considered representative of the wider ecosystem (Roux *et al.* 1999; WRC 2001, 2002; RHP 2003, *in prep.*). Examples of these indices are the South African Scoring System (SASS) (Dickens and Graham 2002), focussing on macroinvertebrates, the Fish Assemblage Integrity Index (FAII) (Kleynhans 1999a), the Riparian Vegetation Index (RVI) (Kemper 2000) and the Index of Habitat Integrity (IHI) (Kleynhans 1996). Using the results of these indices, the river ecosystem is classed in terms of its degree of modification relative to a natural benchmark (undisturbed) condition (Roux *et al.* 1999; Rowntree *et al.* 2000).

## 1.6 AIMS AND OBJECTIVES OF THE STUDY

The aim of this project was, firstly, to rapidly assess the habitat integrity of selected rivers in the south-western Cape as an indication of river health and, secondly, to determine the influence of surrounding land use on this habitat integrity.

There are five objectives in this study:

1. Classify the rivers into longitudinal zones so as to select representative sampling sites for the river health assessments (Chapter 2).

2. Apply the Index of Habitat Integrity for intermediate and rapid assessments to determine the habitat conditions in three selected south-western Cape rivers (Chapter 3).
3. Determine the influence of surrounding land uses on the habitat conditions (Chapter 4).Discuss the present water quality of the rivers assessed (Chapter 5).This study forms part of a series of four studies that were conducted simultaneously, all with the broad aim of rapidly assessing the health of three south-western Cape rivers. The other three studies assessed river health using different river health indices: Hayes (2002) used the FAII, Ollis (*in prep*.) SASS and Withers (*in prep.*) the RVI. The results from this study, together with the other three mentioned above, have been combined to produce a State-of-Rivers Report (RHP *in prep.*). The data accumulated from these studies should also be incorporated into a water resource management system database (Roux *et al.* 1999), so that appropriate management strategies for the improvement of the health of the rivers assessed can be determined.

## 1.7 THE ROLE OF RIVER CLASSIFICATION IN THE RHP

O'Keeffe *et al.* (1994) explain that classification allows for the organisation and understanding of complex, variable objects, systems or ideas, thereby enabling their easier usage. Classification, therefore, allows one to put a stream into context. Many river classification procedures have been suggested. Day *et al.* (1994) suggested classifying streams according to their chemical attributes whilst Joubert and Hurly (1994) suggested using flow-derived variables and Eekhout (1994) suggested a biotic approach. However, the geomorphological characteristics of rivers are used more often in river classification, because it is these physical characteristics that determine the type and abundance of habitats available in a river, which in turn determine the types and abundances of species present, as well as the hydraulic conditions for any given flow discharge (O'Keeffe *et al.* 1994; Rowntree *et al.* 2000). Identifying and classifying river sections in terms of geomorphological criteria also allows for the full diversity of conditions along a river to be represented by selected study sites (Tharme *et al.* 1997; Rowntree *et al.* 2000). Rowntree *et al.* (2000) explain that this allows for the rapid assessment of a river system down its length, as sites representative of each river zone or section can be assessed. Another strength of the geomorphological zone as a river classification tool, is that it can be derived from a desk top exercise. Geomorphological zonation is, therefore, used in the RHP.

A number of geomorphological classification systems have been developed (e.g. Schumm 1977; Pickup 1984; Wadeson and Rowntree 1994; Rowntree and Wadeson 1999), with the earliest being by WM Davis in 1890 (Rowntree *et al.* 2000). Rowntree *et al.* (2000) derived a longitudinal river zonation method that is a modified version of the ecological classification system. This method is based on the fact that channel gradient is a good indicator of channel morphology, such that as gradient decreases, a clear change in the channel morphology is seen and the bed material size changes from coarse to fine along the length of a river. The river can, consequently, be divided into geomorphological zones where, within a particular geomorphological zone, the gradient, channel morphology and bed material are similar both within the same river as well as within the same zone classification between rivers. Particular biological distributions are also associated with this variation in physical characteristics down the length of a river. Being a convenient desktop application this river zonation method is used in the RHP.

## 1.8 THE IMPORTANCE OF HABITAT INTEGRITY IN DETERMINING RIVER HEALTH

According to Kleynhans (1996) both the habitat and biotic integrities of a river determine its ecological integrity or health. Habitat integrity refers to the maintenance of a balanced, integrated composition of physico-chemical and habitat characteristics, on a temporal and spatial scale, that are comparable to the characteristics of the natural habitat of the region. Destruction of a particular habitat may result in the disappearance of certain habitat sensitive species (Roth *et al.* 1996; Giller and Malmqvist 1998; CSIR 2002; Roy *et al.* 2003) and, in fact, habitat loss is considered to be the single most important factor that has contributed towards species extinction in the past century (Giller and Malmqvist 1998; CSIR 2002). For example, habitat loss has been implicated as one of the leading factors in the decline of salmon and steelhead fishery in the Yakima River Basin in Washington State (Cuffney *et al.* 2000). On the other hand, an increase in habitat quality results in an increase in biotic integrity (Hall *et al.* 1996).

The assessment of habitat criteria, therefore, determines the potential of aquatic habitats to support and maintain a balanced, integrated and adaptive community of organisms, having a species composition and functional organisation comparable to that of natural habitats of the region (Karr 1993; Hall *et al.* 1996; Kleynhans 1996; Harper and Everard 1998; Muhar and Jungwirth 1998; Townsend and Riley 1999; CSIR 2002). Hence, a knowledge of the availability and quality of habitats is considered vital for an assessment of overall ecosystem health (CSIR 2002) and consequently habitat assessment has become an important part of evaluating ecological integrity internationally (Campbell 1994; Davies and Schofield 1994; Jackson and Anderson 1994;

Kleynhans 1996; Muhar and Jungwirth 1998; Kemper 1999; Kleynhans 1999b; McQuaid and Norfleet 1999).

In habitat assessments, importance is placed on the functionality of a river to provide suitable living conditions for biota (Kleynhans 1996). Habitat integrity refers to the habitat characteristics and the physico-chemical characteristics of a river (Kleynhans 1999b). The physical habitat of a river is equally (Karr 1993), if not more (Hall *et al.* 1996), important than the water quality in determining the biotic integrity of the river. Improving the water quality of a river system will not improve the biotic integrity of that system as long as the physical habitat available is a limiting factor (Karr and Schlosser 1978; Hall *et al.* 1996).

### 1.8.1 Habitat assessment methods

Examples of habitat assessment methods used world-wide are listed in Table 1.1. These methods rely on qualitative descriptions of certain common criteria (Jackson and Anderson 1994; Kleynhans 1996; Muhar and Jungwirth 1998; Kemper 1999; Kleynhans 1999a; McQuaid and Norfleet 1999; Dallas 2000).

**Table 1.1.** Various international techniques used in assessing the habitat condition of rivers

| INDICES / TECHNIQUES | COUNTRY | SOURCE |
|---|---|---|
| Rapid Bioassessment Protocol for habitat | United States of America (USA) | Plafkin *et al.* (1989) |
| Qualitative Habitat Evaluation Index | USA | Rankin (1995, in Muhar and Jungwirth 1998) |
| Visual Stream Assessment | USA | USDA/NRCS (1998) |
| River Habitat Survey | United Kingdom | Raven *et al.* (1997) |
| A rapid assessment technique for determining the physical and environmental condition of rivers in Queensland | Australia | Jackson and Anderson (1994) |
| Index of Instream Condition | Australia | Centre for Environmental Applied Hydrology (1997) |
| Index of Habitat Integrity | South Africa | Kleynhans (1996, 1999) |
| Index of Habitat Integrity for intermediate and rapid assessments | South Africa | Kemper (1999) |

The results from these assessments are used to compare the present habitat state of the river to its reference (baseline, natural, unmodified) state (Kleynhans 1996; Roux *et al.* 1999; Rowntree *et al.* 2000). Indices designed for use in intermediate and rapid habitat assessments (e.g. Index of Habitat Integrity for intermediate and rapid assessments) have been developed with the idea of being reliable and applicable with little assessor training (Kemper 1999; McQuaid and Norfleet 1999).

## 1.9 THE IMPORTANCE OF WATER QUALITY IN DETERMINING RIVER HEALTH

According to Tharme *et al.* (1997), water quality is a term used to describe the combined effect of physical attributes and chemical constituents of water. It is dependent on numerous factors altering the chemical composition of the water body, normally through activities within the catchment.

The chemical composition of water in a river system is one of the main factors determining the characteristics of the system (Tharme *et al.* 1997). Each river has its own intrinsic chemical composition, which, to a certain extent, is dependent upon its geographic location (Day *et al.* 1994; McCartan *et al.* 1998; Dallas 2000). Geographical differences arise because of differences in climate (temperature, mean annual precipitation, mean annual evaporation), in geomorphology (gradient, erosion) and in geology (Day and King 1995; Tharme *et al.* 1997; McCartan *et al.* 1998; Dallas 2000). Land use, however, may affect the water chemistry of a river as much or even more than its underlying rock composition (McCartan *et al.* 1998). Changes in the intrinsic chemical composition of river waters, will lead to changes in the water quality of the river and hence a change to the ecological status of the river (Dallas 1998).

The maintenance of certain water quality ranges is a precondition to the maintenance of almost all riverine biotic components (Dallas 1998). The South African Water Quality Guidelines for Aquatic Ecosystems specify Target Water Quality Ranges (TWQR) for water quality constituents (DWAF 1996). A TWQR can be defined as a range of concentrations within which no measurable adverse effects are expected on aquatic ecosystem health and should, assuming life-long exposure, ensure their protection (DWAF 1996). They have been designed as water management objectives to ensure aquatic ecosystem health (DWAF 1996; Tharme *et al.* 1997; Dallas 2000) and have been used in previous studies to determine whether the water quality of a river is degraded (Tharme *et al.* 1997; Dallas 2000).

When determining the water chemistry of a river, it is primarily the system variables (temperature and dissolved oxygen), non-toxic inorganics (pH, conductivity, total dissolved salts, turbidity and total suspended salts) and nutrients (nitrite, nitrate, ammonium and soluble reactive phosphorous) that are measured (Hall *et al.* 1996; Tharme *et al.* 1997; Dallas 2000). Toxic constituents (e.g. heavy metals, biocides) are potentially lethal to many aquatic organisms but they are difficult and expensive to measure and are therefore seldom used (Tharme *et al.* 1997; Dallas 2000).

## 1.10 THE IMPORTANCE OF LAND USE MANAGEMENT FOR RIVER HEALTH

The surrounding land use of a catchment affects the habitats available in, and the water quality of, a river (Nash 1993; Hall *et al.* 1996; Roth *et al.* 1996; Allan *et al.* 1997; Townsend and Riley 1999; Lyons *et al.* 2000) and this relationship has become of interest world-wide (Calder 1999). Human alteration of the landscape affects riverine ecosystems via multiple processes operating at different spatial scales (Allan *et al.* 1997; Lyons *et al.* 2000). For example, instream habitat structure and organic matter inputs are determined by local conditions at a site, whereas nutrient supply, sediment delivery, hydrology and channel characteristics are influenced by regional conditions (like landscape features and land use / cover) at a distance upstream and lateral to the site (Allan *et al.* 1997).

Agriculture is traditionally associated with water quality problems (e.g. sedimentation and eutrophication) (Nash 1993). Conversion from natural vegetation to agricultural lands results in changes in the physical nature of the channel, the pattern of the discharge, the bed disturbance regime, the chemistry of stream water, temperature and light regimes and in the input of organic matter (Roth *et al.* 1996; Townsend and Riley 1999). Agricultural activities, like overgrazing, result in vegetation cover loss, soil compaction, bank destabilisation and subsequent increased runoff and erosion (Allan *et al.* 1997; Townsend and Riley 1999; Lyons *et al.* 2000; Evans 2002). Erosion removes undercut banks and overhanging vegetation and the resulting excess sedimentation fills pools, alters channel shapes, fills crevices under rocks and woody debris and increases turbidity thereby limiting macrophyte growth (Braden and Lovejoy 1990; Hall *et al.* 1996; Lyons *et al.* 2000). Consequently important food production, shelter and reproductive areas for aquatic organisms like fish and macroinvertebrates are eliminated (Lyons *et al.* 2000). Sedimentation and, therefore, instream habitat removal at a site, is also strongly influenced by erosion occurring upstream (Brown *et al.* 1997; Lyons *et al.* 2000). Increased logging in river catchments has resulted in increased erosion and sedimentation which has in turn increased the turbidity of river waters whilst decreasing the concentration of dissolved oxygen, necessary to support aquatic life (Nash 1993). Extensive plantations of *Eucalyptus* spp. and *Pinus* spp. have been shown to substantially decrease the water yield of catchments (Nash 1993). Urbanisation with its consequent development in floodplain areas, encroachment of residential areas into the river corridor, physical alterations of the river course, wetland removal and drainage, the planting of exotic vegetation and removal of indigenous vegetation in the riparian zone, has lead to floodplain reclamation (Tharme *et al.* 1997). Although, riparian buffer strips have been seen to improve damaged streams, the removal of riparian land from farming results in economic costs to the farmers (Lyons *et al.* 2000).

Cropland and urban areas are potentially the greatest sources of river pollutants, with high rates of runoff, especially after storms (Simpson 1991; Allan *et al.* 1997; McQuaid and Norfleet 1999). Urban areas are a source of effluent from industry and stormwaters (Tharme *et al.* 1997), whilst the increase in nitrate concentration in rivers passing through agricultural areas (Hall *et al.* 1996; Townsend and Riley 1999), can be attributed to either the high use of fertilisers, the high concentrations of manure or to increased soil loss in these areas (Braden and Lovejoy 1990; Simpson 1991; Hall *et al.* 1996). Higher phosphorous concentrations have also been recorded in rivers passing through pastures (Simpson 1991; Townsend and Riley 1999). Braden and Lovejoy (1990) explain that such nutrient enrichment of river waters stimulates rapid plant growth of micro- and macrophytes which alter the aquatic habitat available. The consequent algal blooms and decomposing organic matter in eutrophic water bodies change the water's colour, taste and smell. Contamination of river waters from toxic chemicals like herbicides and insecticides used on agricultural lands also occurs. It has been shown, however, that conservation tillage, natural vegetation and riparian buffer strips reduce erosion and increase the residue levels in soils, thereby decreasing the impacts from fertilisation and pesticides on rivers (Hall *et al.* 1996; Tharme *et al.* 1997; McQuaid and Norfleet 1999; Lyons *et al.* 2000).

Management of the surrounding land use is, therefore, necessary for the maintenance of good ecological conditions in rivers. To determine management strategies for river catchments, the relationship between land use types and the health of these rivers needs to be studied. (Allan *et al.* 1997). Once riverine areas of poor ecological health are identified, new management strategies for the land uses surrounding these areas can then be determined. This needs to be a cyclical, continuous process of rapid assessment leading to a management plan then later reassessment followed by revision of the management plan (Roux *et al.* 1999).

## 1.11 STUDY LOCATION

The broad study area is the south-western Cape, South Africa. The south–western Cape is found in the Fynbos Biome (Figure 1.1), in the Cape Floral Kingdom (Figures 1.2 and 1.3), which is the sixth and smallest (covering an area of less than 90 000 $km^2$) floral kingdom of the world (Cowling and Richardson 1995). Fynbos is the dominant vegetation type of the Cape Floral Kingdom (Figure 1.3) contributing more than 80% of its species (Cowling and Richardson 1995). The Fynbos Biome is defined by a mediterranean climate with moderate to high amounts of winter rainfall and summer drought (Acocks 1988; Cowling and Richardson 1995; Low and Rebelo 1996). According to Cowling and Richardson (1995) the Fynbos Biome vegetation is characterised by a dominance of low to medium height shrubs. Of the three vegetation types, namely fynbos, renosterveld and subtropical thicket constituting the Fynbos Biome, fynbos is the most widespread. Fynbos is a fire-adapted vegetation type, with fire being a keystone factor in its long-term survival and an integral part of its biology. Low and Rebelo (1996) define fynbos as being characterised by the presence of three elements, namely a restiod component (belonging to the Restionaceae or Cape Reed Family), an ericoid or heath component and a proteoid component (forming the dominant overstorey in Fynbos). They also state that fynbos is characterised by the presence of seven endemic or near-endemic plant families, namely Bruniaceae, Geissolomaceae, Grubbiaceae, Penaeaceae, Retziaceae, Roridulaceae and Stilbaceae.

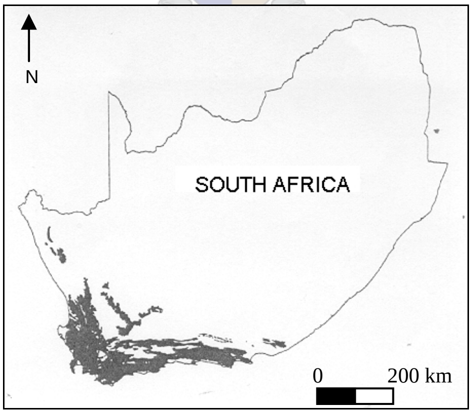


**Figure 1.1.** The location of the Fynbos Biome (shaded) within South Africa (from Low and Rebelo 1996)

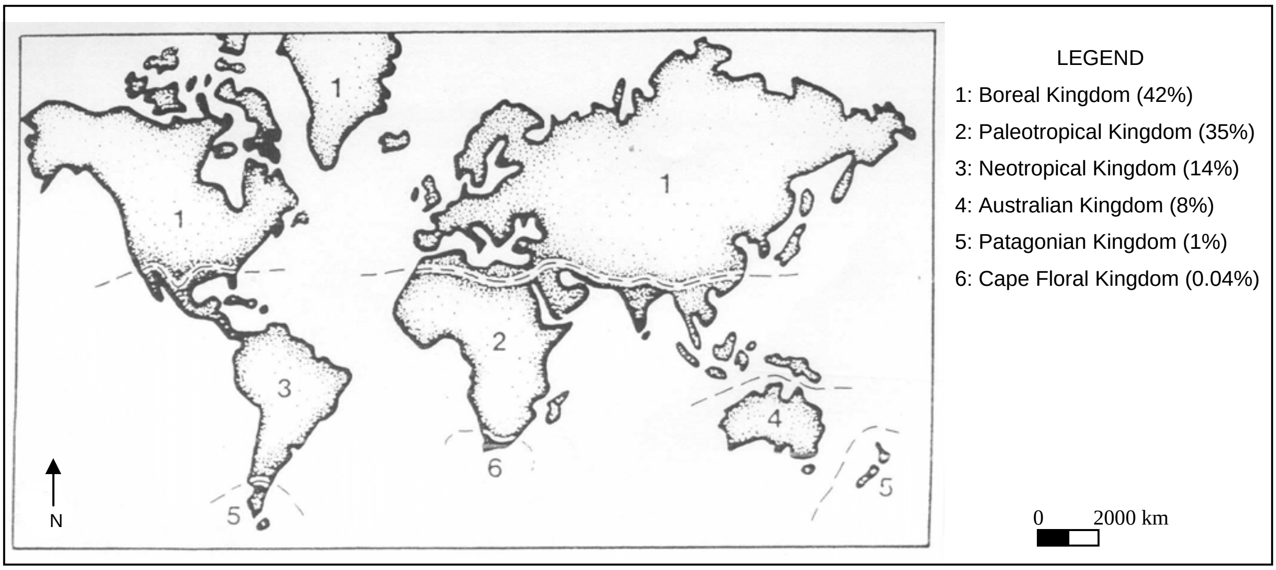


**Figure 1.2.** Botanical Kingdoms of the world. The key in the top right-hand corner gives names of, and percentage of the earth's surface covered by each of the plant kingdoms (from Gale 1992)

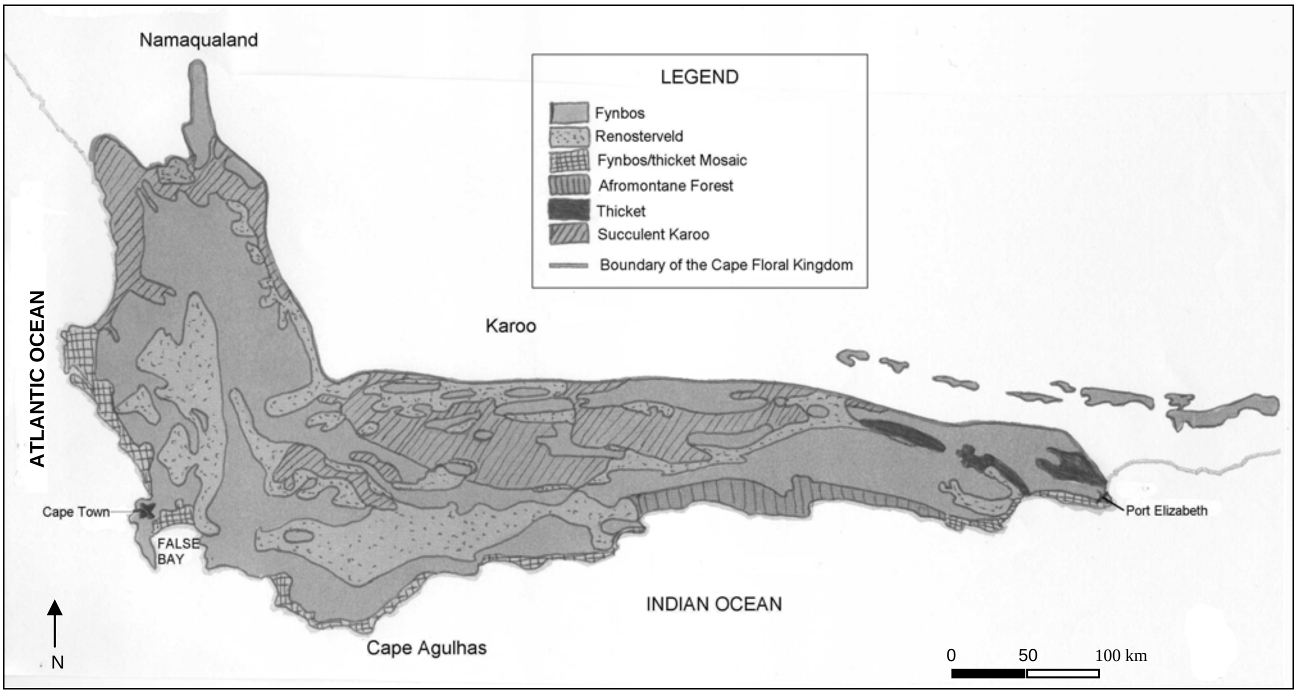


**Figure 1.3.** The Cape Floral Kingdom (from Cowling and Richardson 1995)

Fynbos grows on soils deficient in all the nutrients essential for plant growth (Acocks 1988; Cowling and Richardson 1995). Specifically, levels of nitrogen and phosphorous are present in a fraction of the amount needed to sustain agricultural crops (Cowling and Richardson 1995).

Cowling and Richardson (1995) explain that the fynbos soils are infertile mainly because the quartzites and hard sandstones of the Table Mountain Group and Witteberg Groups, from which they are derived, are nutrient poor. Most mountain soils in the Fynbos Biome are naturally acidic and in high rainfall areas nutrients are leached from the soils, whereas the Bokkeveld Group shales occurring in the lowland plateaux and valley bottoms yield more fertile soils.

Three rivers in the Fynbos Biome were chosen for this study. They are the Lourens, the Hout Bay and the Palmiet Rivers (Figure 1.4). These rivers were chosen for the following reasons:

i. All three rivers start in nature reserves and pass through urban areas in their middle reaches. Nevertheless, the impacts effecting the rivers and the land use surrounding the rivers are differently composed along each river.
ii. They are all of regional importance, either for conservation purposes, for water use or because they are under threat from urban development.
iii. The Lourens River was one of the first in the country to be given a Protected Natural Environment status (Western Cape Provincial Government 1997).
iv. There are already established monitoring sites along these rivers and data is thus available.
v. Each has a diverse fish population, with several different species known to occur along the river lengths.
vi. Due to points i-v above, the Western Cape RHP provisional implementation team (championed by A. Belcher[1]) identified these rivers for evaluation.



### 1.11.1 The Hout Bay River

The Hout Bay River, shown in Figure 1.6, rises above an altitude of 700 m on the western slopes of Table Mountain, runs off the Back Table, down Orange Kloof and through the Hout Bay Valley and Hout Bay village (Brown *et al.* 1997) to drain a catchment area of 33.8 km$^2$ (Grindley 1988; BOLA&EP *et al.* 1996). Being acidic, short, steep and fast flowing, this river is typical of rivers in the Fynbos Biome (Grindley 1988).

The upper reaches of the river are known as the Disa Stream, which cuts deeply into the Disa Gorge upstream of Orange Kloof (Figure 1.5) (Brown *et al.* 1997). The Original Disa Stream flows down from Klaasenkop, above the De Villiers Reservoir, and joins the Disa Stream in Orange Kloof Nature Reserve to form the perennial Hout Bay River (Brown *et al.* 1997; Grindley 1988). The Disa Stream and Hout Bay River together are, however, generally referred to as the Hout Bay River (Figure 1.5). It is approximately 12 km long from source to sea (Grindley 1988).

[1] Department of Water Affairs and Forestry, P/Bag X16, Sanlamhof, 7532, South Africa

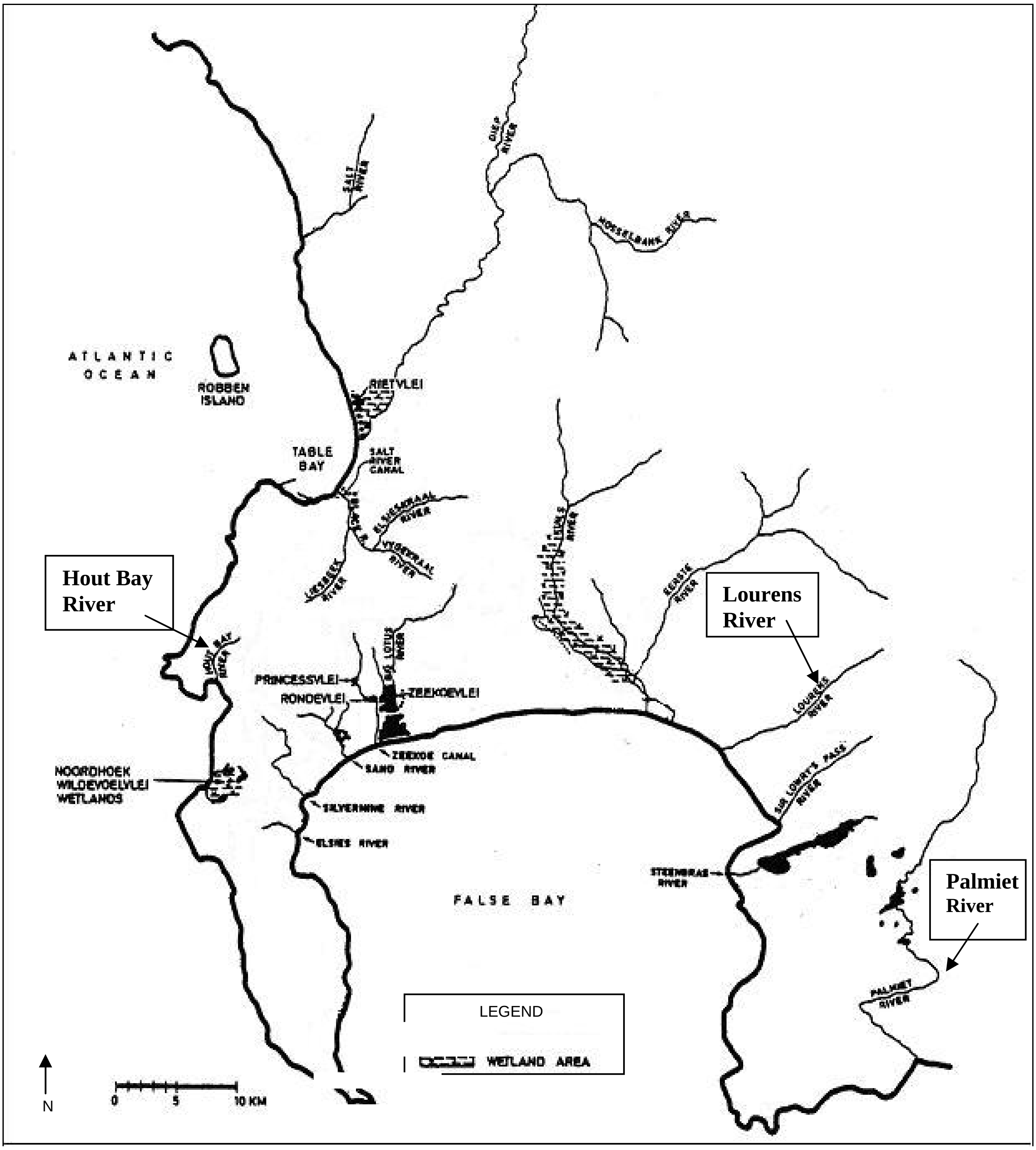


**Figure 1.4.** Location of the three rivers studied (Adapted from Cape Town City Council 1994)

Five dams, with a total capacity of 2.375 million $m^3$ (Grindley 1988), have been constructed on the Back Table of Table Mountain, which impound and divert the headwaters of the Disa and Original Disa Streams feeding the Hout Bay River (BOLA&EP *et al.* 1996). The Hely-Hutchinson Dam, shown in Figure 1.5, feeds into the Woodhead Dam, whilst the Victoria and Alexandra Dams feed into the De Villiers Dam (Grindley 1988). Water from these dams is led via a tunnel through the Twelve Apostles to Kloof Nek (BOLA&EP *et al.* 1996). The City of Cape Town has rights to this water dating back to an Act of Parliament passed in 1887 (BOLA&EP *et al.* 1996). According to

Grindley (1998) the catchment area above the impoundments represents about 7.5% of the total catchment of the Hout Bay River. The volume of water withdrawn from the dams fluctuates through the year depending on rainfall and demand.

From the restricted area of Orange Kloof Nature Reserve in the Cape Peninsula National Park (Figure 1.5), the Hout Bay River passes through residential developments of the upper Hout Bay Valley (Brown *et al*. 1997). Then, in its middle reaches, as the valley opens out and the profile becomes less steep, the river flows through areas characterised by low density homesteads in a rural setting with large gardens and horse paddocks (BOLA&EP *et al.* 1996; Brown *et al.* 1997). After passing through its lower reach, becoming flat with a broad flood plain, the river flows into a short tidal estuary and through its mouth (at 34$^{o}$02'S, 18 $^{o}$21'E) into the sea on Hout Bay Beach (Grindley 1988; Brown *et al.* 1997).

1.11.1.(i) <u>Rainfall and Runoff</u>

The amount of annual rainfall received in the Hout Bay River catchment increases with altitude from about 880 mm at the coast to 1 620 mm in the upper catchment (BOLA&EP *et al.* 1996), with an average annual precipitation of 923 mm (WRC 1994). Mist adds considerably to the total precipitation in the mountainous areas (Grindley 1988). Mean Annual Runoff of the Hout Bay River is 10.4 million $m^3$ (Belcher *pers. comm.* 2003).

1.11.1.(ii) <u>Geology</u>

According to Grindley (1988), the Hout Bay River catchment is comprised of Table Mountain Group sandstone overlying granite, with a narrow band of shale at approximately 200 m. The granite base is responsible for the lower valley having gentler slopes (Grindley 1988).

1.11.1.(iii) <u>Vegetation</u>

The upper catchment slopes are covered with Mountain Fynbos (Campbell 1985; Grindley 1988; BOLA&EP *et al.* 1996; Low and Rebelo 1996). In earlier times the riparian vegetation, besides the *Prionium serratum* marshes, would have included riverine forest species, examples of which can be seen in Orange Kloof Nature Reserve today (BOLA&EP *et al.* 1996). Except for a few individual specimens, the forest and *P. serratum* have been replaced with alien vegetation, much of which is invasive (Grindley 1988; BOLA&EP *et al.* 1996). Examples of alien species include *Acacia longifolia, A. mearnsii, A. melanoxylon, A. saligna, Echinochloa crus-galli, Eucalyptus* spp.,

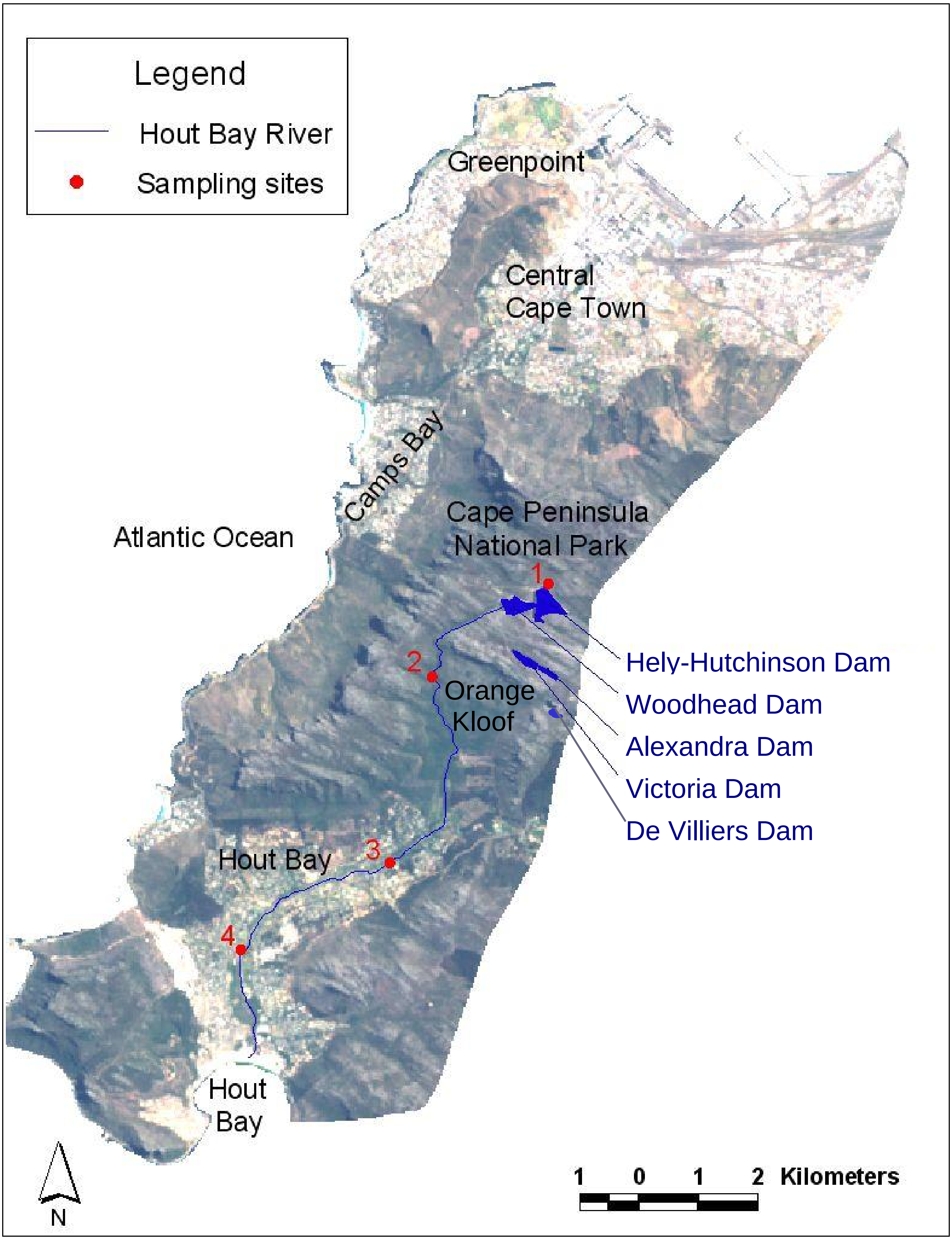


**Figure 1.5.** The Hout Bay River with its quaternary catchment

*Lantana camara, Paraserianthes lophantha, P. clandestinum* and *Sesbania punicea* (BOLA&EP *et al.* 1996; Withers *in prep.*). A detailed description of the riparian vegetation is presented by Withers (*in prep.*).

1.11.1.(iv) Land ownership

From discussions with Newman (*pers. comm.* 2002) it appears that the mountain catchment area, including Orange Kloof, is a protected area falling within the Cape Peninsula National Park. This area is managed primarily for outdoor recreation and for the conservation of indigenous flora. The middle and lower reaches fall under the jurisdiction of the City of Cape Town, South Peninsula Administration. The land adjacent to the river in these reaches is a mixture of public open space and privately owned land (Cape Metropolitan Council 2002). In the early 1990's, a low income, high-density settlement at Imizamo Yetho developed in the middle catchment (BOLA&EP *et al.* 1996).

### 1.11.2 The Lourens River

The approximately 20 km long Lourens River drains a catchment area of 140 $km^2$ (Tharme *et al.* 1997) as it flows in a southwesterly direction towards the False Bay coast (Figures 1.4 and 1.6). Rising at an altitude above 1 000 m at its source in the Diepgat Ravine in the Hottentots Holland Mountains (Tharme *et al.* 1997, Dabrowski 2001), the Lourens River flows through the Hottentots Holland Nature Reserve before entering the forestry and agricultural areas of Lourensford and Vergelegen Estates (Figure 1.6). In its upper reaches the Lourens River is joined by a number of minor tributaries (Tharme *et al.* 1997). The river profile flattens out as its middle reaches flow through farmlands, peri-urban areas, municipal open space, small business areas, residential suburbs, the Somerset West town centre and a light industrial area below the N2 (Figure 1.6). The river then flows through a stretch of disturbed Coastal Renosterveld vegetation (Boucher 1997) before entering the Strand urban area with a sewage farm and a golf course along its right bank. After flowing into a small estuary, bordered by dunes covered with Remnant West Coast Strandveld, the Lourens River flows through its mouth into False Bay just west of the Strand (Figure 1.6).

1.11.2.(i) Rainfall and Runoff

The mean annual precipitation of the Lourens River catchment is 1 260 mm (WRC 1994; Tharme *et al.* 1997). The Virgin Mean Annual Runoff, calculated at 122 million $m^3$, has decreased due to abstraction from forestry, agriculture and urban use (Tharme *et al.* 1997) to 25.3 million $m^3$ today

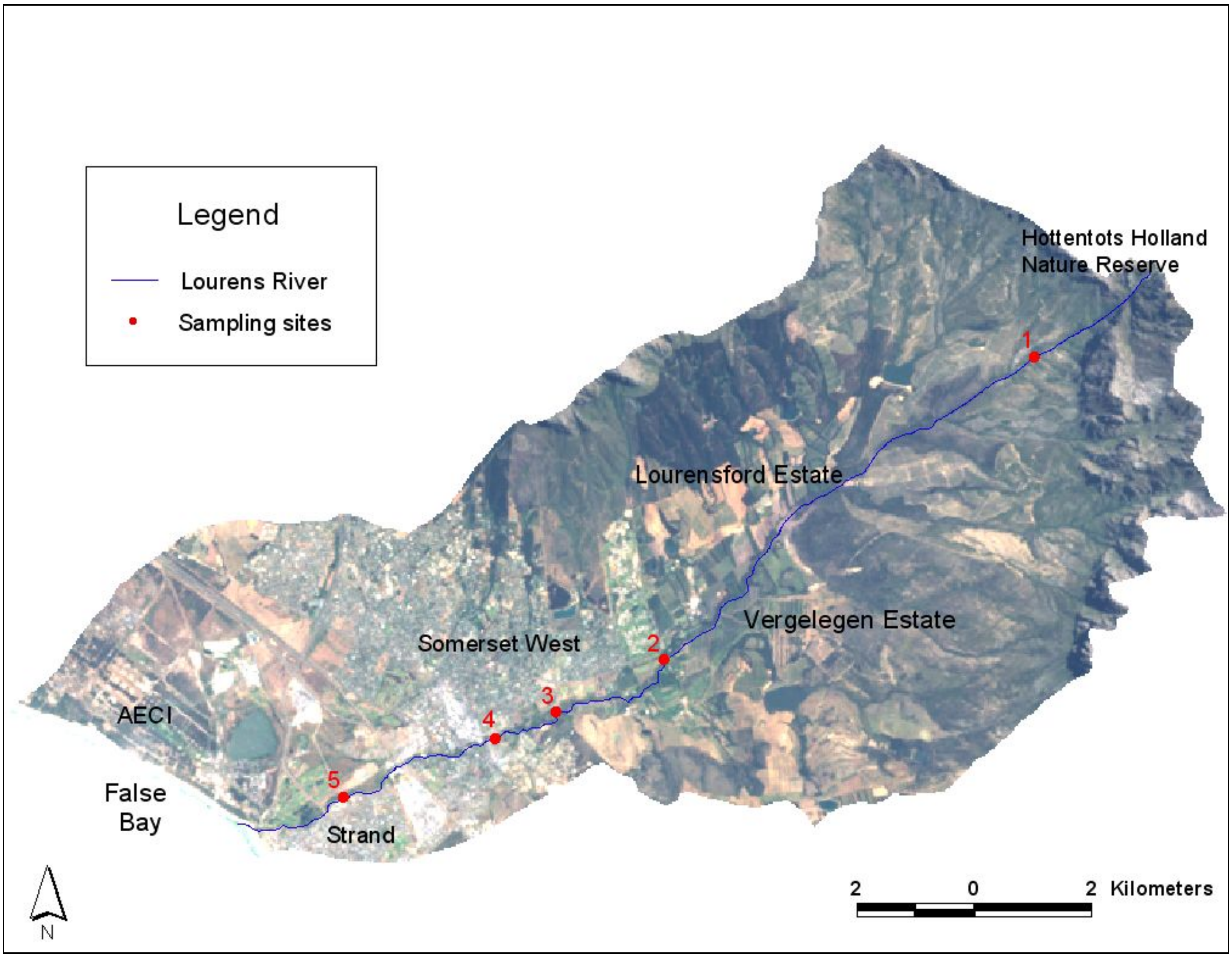


**Figure 1.6.** The Lourens River with its quaternary catchment

(Belcher *pers. comm.* 2003). Approximately 13% of the mean annual runoff occurs in summer with 87% occurring in winter (Tharme *et al.* 1997).

1.11.2.(ii) Geology

According to the map produced by Moolman (2002), the catchment geology consists of three major zones. Firstly, the headwaters of the Lourens River cut primarily through Table Mountain Group sandstones, the dominant component of the Cape Fold Belt mountains, which include the Hottentots Holland Mountains (Tharme *et al.* 1997). In its Mountain Stream reaches, the river passes through the biotite granites of the second geological zone, consisting of Cape Granite. The middle and lower reaches of the river then move over shales of the Malmesbury Group, the third geological zone. Near the estuary, the soils are mainly aeolian in origin, consisting mostly of marine-derived sand (Tharme *et al.* 1997).

1.11.2.(iii) Vegetation

In the upper catchment mountainous areas, the natural vegetation is classified as Mountain Fynbos (Campbell 1985; Low and Rebelo 1996). As can be seen from Figure 1.5, downstream of the Hottentots Holland Nature Reserve, this natural vegetation has been largely replaced by forestry (*Pinus pinaster* and *Eucalyptus* spp. plantations) and perennial agriculture (apples, pears, plums, lemons, grapes) (Tharme *et al.* 1997). In the lowland areas extensive vineyard and urban development has resulted in very little of the natural Coastal Renosterveld remaining (Tharme *et al.* 1997). Along the entire course of the Lourens River there has been, and still continues to be, considerable indigenous vegetation removal, resulting in the remaining riparian vegetation consisting of numerous alien species (e.g. *A. longifolia, A. mearnsii, A. melanoxylon, A. saligna, Cinnamomum camphora, Pennisetum clandestinum* and *Salix babylonica*) interspersed with indigenous riparian species (Tharme *et al.* 1997; Withers *in prep.*). A complete assessment of the riparian vegetation can be found in Boucher (1997) and Withers (*in prep.*).

1.11.2.(iv) Land ownership

The Lourens River falls under the jurisdiction of the City of Cape Town, Helderberg Administration (Wright *pers. comm.* 2002). The Hottentots Holland Nature Reserve, surrounding the upper catchment, is managed by the Western Cape Nature Conservation Board to preserve its natural resources and for recreation (Alberts *pers. comm.* 2003), whilst the remainder of the land is privately owned agricultural land. Within the municipal area of Somerset West, the majority of riparian land is privately owned, whilst in Strand it is mostly designated public open space (Tharme *et al.* 1997; Cape Metropolitan Council 2002). African Explosive and Chemical Industry (AECI) owns land along the lower river and estuary, including the Dick Dent Bird Sanctuary incorporating the old maturation ponds of the Strand Sewage Works (Tharme *et al*. 1997).

### 1.11.3 The Palmiet River

Rising at an altitude above 1 000 m in the vicinity of Landdroskop in the Hottentots Holland Mountains, the approximately 70 km long Palmiet River, shown in Figure 1.7, drains a catchment of 500 $km^2$ (Gale 1992; Day 1998). The river is fed by eleven perennial tributaries, all with catchments greater than 4.5 $km^2$, as well as by numerous smaller seasonal streams (Gale 1992; Day 1998). According to Gale (1992) and Day (1998), the Palmiet River falls rapidly over the first few kilometres and initially flows in an easterly direction through fynbos vegetation and pine plantations. Then, after about four kilometres, the river flows southwards into the Elgin Valley, where it is impounded by the Nuweberg and Eikenhof dams. After passing through the town of Grabouw, it flows through plantations, orchards and other agricultural land before being impounded by a further three large in-channel dams, namely the Kogelberg, Appelthwaite and Arieskraal Dams. Downstream of Arieskraal Dam, the river is joined by the Klein Palmiet River, after which it swings north-east for six kilometres before heading south again and exiting the Elgin Valley. A large number of smaller in- and off-channel farm dams exist in these upper to middle reaches of the Palmiet catchment. Upstream of the Kogelberg Nature Reserve, the Palmiet River and its tributaries, especially the Huis and Krom Rivers, are subjected to extensive impoundment primarily for irrigation water. In some areas water is also abstracted directly from the rivers themselves and numerous boreholes abstract water from groundwater stores. Water pumped from the Kogelberg Dam to the Rockview Dam is also used to generate electricity as part of the Palmiet Pump Storage Scheme. Both the towns of Grabouw, upstream of, and Kleinmond, downstream of the Kogelberg Nature Reserve, utilise water from the Palmiet River.

On entering the Kogelberg Nature Reserve, the Palmiet River flows south-west passing through a deep steep-sided valley between the Dwarsrivierberg and Perdeberg mountain ranges (Gale 1992; Day 1998). Downstream of its confluence here with the near-pristine Dwars and Louws Rivers, the Palmiet River turns south-east and flows towards the Atlantic Ocean (Figure 1.7). In its lower reaches the Palmiet River flows across a narrow coastal plain and enters its small estuary just west of the town of Kleinmond (Gale 1992; Day 1998).

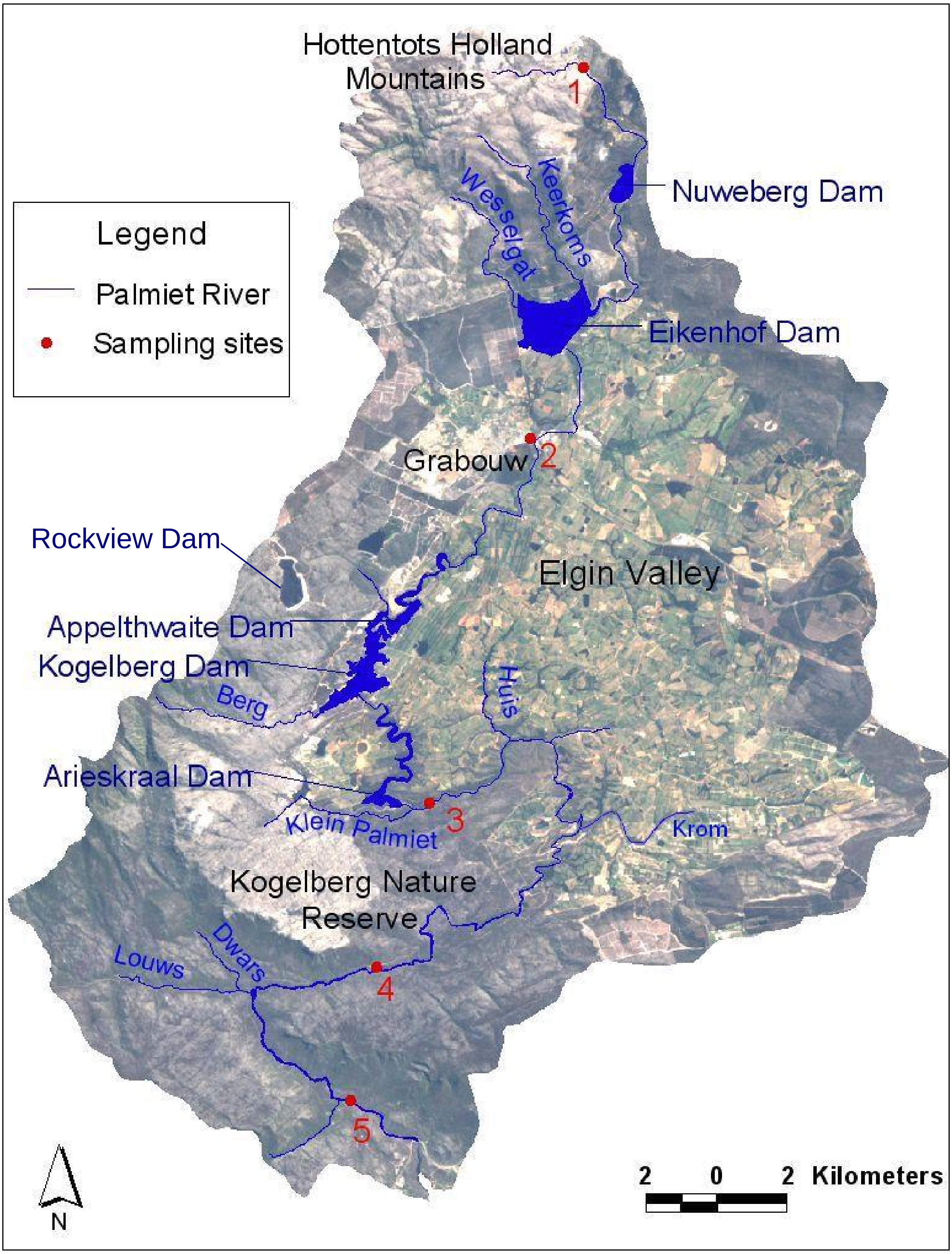


**Figure 1.7.** The Palmiet River with its quaternary catchment

1.11.3.(i) Rainfall and Runoff

Orographic rainfall occurs in the Palmiet River catchment, with the mountainous regions receiving more rain than the valleys (Gale 1992; Day 1998). Rainfall varies from 700 mm annum$^{-1}$ in the low-lying central, eastern and coastal region to around 1 500 mm a$^{-1}$ in the higher lying inland areas (Gale 1992). The mean annual rainfall for the entire catchment is 1 176 mm a$^{-1}$ (WRC 1994). The total MAR from the catchment is approximately 253 x 10$^{6}$ m$^{3}$a$^{-1}$ (Belcher *pers. comm.* 2003). Runoff varies considerably on both monthly and annual time scales, with generally little flow in summer and high flows during the period June to September (Gale 1992).

1.11.3.(ii) Geology

Gale (1992) and Day (1998) show that the Palmiet River is typical of geomorphically 'young' rivers of the Cape. Rocks of the Table Mountain Group (TMG) dominate the geology of the upper and lower catchment areas. Their resistance to erosion has resulted in the formation of high TMG-dominated mountain ridges. TMG soils are typically low in nutrients and highly leached. These acidic, low nutrient soils support fynbos vegetation. The more erodible shales and sandstones of the Bokkeveld Group occur in the middle catchment. These rocks release higher concentrations of nutrients and salts than the TMG rocks and consequently, the soils derived from the shales are used primarily for agriculture.



1.11.3.(iii) Vegetation

The upper areas of the Palmiet River catchment, within the Hottentots Holland Nature Reserve, are covered with near-pristine Mountain Fynbos vegetation (Campbell 1985), although the riparian vegetation is invaded with alien species like *A. melanoxylon* (Day 1998). Downstream natural vegetation gives way to forestry (*P. pinaster)* plantations and agricultural areas (Day 1998). Fruit farming is the main agricultural activity in the area (Day 1998), with apples being the main crop and other deciduous fruits like pears and peaches also being grown (Gale 1992). The lower part of the catchment lies within the Kogelberg Nature Reserve, an area of relatively undisturbed fynbos vegetation (Boucher 1978; Day 1998). A detailed description of the riparian vegetation is presented by Withers (*in prep.*).

1.11.3.(iv) Land ownership

From discussions with Johns (*pers. comm.* 2002) it appears that the Hottentots Holland Nature Reserve is state owned and managed by the Western Cape Nature Conservation Board, whilst the agricultural lands within the catchment are mainly privately owned. The urban area of Grabouw falls under the jurisdiction of the Theewaterskloof Municipality and the Kogelberg Nature Reserve is managed by the Western Cape Nature Conservation Board as a mountain catchment area.

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# THE GEOMORPHOLOGICAL ZONATION OF SELECTED SOUTH-WESTERN CAPE RIVERS FOR THE RIVER HEALTH PROGRAMME

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## ABSTRACT

The South African National River Health Programme (RHP) determines the ecological health of broad river zones by assessing representative sites in each zone The desktop geomorphological classification system for river zonation used in RHP assessments, has not been sufficiently previously tested on the short rivers draining the Western Cape Sandstone Mountains. Forming part of a river health assessment of three south-western Cape Rivers, this study provides further data necessary to substantiate and refine the method. Although the method worked well for the longer Palmiet River, the Hout Bay River Upper Foothill Zone and the Hout Bay and Lourens Rivers Lowland River Zones had steeper gradients than expected. This is probably due to the Lourens and Hout Bay Rivers being far shorter and, consequently, steeper than any on which the method was previously tested. Given the results, it appears that the notion of one river gradient classification system being applicable throughout South Africa, with its diverse geology and climate, is unlikely. Rather a system modifying river types for various physiographic and hydrological features or regions, or according to a factor based on river length, is more realistic. The sites chosen for the 2002 south-western Cape river health assessment are also discussed.

***Key words:*** *River Health Programme, geomorphological classification, river zones*

## GLOSSARY

The following definitions are according to Dallas (2000) and Stellenbosch University (2002).

| | |
|---|---|
| Confined valley floor | Channel laterally confined by valley side walls |
| Moderately-confined valley floor | Channel course determined by macro-scale features, but some lateral migration is possible. |
| Non-confined valley floor | Channel free to migrate laterally over the valley floor (associated with a floodplain). |
| Compound Channel | Macro-channel present. |
| Simple Channel | No macro-channel present. |
| Macro-channel width | The outer channel of a compound channel. The bank top is well above "normal" flood levels but may be inundated infrequently (e.g. once in 20 years). The flood bench between the active and macro-channel bank is usually vegetated. Macro-channel banks may or may not be vegetated. |
| Active channel width | The area of the channel(s) that has been inundated at sufficiently regular intervals to maintain channel form and to keep the channel free of established terrestrial vegetation. |
| Multiple thread channel: anastomising / anabranching | Multi-thread channel separated by vegetated or otherwise stable alluvial islands or bedrock. |

**Morphological Units**

<u>Bedrock</u>

| | |
|---|---|
| Plunge pool | Erosional feature below a waterfall. |
| Waterfall | Abrupt continuity 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. |

<u>Alluvial</u>

| | |
|---|---|
| Riffle | A transverse bar formed of gravel or cobble, commonly separating pools upstream and downstream. |
| Rapid | Steep transverse bar formed from boulders. |

**Reach Classifications**

<u>Alluvial Channels</u>

| | |
|---|---|
| Step-pool | Characterised by large clasts (boulders or cobbles) organised into discrete channel spanning accumulations that form a series of steps separating pools containing finer material. |
| Plane-bed | Topographically uniform bed formed in coarse alluvium (cobble or small boulder) lacking well defined scour or depositional features. |
| Pool-riffle | Characterised by an undulating bed that defines a sequence of bars of cobbles or gravel (riffles) and pools. |

<u>Bedrock Channels</u>

| | |
|---|---|
| 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 pools backed up behind channel spanning bedrock intrusions forming rapids. |

**Hydraulic biotopes**

| | |
|---|---|
| Back water | A morphologically defined area alongside but physically separated from the channel; connected to it at its downstream end. Occurs over any substrate. Barely perceptible flow to no flow. |
| Pool | Has direct hydraulic contact with upstream and downstream water. Occurs over any substrate. Barely perceptible flow. |
| Glide | Occurs over any substrate as long as the depth is sufficient to minimise relative roughness. Exhibits uniform flow with no significant convergence or divergence. Smooth boundary turbulent flow; clearly perceptible flow without surface disturbance. |
| Chute | Typically occurs 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 | Occurs over any substrate apart from silt. Relative roughness low. They occur in the transition zone between riffles and the downstream pool. Rippled flow. |
| Riffle | Occurs over coarse alluvial substrates from gravel to cobble. Relative bed roughness is high. Undular standing waves or breaking standing waves. |

| | |
|---|---|
| Rapid | Occurs over a fixed substrate such as a 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, contact with the substrate largely maintained. |
| Waterfall | Associated with bedrock steps; cliff like features or large channel spanning boulders. Face near vertical or overhanging. Free-falling flow, generally separated from substrate. |

**Flow types**

| | |
|---|---|
| Barely perceptible flow | Smooth surface; flow only perceptible through the movement of floating objects. |
| Smooth boundary turbulent flow | 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. |
| Free-falling | Water falls vertically without obstruction. |
| Broken standing waves | Standing waves present, which break at the crest (white water). |
| Undular standing waves | Standing waves form at the surface but there is no broken water. |
| Chute | Water forced between two rocks, usually large cobble or boulders, flowing fast; too low for the water to be considered free-falling. |
| Cascade | Water tumbling down in a step-like series; fast flow; covering substrate in a sheet. May be a mosaic of smooth and broken water. |

**Substrate particles**

| Category | Size range (mm) |
|---|---|
| Silt | <0.06 |
| Sand | 0.06-2 |
| Gravel | 2-16 |
| Pebble | 16-64 |
| Cobble | 64-250 |
| Boulder | >250 |
| Bedrock | slabs of rock |

## 2.1 INTRODUCTION

### 2.1.1 The need for river zonation in the River Health Programme

Classification helps to organise and thereby understand complex and variable data, systems and ideas so that one can work with them more easily (O’Keeffe *et al.* 1994). Rivers are such systems and have been a frequent subject for classification by practitioners from a wide range of disciplines (Wadeson and Rowntree 1994). River classification enables one to answer many questions relating, for example, to the natural pre-disturbance characteristics of rivers, to understand river behaviour, or to assess river degradation by comparing an undisturbed river and a similar, yet disturbed one (O’Keeffe *et al.* 1994; Wadeson and Rowntree 1994).

The National River Health Programme (RHP), initiated in South Africa in 1994, is designed to monitor the ecological state of rivers, to ensure that they continue with their vital functions for present and future generations (WRC 2001, 2002; RHP 2003, *in prep.*). The RHP determines the health of broad longitudinal river zones by assessing selected representative study sites in each zone (Rowntree *et al.* 2000). The RHP, therefore, requires the longitudinal classification of rivers.

### 2.1.2 The difficulties of river classification

Rivers present two particular difficulties for classification. Firstly, they are longitudinal systems passing through a number of different landscapes and, therefore, their catchments cannot be described as one homogenous land-type (O’Keeffe *et al.* 1994). Secondly, rivers are not a loose group of isolated ecosystems. Rather, they are longitudinal functional units with conditions in the upper reaches successively influencing those in the lower reaches (O’Keeffe *et al.* 1994; Wadeson and Rowntree 1994; Davies and Day 1998). A further problem is that classification must, as far as possible, use data not reflecting anthropogenic modifications (O’Keeffe *et al.* 1994), and unfortunately, very few rivers today are not modified in some way (O’Keeffe *et al.* 1994; Davies and Day 1998; Rowntree *et al.* 2000). For this reason, independent physical data is used more often than biotic data in the classification of rivers (O’Keeffe *et al.* 1994).

### 2.1.3 Geomorphological river classification

It is the physical characteristics (hydrology and geomorphology) of rivers that determine the type and abundance of habitats available in a river, which in turn determine the types and abundances of species present, as well as the hydraulic conditions for any given flow discharge (O’Keeffe *et al.* 1994; Rowntree *et al.* 2000). Identifying and classifying river sections in terms of geomorphological criteria also allows for the full diversity of conditions along a river to be represented by selected study sites (Tharme *et al.* 1997; Rowntree *et al.* 2000). For these reasons geomorphological classification is used in the RHP (Rowntree *et al.* 2000).

Many geomorphological classifications have been suggested (e.g. Schumm 1977; Pickup 1984; Wadeson and Rowntree 1994; Rowntree and Wadeson 1999); the earliest, according to Rowntree *et al.* (2000), being that of Davis in 1890. However, the convenient desktop method developed for South African rivers by Rowntree *et al.* (2000), allows for the derivation of the spatial frameworks required by the RHP. This method, which assumes that channel gradient measured from a 1:50 000 topographical map is a good predictor of channel morphology, has been tested on three rivers, namely, the Sabie, Buffalo and Olifants Rivers. The 210 km Sabie River in Mpumalanga originates above 1 700 m in the highveld of the Great Escarpment, whilst the 125 km Buffalo River has its source above 1 300 m in the forested Amatola Mountains in the Eastern Cape and the 280 km Olifants River, its source above 700 m in the Cederberg Mountains of the Western Cape. These rivers each represent distinct geomorphological environments, different, as well, for example, to those experienced by the short, steep rivers flowing off the Table Mountain Group sandstones in the south-western Cape. It is, therefore, important that further data is collected from other South African rivers to substantiate and refine this river classification method.

### 2.1.4 Research aim

This paper forms part of a river health assessment conducted in 2002 on three south-western Cape rivers as part of the RHP (Chapter 1). The aims of this paper are firstly, to zone the three rivers using the geomorphological classification system of Rowntree *et al.* (2000) and to choose at least one representative site for river health assessment per zone; and secondly, to provide comment on the success of the method in zoning these rivers and on its ease of use and practicality.

### 2.1.5 Study area

Three rivers, namely the Hout Bay, Lourens and Palmiet Rivers were studied in the south-western Cape, in the Fynbos Biome, South Africa (Chapter 1).

## 2.2 METHODS

### 2.2.1 River Zonation

River zonation was conducted according to the method described by Rowntree *et al*. (2000). Digital stream network renditions of the Hout Bay, Lourens and Palmiet Rivers were obtained from a

1:50 000 digital topographic map of the Western Cape, South Africa (Directorate of Surveys and Mapping 2000). River segments between each contour interval were spatially derived in the ArcView Geographical Information System (GIS) programme (ESRI 2003) using a GIS script written by Soutar (2002). The data was then manipulated in the Microsoft Excel spreadsheet programme to create longitudinal profiles of each river. The profiles, together with their corresponding data, were analysed along their lengths for natural points of inflection, as these points of inflection indicate break points between different geomorphological zones (Rowntree *et al.* 2000; Wadeson *pers. comm*. 2002). Where appropriate, short reaches of a steeper or gentler gradient were included in a longer zone, so as to reflect the main inflections and natural breaks in the longitudinal profile. The general gradients of these zones were then calculated in Microsoft Excel and used to place the zones into the geomorphological zonation categories described in Table 2.1. Gradient is defined as the ratio of change in height (meters) to distance travelled (meters) (Rowntree *et al.* 2000).

River health assessments should occur at sites which are accessible; in other words situated close to access roads (Eekhout, Brown and King 1996). Due to the difficulty in accessing the Mountain Head Water Stream Zone in the three rivers assessed, the Mountain Head Water Stream and Mountain Stream Zones, defined in Table 2.1, were grouped together into a Mountain Stream Zone.

Field verification of the results was undertaken by the assessor during field assessments of the sites chosen to represent each zone in the river health assessment. The results were also compared to and modified, where considered appropriate, according to previous zonations (performed using different zonation methods) of the same rivers (Tharme *et al.* 1997; Day 1998 and GIS layers of the Lourens and Hout Bay Rivers from Southern Waters Ecological Research and Consulting cc.[2]) and from comments by Wadeson (*pers*. *comm*. 2003a, b, c).

### 2.2.2 Site selection for river health assessment sampling

The three rivers were initially surveyed, by vehicle, by the four-man team conducting the simultaneous river health assessments (Chapter 1). At least one monitoring site considered representative (in terms of the stream condition and impacts) of each zone was chosen. Sites chosen also needed to be easily accessible (Eekhout *et al.* 1996) and appropriate for use by all the four River Health Indices used in this river health assessment (Chapter 1; Hayes 2002; Ollis *in prep.*;

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Withers *in prep.*). Using Dallas (2000) as a manual, each site was described so as to ensure that a set of baseline conditions, against which future assessments can be compared, exists.

**Table 2.1.** Geomorphological zonation of river channels (taken from Rowntree *et al.* 2000)

| ZONE | GRADIENT CLASS | CHARACTERISTIC CHANNEL FEATURES |
|---|---|---|
| Source | Not specified | Low gradient, upland plateau / basin able to store water. Spongy or peaty hydromorphic soils. |
| Mountain Head Water Stream (MHWSZ) | >0.1 | Very steep gradient stream dominated by vertical flow over bedrock with waterfalls and plunge pools. Normally $1^{st}$ / $2^{nd}$ order streams. Reach types include bedrock fall and cascades. |
| Mountain Stream (MSZ) | 0.04-0.099 | Steep gradient stream dominated by bedrock and boulders, locally cobble / coarse gravels in pools. Reach types include cascades, bedrock fall, and step-pool. Approximate equal distribution of 'vertical' and 'horizontal' flow components. |
| Transitional (TZ) | 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 (UFZ) | 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 (LFZ) | 0.001-0.0049 | 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 (LRZ) | 0.00001-0.0009 | 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. |
| Rejuvenated Bedrock Fall / cascades (RBFZ) | >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 Foothill (RFZ) | 0.001-0.019 | Steepened section within the middle reaches of the river caused by uplift, often within or downstream of a 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 floodplain may be present between the active and macro-channel. |
| Upland Floodplain (UFPZ) | <0.005 | An upland low gradient channel often associated with uplifted plateau as occur beneath the Eastern Escarpment. |

## 2.3 RESULTS

### 2.3.1 Hout Bay River

The Hout Bay River was divided into the three geomorphological zones shown in Figure 2.1. Four sites considered to be representative of each respective zone were chosen for river health assessment. Detailed descriptions of these sites at the time the river health assessments were conducted are presented in Table 2.2. These descriptions provide baseline data from which to compare future biomonitoring and river health assessment results.

2.3.1.(i) Mountain Stream Zone

The top zone of the Hout Bay River has a gradient of 0.140 (Figure 2.1) and, therefore, according to Table 2.1, it should be categorised as a Mountain Head Water Stream Zone (MHWSZ). However, due to the MHWSZ and Mountain Stream Zone (MSZ) being grouped together into the MSZ in this study, this zone was classified as being a MSZ.

Sites 1 and 2 were chosen as representative sites of this zone (Figure 2.1).

Site 1 (Figure 2.2) is located above Hely-Hutchinson Dam (Figure 2.1). Surrounded by natural, relatively undisturbed Mountain Fynbos vegetation, this site was chosen to represent the upper near-pristine reaches of the MSZ above any impoundments.



Site 2 (Figure 2.3) was chosen to represent the lower reaches of the MSZ for three main reasons:

(1) Firstly, Site 2 is situated below the five in-channel dams, which impound the head waters of the Hout Bay River below Site 1, thereby impacting the lower reaches of the MSZ;

(2) secondly, Site 2 is situated in the restricted Orange Kloof Nature Reserve where it is surrounded by near-pristine natural vegetation; and

(3) thirdly, Site 2 is relatively easily accessible by the dirt access road through Orange Kloof.

Therefore, Site 2 was considered to be representative of the lower reaches of the MSZ, which are surrounded by natural conserved vegetation but impacted by upstream inundation.

The gradient of the reaches in which Sites 1 and 2 are found, are 0.255 and 0.144 respectively. Although the gradient of Site 1 is 1.77 times steeper than the MSZ's gradient of 0.140, both the gradients for Sites 1 and 2 can be classified as MSZ. Both Sites 1 and 2 thus appear to be representative of the MSZ of the Hout Bay River.

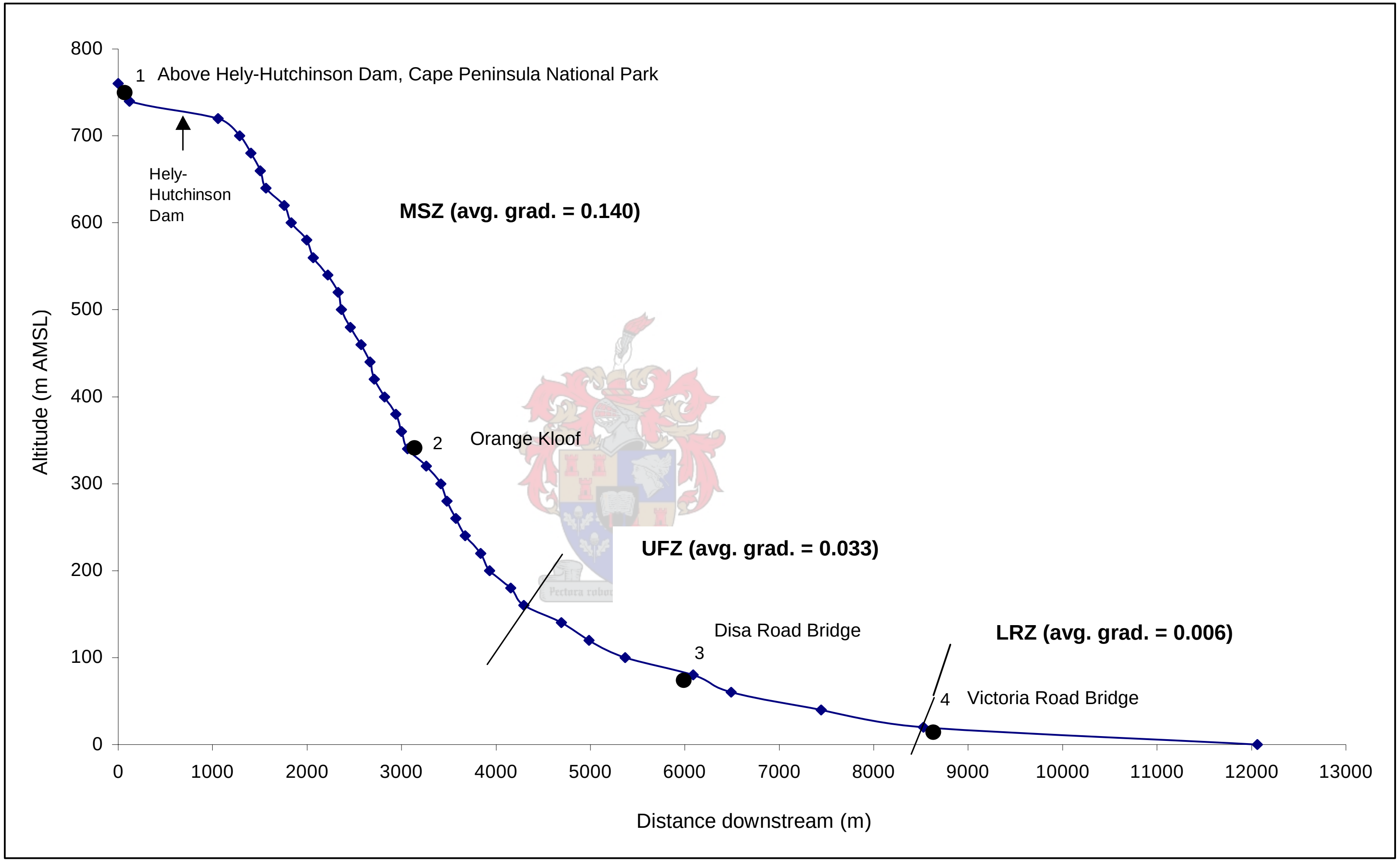


**Figure 2.1.** Hout Bay River Profile showing geomorphological zones (MSZ = Mountain Stream Zone, UFZ = Upper Foothill Zone, LRZ = Lowland River Zone), the average gradient (avg. grad) of each zone and sampling sites 1-4)

**Table 2.2.** Hout Bay site descriptions

| | Hout Bay River | | | |
|---|---|---|---|---|
| | Site 1 | Site 2 | Site 3 | Site 4 |
| Zone | MSZ | MSZ | UFZ | LRZ |
| | 40 m upstream of Hely-Hutchinson Dam, in small feeder stream | In Orange Kloof, 50 m upstream of road crossing. | 100 m upstream of Disa Road bridge | 100 m upstream of Victoria Road bridge |
| Co-ordinates | 33°58.449' S 18°24.601' E | 33°58.287' S 18°23.353' E | 34°00.931' S 18°22.863' E | 34°01.758' S 18°21.230' E |
| Date(s) of sampling | 01/05/2002 and 08/10/2002 | 01/5/2002 and 08/10/2002 | 02/05/2002 and 07/10/2002 | 02/05/2002 and 07/10/2002 |
| Surrounding land use | Natural Mountain Fynbos of Cape Peninsula National Park | Natural Afromontane Forest vegetation. River has been impounded upstream by 5 in-channel dams | Areas characterised by low-density homesteads in a rural setting with large gardens and horse paddocks. Downstream of commercial forestry plantations | Residential suburbs and horse paddocks |
| Channel form | Simple | Compound | Compound | Simple |
| Average active channel width | 6-7 m | 8 m | 3-4 m | 6 m |
| Channel pattern | Single moderately laterally inactive channel, probably becoming anastomising / anabranching flowing around islands of vegetation, boulders and cobbles during winter rains | Single channel, laterally inactive | Single, moderately laterally inactive channel | Single, laterally moderately inactive channel |
| Lateral mobility | Confined | Confined | Confined | Confined Previously river would have been non-confined, with large floodplain. But is presently cut off from its floodplain by an exotic *Pennisetum clandestinum* grass covered levee built for flood control. Confined on left bank by in-filling for urban properties and horse paddocks, with stables extending to edge of river bank. |

**Table 2.2 continued.** Hout Bay site descriptions

| | Site 1 | Site 2 | Site 3 | Site 4 |
|---|---|---|---|---|
| Channel type | Mixed bedrock and alluvium | Mixed bedrock and alluvium | Alluvial, dominated by sand and cobbles | Sandy alluvium |
| Embeddedness at sampling time | 0-25% | 0-25%, although fine silt layer deposited on some rocks | 26-50% in Autumn, 0-25% in Spring | N/A |
| Dominant water physical biotopes | Cascades, glides, pools and backwater pools | Pools, cascades, small water falls and runs | Glides and riffles | Slow moving pools and glides creating uniform flow |
| Water level at sampling time | Moderate flow | Autumn: moderate flow<br>Spring: not recorded | Moderate flow | Low flow |
| Water turbidity at sampling time | Tea-coloured but clear | Tea-coloured and clear but opaque in pools | Tea-coloured and clear with suspended particles observed during spring | Opaque and silty |
| Canopy cover | Open | Closed | Open | Partially open, closed in places due to encroaching vegetation and overhanging bushes |
| Riparian composition | No distinct riparian zone with Mountain Fynbos stretching down river banks. Middle islands of Restionaceae, *Erica* sp., *Berzelia* sp. and ferns. | Large indigenous riparian forest trees | Extensive alien vegetation invasion, with *Acacia* sp. and *Eucalyptus* sp. prevalent and *Pennisetum clandestinum* grass dominating. | Dominated by alien vegetation. *Pennisetum clandestinum* grass prevalent on both banks |
| Instream vegetation | Mosses, *Isolepis* sp. and algae present where water not flowing strongly. | Isolated patches of algae | Very little algae observed | *Phragmites australis* reeds encroaching into shallower water |
| Additional comments | - | - | - | Storm water outlet pipe at site. Litter observed at site. Horse trails occur along right bank and enter river bed during low flows under Victoria Road Bridge. Evidence that river previously broke through levee during high flow event. |


**Figure 2.2. (a)** Upstream and **(b)** downstream of Hout Bay River Site 1 (Hely-Hutchinson Dam)

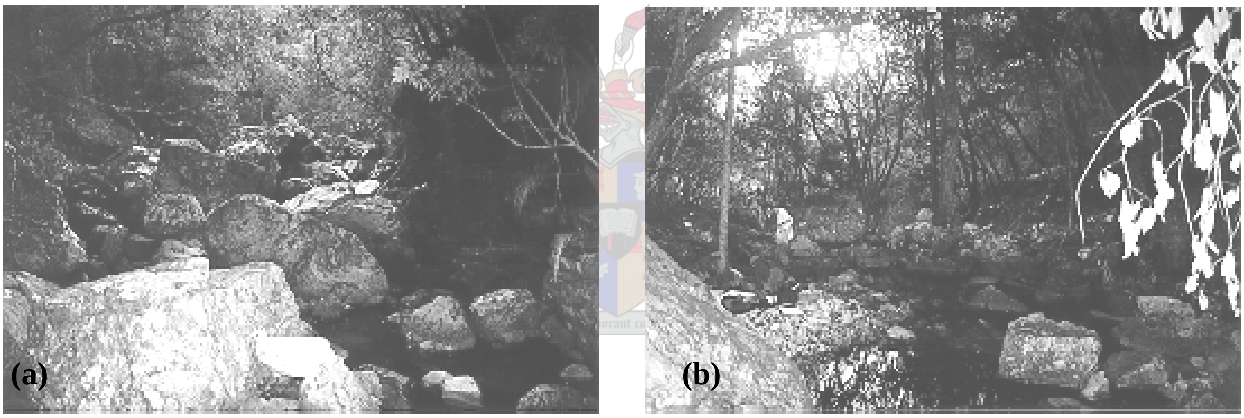


**Figure 2.3. (a)** Upstream and **(b)** downstream of Hout Bay River Site 2 (Orange Kloof)

Although Sites 1 and 2 are situated in the same geomorphological zone (Figure 2.1), Figures 2.2 and 2.3 together with Table 2.2, show that the physical characteristics of the two sites differ considerably. Firstly, the riparian vegetation at Site 2 consists of large Afromontane Forest trees, which is very different to the open Mountain Fynbos vegetation present at Site 1. Secondly, where waterfalls are absent at Site 1, they occur at Site 2 and thirdly, large boulders instead of the bedrock and cobbles at Site 1, dominate the substrate at Site 2. However, the characteristics of Site 2 are typical of mountain stream sites found in gorge formations (Wadeson *pers*. *comm*. 2003a).

2.3.1.(ii) <u>Upper Foothill Zone</u>

The middle zone of the Hout Bay River has a gradient of 0.033 (Figure 2.1) and thus, according to Table 2.1 should be classed as a Transitional Zone. However, from field visits, it was found that this zone had a cobble-bed channel and pool-riffle and plane-bed reach types, with the lengths of the pools and riffles being similar. These are characteristics indicative of an Upper Foothill Zone (UFZ). In light of this, the fact that the limits of the zones, presented in Table 2.1, still need substantiation and possible refinement (Rowntree *et al.* 2000) and the previous zoning of the Hout Bay River obtained in GIS layers from Southern Waters Ecological Research and Consulting cc.[3], together with discussions with Wadeson (*pers. comm.* 2003a), it was apparent that this zone should rather be classified as an UFZ.

Site 3 (Figures 2.1 and 2.4) was chosen to represent the UFZ of the Hout Bay River because, being located in the upper outskirts of Hout Bay Village, it is situated downstream of commercial forestry plantations and is surrounded by peri-urban properties with large gardens and horse paddocks extending down to the river's edge (BOLA&EP *et al.* 1996; Brown *et al.* 1997). It, therefore, includes the major impacts affecting the UFZ of this river.

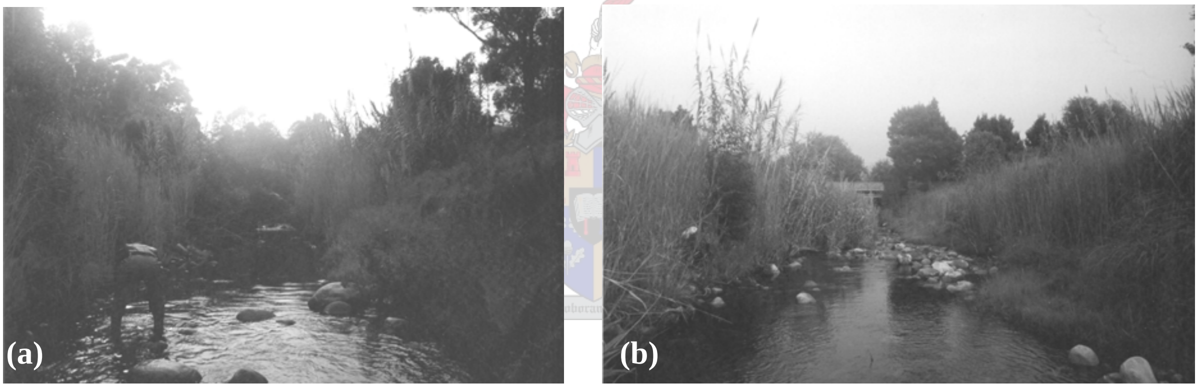


**Figure 2.4. (a)** Upstream and **(b)** downstream of Hout Bay River Site 3 (Disa Road Bridge)

The gradient of the reach in which Site 3 occurs has a gradient of 0.021 and hence, like this zone with a gradient of 0.033, Site 3 should be classified as a Transitional Zone. It, therefore, appears that Site 3 is representative of the broader geomorphological zone in which it is found.

2.3.1.(iii) <u>Lowland River Zone</u>

The third zone identified in the Hout Bay River has a gradient of 0.006 (Figure 2.1), which, according to Table 2.1, could place this zone in the UFZ, Lower Foothill Zone (LFZ) or Rejuvenated Foothill Zone (RFZ). However, a field visit showed that this zone has an alluvial fine-bed channel together with the remnants of a floodplain. These characteristics although modified are, according to Table 2.1, characteristic of a Lowland River Zone (LRZ). In light of this, the fact that

[3] PO Box 13280, Mowbray, Cape Town, 7705

the limits of the zones still need substantiation and possible refinement (Rowntree *et al.* 2000) and from the zoning of the Hout Bay River available in GIS layers from Southern Waters Ecological Research and Consulting cc.[4], together with discussions with Wadeson (*pers. comm.* 2003a) it was decided that this zone should be classified as LRZ.

Site 4 (Figures 2.1 and 2.5), situated in the middle of Hout Bay Village amongst residential suburbs and horse paddocks, represents the main impacts experienced by the LRZ of the Hout Bay River. Site 4 was, therefore, chosen as a representative sampling site for the LRZ.

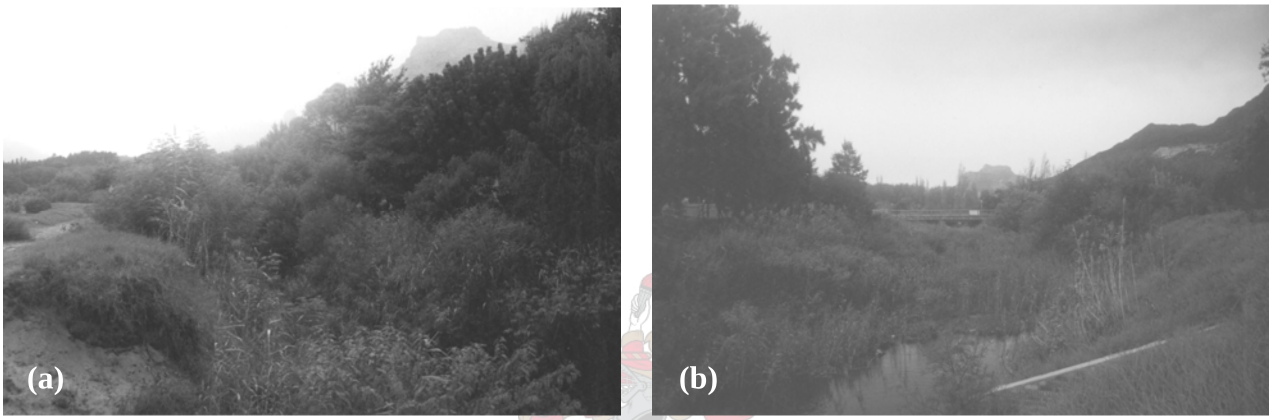


**Figure 2.5. (a)** Upstream and **(b)** downstream of Hout Bay River Site 4 (Victoria Road Bridge)

Only one reach comprises this LRZ. Therefore the gradient of this zone is equal to the gradient of reach in which Site 4 occurs. Hence, Site 4 is representative of the broader geomorphological zone.

### 2.3.2 Lourens River

The Lourens River was divided into the three geomorphological zones shown in Figure 2.1. Five sites considered to be representative of the respective zones were chosen for the river health assessment. Detailed descriptions of these sites are presented in Table 2.3. These descriptions present baseline data against which future biomonitoring and river health assessment results can be compared.

[4] PO Box 13280, Mowbray, Cape Town, 7705

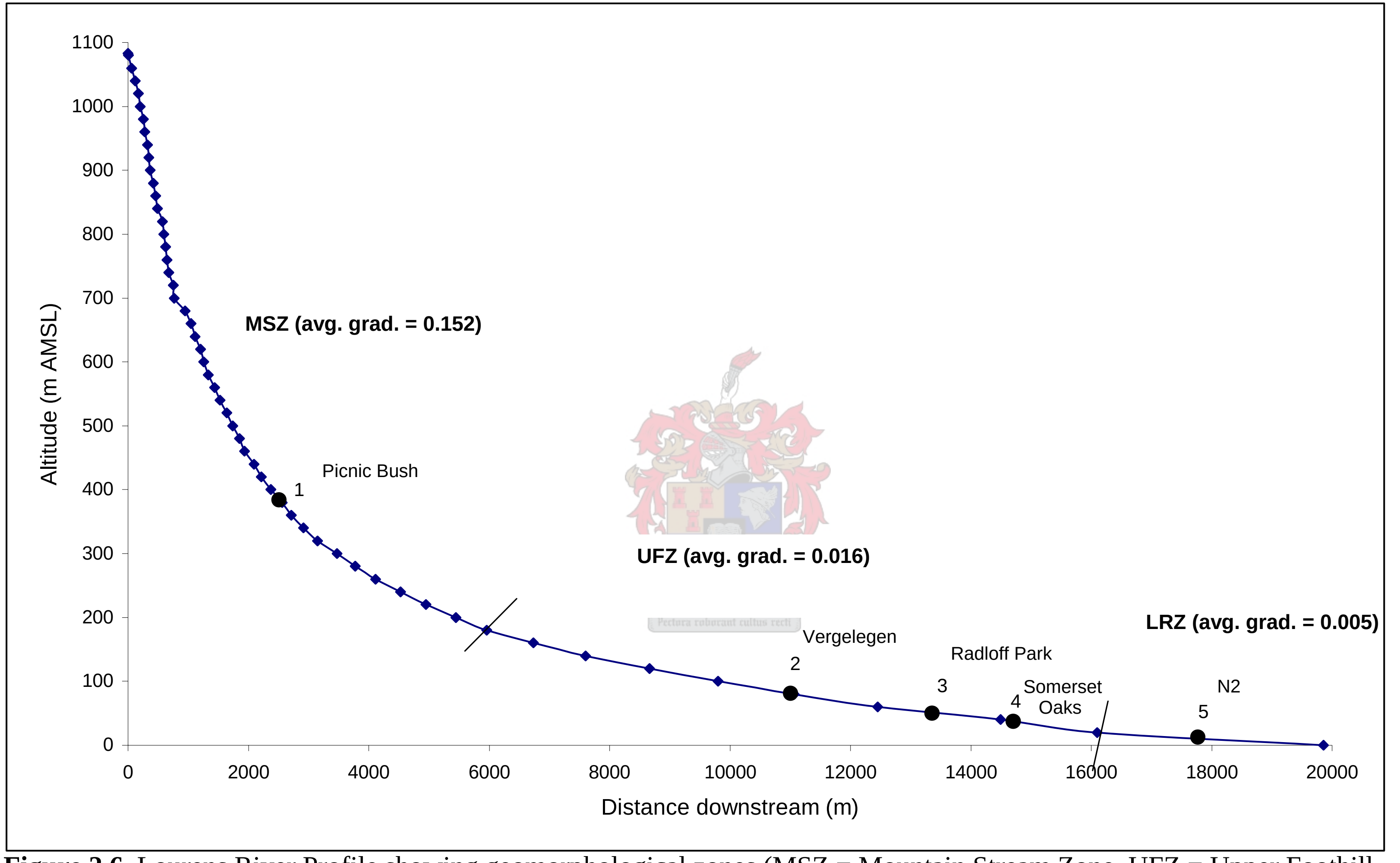


**Figure 2.6.** Lourens River Profile showing geomorphological zones (MSZ = Mountain Stream Zone, UFZ = Upper Foothill Zone, LRZ = Lowland River Zone), the average gradient (avg. grad.) of each zone and sampling sites 1-5)

**Table 2.3.** Lourens River site descriptions

| | Lourens River | | | | |
|---|---|---|---|---|---|
| | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 |
| Zone | MSZ | UFZ | UFZ | UFZ | LFZ |
| Location | Picnic Bush, 40 m upstream of dirt road crossing, Lourensford Estate | Immediately upstream of wooden pedestrian bridge, Vergelegen Estate | Just downstream of concrete floodberm at Lower Radloff Park | Opposite Somerset Oaks townhouses in Somerset West Town | Below light industrial area below N2, at end of dirt track leading from Victoria Road through open space adjacent to road |
| Co-ordinates | 34$^o$01.741' S 18$^o$57.407' E | 34$^o$04.502' S 18$^o$53.341' E | 34$^o$04.983' S 18$^o$52.144' E | 34$^o$05.212' S 18$^o$51.480' E | 34$^o$05.775' S 18$^o$49.772' E |
| Date(s) of sampling | 22/04/2002 and 17/09/2002 | 22/04/2002 and 17/09/2002 | 26/04/2002 and 11/10/2002 | 18/09/2002 | 26/04/2002 and 18/09/2002 |
| Surrounding land use | Natural vegetation | Agriculture, Vergelegen lawns and farm buildings | Recreational area of Radloff Park, urban properties, gardens, agriculture | Generally urban residential areas with open space on the left bank. | Generally residential suburbs with urban open space bordering the side |
| Channel form | Simple | Simple | Compound | Compound | Compound |
| Average (active) channel width | 5-6 m | 8-9.5 m | 4 m | 6.5 m | 4-9 m |
| Channel pattern | Single-threaded, low sinuosity | Single-threaded, low sinuosity | Single-threaded, moderately laterally inactive | Single low sinuosity | Single, moderately laterally inactive |
| Lateral mobility | Confined | Moderately confined | Confined | Confined, right bank confined by gabions. (river just upstream previously probably flowed further right but has been controlled due to riparian housing) | Confined |
| Channel type | Alluvial, boulders and cobbles dominating | Alluvial, cobbles dominating | Alluvial, dominated by cobbles | Alluvial, dominated by cobbles | Alluvial, dominated by sand, with cobbles at bottom of pools and in middle areas of channel. Bedrock protusions evident. |

**Table 2.3 continued.** Lourens River site descriptions

| | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 |
|---|---|---|---|---|---|
| Embeddedness at sampling time | 0-25% | 26-50% | 51-75% | 0-25% | 51-75% |
| Dominant water physical biotopes | Cascades and pools | Riffles and runs with few moderately deep pools along stream margins | Slow-flowing pools and riffles | Pools, riffles and runs | Pools linked by runs and riffles |
| Water level at sampling time | Autumn: moderate flow Spring: high flow | Autumn: moderate flow Spring: high flow | Autumn: moderate flow Spring: high flow | High flow during spring | Autumn: moderate flow Spring: high flow |
| Water turbidity at sampling time | Tea-coloured but clear | Autumn: clear but discoloured Spring: slightly opaque and silty | Tea-coloured and slightly silty | Tea-coloured but clear | Autumn: silty and turbid Spring: discoloured and slightly opaque |
| Canopy cover | Almost completely closed upstream of site but partially open /open at site | Open | Partially open, closed primarily by alien trees | Open | Partially open |
| Riparian composition (a more detailed description is presented in Withers *in prep.*) | Indigenous riparian tree, shrub and fern species | Left bank dominated by alien vegetation, with exotic lawn and garden escapees dominating the understorey. Less alien invasion (+/-50%) and good indigenous recruitment on right bank. | Urban gardens extend to edge of right bank, which is heavily invaded by exotic vegetation and badly eroded. Left bank, downstream of floodberm is overgrown with alien vegetation. | Very limited on right bank with urban properties extending to edge of bank steepened with gabions; vegetation occurring is alien with many garden escapees present. Left riparian zone almost entirely composed of alien vegetation. | Invaded with alien species although some indigenous species remain. Exotic *Pennisetum clandestinum* grass densely covers steep river banks. Banks are undercut in places and river has eroded around large alien *Salix babylonica* in the channel. |
| Instream vegetation | No macrophytes, some algae present | No macrophytes or algae present | Algae present, no macrophytes. | No macrophytes or algae present | The macrophyte, *Isolepis prolifer*, grows in shallow water and on shelf of pools. Algae strands present. |

**Table 2.3 continued.** Lourens River site descriptions

| | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 |
|---|---|---|---|---|---|
| Additional comments | - | - | Large amount of litter observed | - | Large amounts of litter; vagrants use site. Storm water outlet pipe at site. |

2.1.1.(i) Mountain Stream Zone

The top zone has a gradient of 0.152 (Figure 2.6) and consequently, similarly to HoutBay Site 1, it can be classified as a MSZ.

From the initial survey it appeared that the MSZ seemed relatively unimpacted and surrounded by natural vegetation. Site 1, Picnic Bush (Figures 2.6 and 2.7, Table 2.3), was chosen to represent the MSZ because, firstly, it is the top most easily accessible point along the Lourens River. Secondly on reaching Site 1 the Lourens River has passed from its source through the Hottentots Holland Nature Reserve and into the upper regions of Lourensford Estate, where indigenous vegetation is still dominant. Therefore, up to this point the river has hardly been impacted by anthropogenic activities. Therefore, Site 1, being surrounded almost entirely by natural vegetation and being relatively unimpacted itself, was considered to be representative of the relatively unimpacted MSZ of the Lourens River.

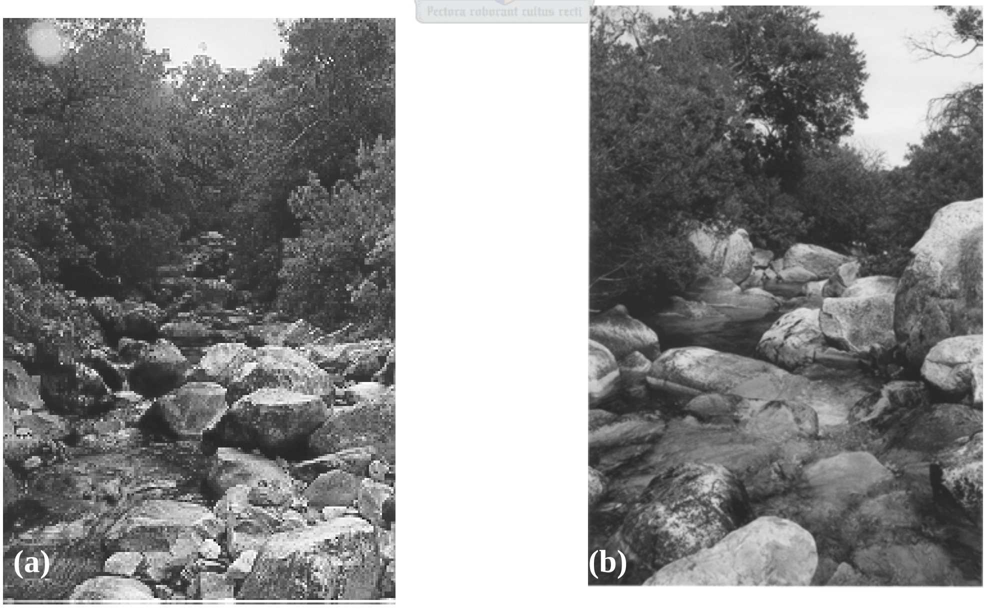


**Figure 2.7. (a)** Upstream and **(b)** Downstream of Lourens River Site 1 (Picnic Bush)

The gradient of the reach in which Site 1 occurs is 0.108, which is not as steep as the gradient of this zone (0.152). However, it must be remembered that in this study, the MHWSZ and the MSZ have been combined into the MSZ and hence the gradient of the resulting MSZ may be steeper than otherwise expected. The gradient of Site 1 however can be classified as belonging to the MSZ and consequently, Site 1 is considered to be representative of the MSZ of the Lourens River.

2.3.2.(i) Upper Foothill Zone

The middle zone on the Lourens River, has an average gradient of 0.016 (Figure 2.6) and, consequently, from Table 2.1 it can be described as an UFZ.

The upper reaches of the UFZ of the Lourens River are impacted primarily by the commercial forestry and agricultural activities of Lourensford and Vergelegen Estates. Therefore, being situated amongst the agricultural areas of Vergelegen Estate and below Lourensford Estate, Site 2 (Figures 2.6 and 2.8; Table 2.3) was considered to be representative of the Lourens River UFZ upper reaches.


**Figure 2.8. (a)** Upstream and **(b)** downstream of Lourens River Site 2 (Vergelegen)

The main impact of the UFZ lower reaches, below Site 2, is urbanisation. Residential suburbs interspersed with urban open spaces, like Radloff Park, and orchards, are now found adjacent to the Lourens River. Being situated on the upper outskirts of Somerset West town with surrounding urban, recreational and agricultural (orchards) land uses, Site 3 (Figures 2.6 and 2.9; Table 2.3) Radloff Park, was chosen to represent the typical Lourens River in these lower UFZ reaches.


**Figure 2.9. (a)** Upstream and **(b)** downstream of Lourens River Site 3 (Radloff Park)

During the river health assessment two samples, one in autumn (March - May) 2002 and another in spring (September - November) 2002, were conducted (Chapter 3). Whilst conducting the spring 2002 sample, the River Health Team decided that Site 3, situated on the upper outskirts of Somerset West town, was not sufficiently representative of the impact of urbanisation, which is the primary impact in the lower reaches of the UFZ. Site 4 (Figures 2.6 and 2.10; Table 2.3), located further downstream, within Somerset West town was, therefore, chosen and assessed. Site 4 is situated at Somerset Oaks Town Houses with urban open space on the left bank. It is recommended that this site instead of Site 3 be used in future biomonitoring assessments.


**Figure 2.10. (a)** Upstream and **(b)** downstream of Lourens River Site 4 (Somerset Oaks)

The gradients of the reaches in which Sites 2, 3 and 4 are found are 0.016, 0.014 and 0.010 respectively. According to Table 2.1 these reaches can all be classified as UFZ reaches. With gradients similar to the 0.016 gradient of the broader river zone in which they are found, all three sites are considered representative of the middle zone of the Lourens River. However, Site 2, having the same gradient as the broader river zone, is considered to best represent the geomorphological zone in terms of gradient.

2.3.2.(ii) Lowland River Zone

The last zone identified along the Lourens River has a gradient of 0.005 (Figure 2.6). According to Rowntree *et al.* (2000) this gradient could place the zone in the UFZ, LFZ or RFZ (Table 2.1). During field verification it became apparent, however, that although the zone is highly modified, it has characteristics that place it in the LRZ (Wadeson *pers. comm*. 2003b). It appears that in this zone the river would naturally have migrated freely across its floodplain. Channel incision, however, has occurred resulting in the steeper river banks visible today. This incision may either be due to rejuvenation from a natural phenomenon like lowering of the sea level or upliftment of the upper river reaches, or it may be due to increased runoff from urbanisation, or the result of the *Salix babylonica* planted to stabilise the river banks (Wadeson *pers. comm*. 2003b). This down cutting of the channel has also resulted in the protruding bedrock seen in this zone today (Wadeson *pers. comm*. 2003b). Therefore, based on this physical evidence, the lower zone of the Lourens River was classified as a LRZ.

Site 5 (N2) (Figures 2.6 and 2.11; Table 2.3) was selected as the representative site for this LRZ because: firstly, the physical characteristics of Site 5 are typical of the river in this zone, and secondly, situated below Somerset West town centre, a light industrial area and more residential suburbs, Site 5 is representative of the majority, if not all, of the impacts occurring in the LRZ of the Lourens River.

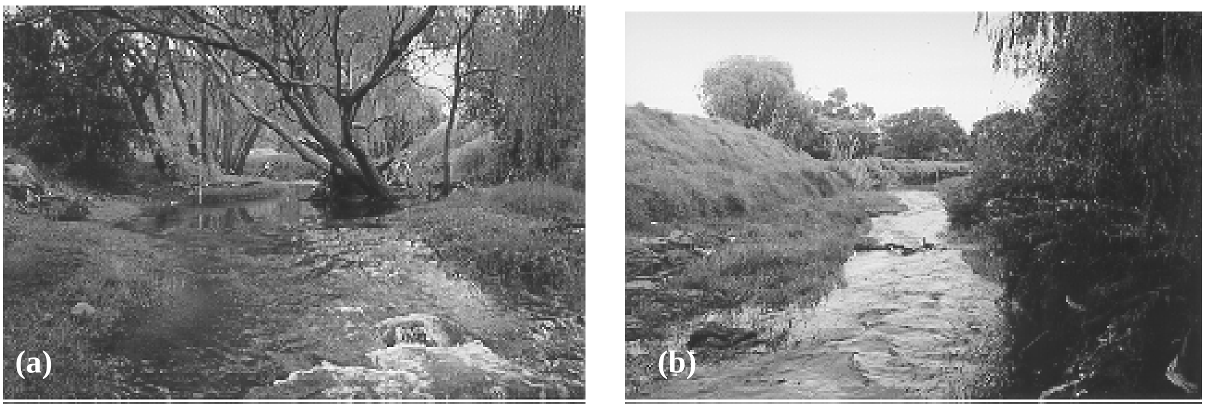


**Figure 2.11. (a)** Upstream and **(b)** downstream of Lourens River Site 5 (N2)

This lower zone is only comprised of one reach (Figure 2.6) and consequently the gradient of the reach in which Site 5 occurs is 0.005, which is the same as that of the broader zone. Site 5 is, therefore, considered to be representative of the lower zone of the Lourens River.

### 2.3.3 Palmiet River

The three geomorphological zones shown in Figure 2.12, were identified along the Palmiet River. Five sites considered to be representative of the respective zones were chosen for the river health assessment. Detailed descriptions of these sites are presented in Table 2.4. These descriptions present baseline data with which to compare future biomonitoring and river health assessment results.

2.3.3.(i) Mountain Stream Zone

The upper zone of the Palmiet River has a gradient of 0.061 and thus according to Table 2.1 can be classed as a MSZ (Figure 2.12).

The majority of the MSZ is unimpacted and near-pristine. Site 1 is situated above any commercial forestry areas and is surrounded by natural Mountain Fynbos vegetation (Figure 2.13; Table 2.4). On reaching Site 1, the Palmiet River is relatively unimpacted having only passed through virtually pristine areas of the Hottentots Holland Nature Reserve. Site 1 was, therefore, considered to be representative of the MSZ.

The gradient of the reach in which Site1 is found is 0.041, which is considerably less than the 0.150 gradient of the broader MSZ. However, it must be remembered that in this study the MHWSZ and the MSZ have been combined into the MSZ and hence, the gradient of the resulting MSZ may be steeper than otherwise expected. A gradient of 0.041 places the reach of Site 1 into the MSZ (Table 2.1) and hence Site 1 is considered to be representative of the zone.

2.3.2.(ii) Upper Foothill Zone

The middle zone of the Palmiet River has a gradient of 0.013 (Figure 2.12) and thus according to Table 2.1 is classified as an UFZ.

According to Chapter 1, the Palmiet River in this UFZ is impounded first by Nuweberg and Eikenhof Dams (Figure 2.12) as it passes through forestry and agricultural areas before entering the town of Grabouw. After Grabouw the river passes through more agricultural land and is impounded by the Kogelberg, Appelthwaite and Arieskraal Dams, after which it flows through more agricultural and forestry areas before entering the Kogelberg Nature Reserve.

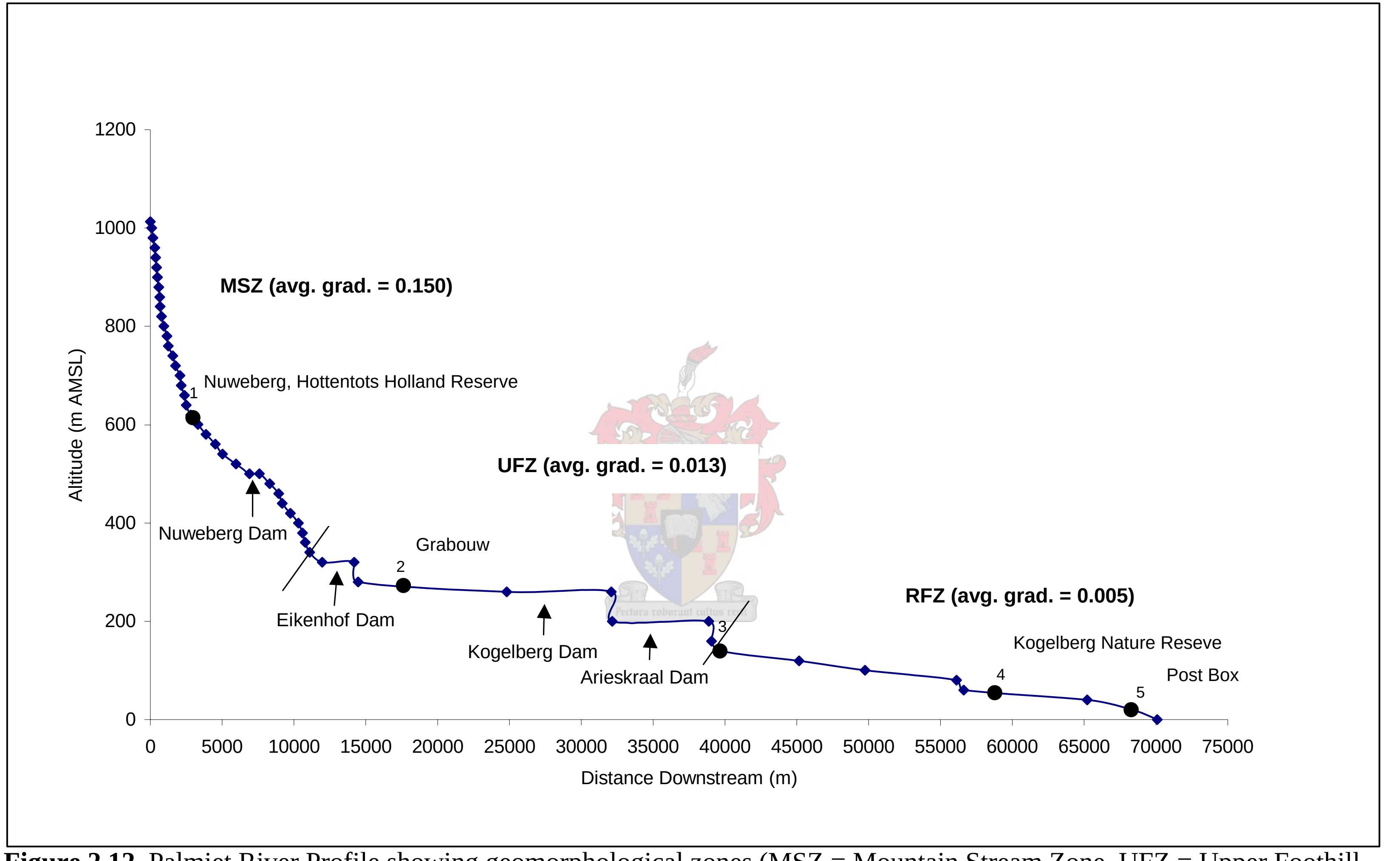


**Figure 2.12.** Palmiet River Profile showing geomorphological zones (MSZ = Mountain Stream Zone, UFZ = Upper Foothill Zone, RFZ = Rejuvenated Foothill Zone), the average gradient (avg. grad.) of each zone and sampling sites 1-5)

**Table 2.4.** Palmiet River site descriptions

| | Palmiet River | | | | |
|---|---|---|---|---|---|
| | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 |
| Zone | MSZ | UFZ | UFZ | RFZ | RFZ |
| Location | 20-30m upstream of road crossing in Hottentots Holland Nature Reserve | Immediately downstream of Main Road bridge in the town of Grabouw | Just upstream of road crossing below Arieskraal Dam | Situated in Kogelberg Nature Reserve, below confluence of Krom tributary, at IFR site 3 (Day *et al.* 1998) | In Kogelberg Nature Reserve, at the old post box |
| Co-ordinates | 34$^{o}$03.351’ S 19$^{o}$02.465’ E | 34$^{o}$09.102’ S 19$^{o}$01.418’ E | 34$^{o}$14.641’ S 18$^{o}$59.666’ E | 34$^{o}$17.185’ S 18$^{o}$58.701’ E | 34$^{o}$19.214’ S 18$^{o}$58.170’ E |
| Date(s) of sampling | 12/05/2002 and 30/09/2002 | 10/05/2002 and 30/09/2002 | 10/05/2002 and 30/09/2002 | 11/05/2002 and 29/09/2002 | 11/05/2002 and 29/09/2002 |
| Surrounding land use | Natural fynbos | Surrounded by urban developments, downstream of forestry and agricultural areas | Downstream of heavy inundation, surrounded immediately by forestry and natural vegetation, farm lands bordering these | Natural vegetation | Surrounded by natural vegetation |
| Channel form | Simple | Compound | Compound | Compound | Compound |
| Average active channel width | 4-5 m | 8-12 m | 20 m | 15 m | 30-40 m |
| Channel pattern | Single, laterally inactive channel. | Single, moderately inactive channel. River previously probably flowed wider, but today confined by urban developments. | Single, becoming anabranching / anatomising in places. Moderately laterally inactive. | Single, meandering, laterally active channel with significant bends | Anabranching / anatomising with islands of vegetation (mainly *Prionium serratum*), bedrock and alluvium |
| Lateral mobility | Confined | Moderately confined | Moderately confined | Confined | Moderately confined |
| Channel type | Alluvial, with boulders and cobbles dominating | Alluvial, dominated by cobbles | Alluvial, cobbles dominating | Mixed bedrock and alluvium, locally bedrock controlled | Mixed bedrock and alluvium, dominated by cobbles and gravels |
| Embeddedness at sampling time | 0-25% | Undetermined | Undetermined | 0-25% | 0-25% |

**Table 2.4 continued.** Palmiet River site descriptions

| | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 |
|---|---|---|---|---|---|
| Dominant water physical biotopes | Glides, cascades, pools, back water pools and riffles | Pools, glides and runs | Pools, glides, runs and rapids with isolated back water pools also present | Pools and glides with rapids immediately below site | Pools, glides, riffles and rapids |
| Water level at sampling time | Moderate flow | Moderate flow | Autumn: High flow Spring: Moderate flow | High flow | High flow |
| Water turbidity at sampling time | Clear | Opaque | Tea-coloured but also noted as opaque during autumn sampling | Tea-coloured and opaque in deeper areas | Clear but tea-coloured |
| Canopy cover | Open | Open | Open | Open | Open |
| Riparian composition | Indistinctive riparian zone with Mountain Fynbos stretching down the riparian bank. *Prionium serratum* stands prevalent near water's edge | Extensive alien invasion | Visible riparian zone dominated by indigenous species on both banks | Indigenous riparian zone on both banks | Not very distinctive riparian zone, with natural fynbos stretching down to river |
| Instream vegetation (see Withers *in prep.*) | *Isolepis* sp. | None visible | None recorded | None recorded | Islands of *Prionium serratum* very prevalent along waters edge and instream |
| Additional comments | - | Site used by vagrants. Litter abundant | A landslide is a dominant feature on the right bank | - | - |

For a number of reasons, outlined below, Sites 2 (Figure 2.14) and 3 (Figure 2.15) were chosen as representatives of this UFZ (Figure 2.12).

Firstly, Site 2 (Figures 2.12 and 2.14; Table 2.4) being situated in Grabouw, about 5 kilometres downstream of Nuweberg Dam and downstream of forestry and agricultural areas, represents the major impacts experienced by the upper reaches of the UFZ. This site was chosen specifically to show the influence of urban areas on the Palmiet River, and being located in on the bridge in Grabouw town, is easily accessible.

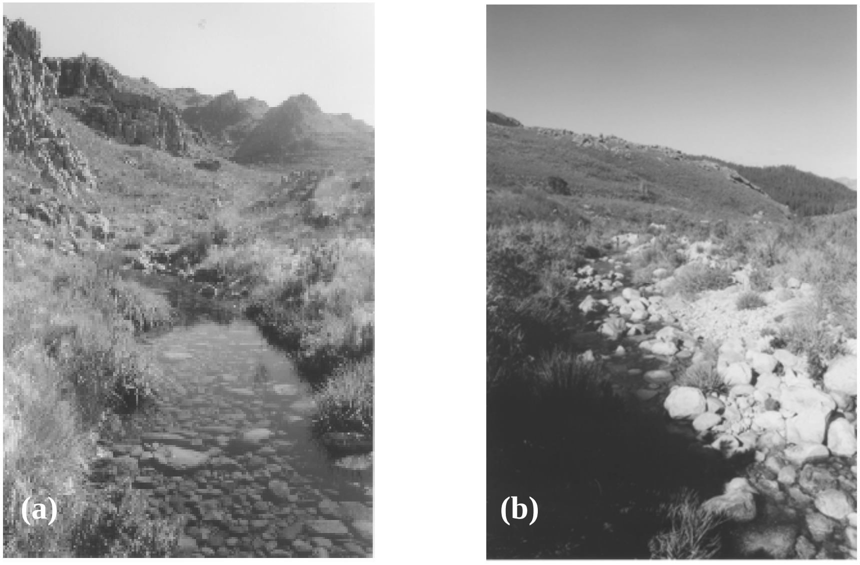


**Figure 2.13. (a)** Upstream and **(b)** downstream of Palmiet River Site 1 (Nuweberg)

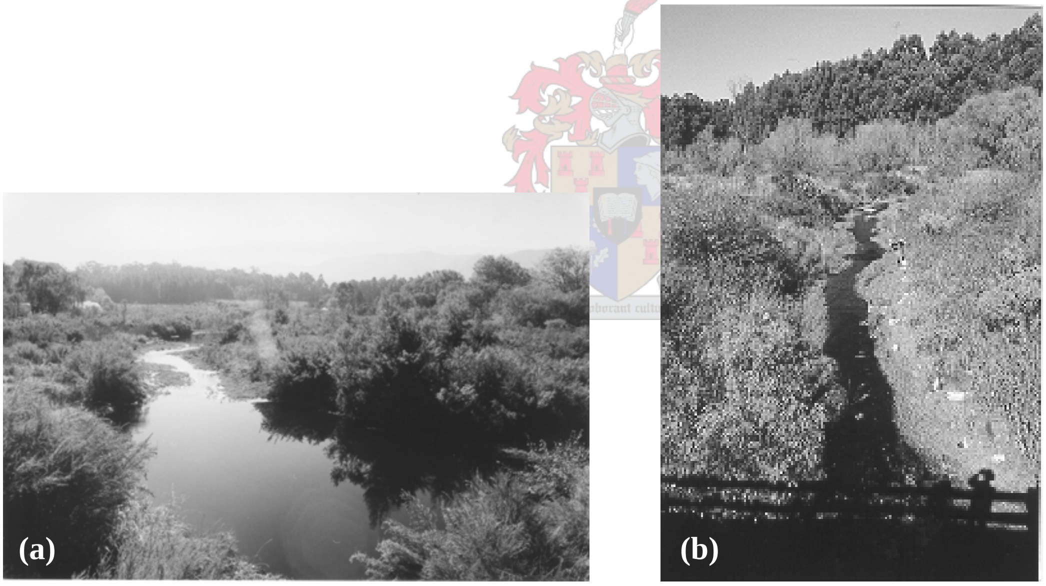


**Figure 2.14. (a)** Upstream and **(b)** downstream of Palmiet River Site 2 (Grabouw)

Secondly, Site 3 (Figures 2.12 and 2.15; Table 2.4) was chosen to represent the major impacts of impoundment and agriculture found along the UFZ of the Palmiet River. Being situated below Arieskraal Dam and being surrounded on the left bank by areas invaded with *Pinus pinaster* bordered by orchards, Site 3 was considered representative of these major impacts effecting the UFZ. Site 3 is at the interface between the UFZ and Rejuvenated Foothill Zone (RFZ) (Figure 2.12). It has been debated whether this site should be defined as an UFZ or a RFZ. However, the



**Figure 2.15. (a)** Upstream and **(b)** downstream of Palmiet River Site 3 (Arieskraal)

author decided to place the site into the UFZ as it is at the end of this zone and so reflects the impacts experienced by the whole UFZ.

The gradient of the reach in which Site 2 occurs is 0.0021, which is considerably flatter than the 0.013 gradient of the middle UFZ (Figure 2.12.). On the other hand, the gradient of the reach in which Site 3 occurs is 0.27, which is considerably steeper than the gradient of the zone. Large inundation due to the construction of dams occurs in the middle reaches of the Palmiet River. This construction has changed the natural profile of the river resulting in the terraced pattern of alternating steepened and flattened sections seen in the profile shown in Figure 2.12. The gradients of these sites cannot, therefore, be considered representative of the gradient of the broader zone to which they belong. However, the general gradient of the zone characterises it as a UFZ and this classification is supported by the charcteristic channel features observed at Sites 2 and 3.

2.3.3.(ii) <u>Rejuvenated Foothill Zone</u>

The lower zone of the Palmiet River has a gradient of 0.005 (Figure 2.12), which, according to Table 2.1, could place it in the UFZ, LFZ RFZ. However, from the field visits it was found that, like foothill rivers, this zone has a gravel / cobble bed with pool / rapid morphology but the effect of uplift in this zone is evident. Therefore, this zone was classified as a RFZ.

In this zone the Palmiet River passes through the natural fynbos areas of the Kogelberg Nature Reserve. Due to the majority of this zone being situated in a Nature Reserve, the river experiences no localised impacts. The river is, however, still impacted by considerable upstream activities (e.g. water abstraction and runoff from intensively farmed agricultural lands) both bordering the main channel and occurring on tributaries outside the Kogelberg Nature Reserve.

As shown in Figure 2.12, Site 4 (Figure 2.16; Table 2.4) is situated towards the middle of the RFZ. This site was, therefore, chosen to represent the upper and middle reaches of the RFZ. Situated below the confluence of the heavily agriculturalised Krom River tributary, this site also reflects its upstream impacts on this section of the Palmiet River.

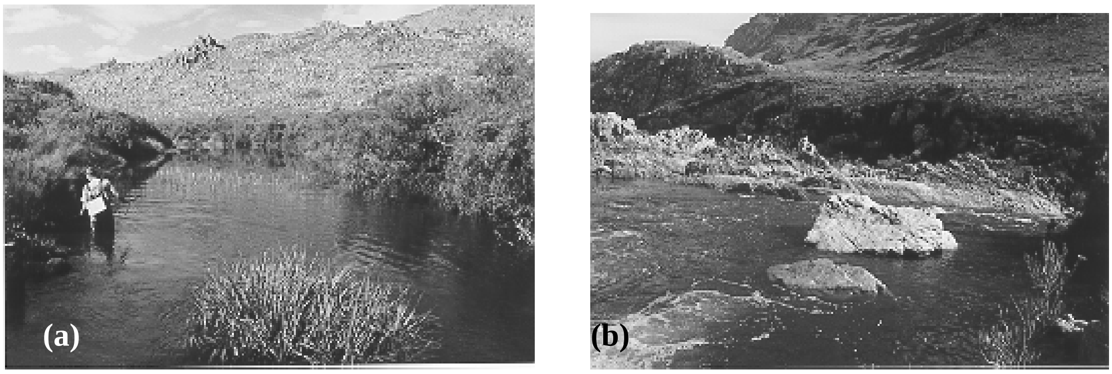


**Figure 2.16. (a)** Upstream and **(b)** downstream of Palmiet River Site 4 (Kogelberg)

Surrounded completely by natural fynbos, Site 5 (Figures 2.12 and 2.17; Table 2.4) is situated at the old post box near the bottom of the Kogelberg Nature Reserve. This site was chosen to represent the lower reaches of the RFZ, after the river has passed through the pristine Kogelberg Nature Reserve and has benefited from the flow from the Louws and the Dwars River tributaries, which drain pristine Mountain Fynbos areas.

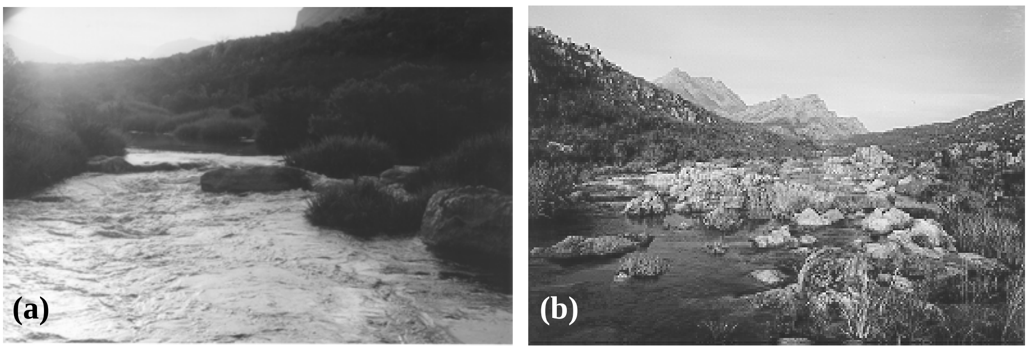


**Figure 2.17. (a)** Upstream and **(b)** downstream of Palmiet River Site 5 (Post Box)

The gradients of the reaches in which Sites 4 and 5 are found are 0.002 and 0.006 respectively. Although these gradients are both within the gradient class specified for the RFZ, it appears that Site 5, with a gradient of 0.006 is more representative of the broader RFZ with its gradient of 0.005.

## 2.4 DISCUSSION

Due to the Mountain Head Water and Mountain Stream Zones being assessed together in this study, comments cannot be made about the successfulness of Rowntree *et al.'s* (2000) method in distinguishing between these two zone classifications. Nevertheless, the gradients designated to each geomorphological zone appeared to be correct for the majority of the geomorphological zones occurring along the three rivers assessed. The UFZ along the Hout Bay River, as well as the Lowland River Zone (LRZ) of the Lourens and Hout Bay Rivers, however, posed problems.

According to the gradient of the UFZ of the Hout Bay River, it should be classified as a Transitional Zone. However, according to the characteristic channel features of the site representative of this zone, it should be classed as a less steep UFZ. Similarly, the gradients of the LRZ of the Lourens and Hout Bay Rivers placed them in the UFZ, but the channel characteristics of their representative sites resulted in them being classified as LRZ, which is expected to have a lower gradient. Possible reasons for this are that, firstly, the sites chosen were not actually representative of their respective zones or, secondly, that the gradients defined by Rowntree *et al.* (2000) are not applicable to these rivers and need adjustment.

Each site chosen was located at a distance from the boundaries between adjacent zones and there can, therefore, be no discrepancy as to which zone each site belongs. The LRZ of both the Hout Bay and the Lourens Rivers are each comprised of only one reach. The gradient of this reach, in which the sites assessed are found, is therefore equivalent to the gradient of the respective LRZ. The gradient of the sites assessed are, therefore, equal to the gradient of the LRZ of each river and consequently, the sites accurately represent the zone in which they are found. The channel characteristics of each site observed during the field verification visits, therefore, do apply to the specific zone which it represents. Support for classifying the lower Lourens River Zone as a LRZ is also given by the previous zonation of the Lourens River performed by Tharme *et al.* (1997), which defines this zone as a zone equivalent to the LRZ defined by Rowntree *et al.* (2000). Similarly, categorising the lower Hout Bay Zone as a LRZ is supported by a previous zonation study of the Hout Bay River, (available in GIS layers from Southern Waters Ecological Research and Consulting cc.[5]), which categorised this lower zone as being a LRZ. The gradient of the UFZ zone of the Hout Bay River is 0.033, whereas the gradient of Site 3 occurring in this zone is 0.021. Although the gradient of the zone is 1.6 times steeper than the gradient of the reach in which Site 3 is found, both gradients place the respective zone and reach into the Transitional Zone classification

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class defined by Rowntree *et al.* (2000). Site 3 can, therefore, be considered to be representative of the broader zone in which it occurs and the characteristics of Site 3 can, with some confidence, be applied to the zone it represents. The sites chosen can, therefore, be considered representative of their respective zones.

The method of Rowntree *et al.* (2000) has been tested by its authors on three rivers, namely the Sabie, Buffalo and Olifants Rivers. These rivers are all considerably more than 100 kilometres in length, with the shortest being the 125 km long Buffalo River (Rowntree *et al.* 2000). Rising at similar altitudes to those studied by Rowntree *et al.* (2000), the rivers classified in this study are much shorter, with the Hout Bay only being 12 km, the Lourens 20 km and the Palmiet River 70 km in length (Chapter 1). The rivers examined in this study, therefore, generally have much steeper profiles than those studied by Rowntree *et al.* (2000). If one uses data from this study together with that from Rowntree *et al.*'s (2000) study, it becomes apparent, from the ratio of approximate altitude from source to sea of each river versus its length, that the Hout Bay River, with a ratio of 0.058, and the Lourens River, with a ratio of 0.050, are far steeper than the Palmiet (ratio 0.014), the Buffalo (ratio 0.010), the Sabie (ratio 0.008) and the Olifants (ratio 0.003) Rivers. This perhaps explains why the LRZ found along the Lourens and Hout Bay Rivers, as well as the UFZ found along the Hout Bay River, have steeper gradients than those predicted by Rowntree *et al.* (2000). This evidence supports Rowntree *et al.*'s (2000) idea that field verification of the desktop zonation analysis is vital and indicates that perhaps a zonation method modified per river type based on physiographic and hydrological features or regions is perhaps a realistic modification to a simple nationally applicable method.

It is clear that this zonation method has not been previously sufficiently tested on the short, steep rivers draining the Western Cape sandstone mountains, such as the Lourens (20 km) and Hout Bay Rivers (12 km). Interestingly, the Palmiet River, which also drains Western Cape sandstone mountains, but is a longer river being more than three times the length of the Lourens River and almost six times longer than the Hout Bay River, could be effectively subdivided into the appropriate categories defined by Rowntree *et al.* (2000). This evidence suggests that a possibility for refining the method of Rowntree *et al.* (2000) is to perhaps modify the definition categories of the zones by a factor based on the length of the river. In other words if, for example, the river is < 50 km long, then one set of ratios is relevant, whereas if the river is 51 – 250 km long then another set is applicable and so on. Modification of the categories, defined by Rowntree *et al.* (2000), in such a manner could then become standard procedure for the zonation of rivers in the

RHP. Further investigation into the feasibility, practicality and accurateness of such a method and other possible refinement procedures is, however, necessary.

Being a desktop method, this method was found to be convenient and user-friendly. It is also efficient time-wise, provided that the river networks are available in GIS format. However, the occurrence of large in-channel dams (as was seen along the Palmiet River) complicated the zonation method, as their construction changed the natural profile of the river extensively. Once each river had been zoned, selecting sites representative of each zone could be conducted with ease. It was found, however, that selecting one representative site per zone was not always sufficient as some zones cover large distances with remarkably different impacts and consequently differing conditions along their length. It is up to the discretion of the assessor to determine the number of sites that are required to represent the condition of a zone.

## 2.5 CONCLUSIONS

Given the results obtained in this study, the notion that one gradient classification system will be applicable nationally throughout South Africa, with its diverse geology and climate, is unlikely, (Wadeson *pers. comm*. 2002). Instead this classification system needs to be modified for various physiographic and hydrological regions or features or according to a factor based on the length of the river. More information and data is needed, however, before such a concept can be implemented. In the meantime this method generally appears to be successful in the longitudinal zonation of South African rivers for the RHP provided that field verification of the desktop analysis is conducted.

This study was the first step in conducting 2002 river health assessments on the Hout Bay, Lourens and Palmiet Rivers (Chapter 3; Hayes 2002; Ollis *in prep*.; Withers *in prep.*). The data from this study will be used to update the geomorphological zonation database (Wadeson *pers*. *comm*. 2002), which it is hoped will aid in substantiating and refining this geomorphological classification method for future use.

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# A HABITAT INTEGRITY ASSESSMENT OF THE HOUT BAY, LOURENS AND PALMIET RIVERS, SOUTH-WESTERN CAPE, SOUTH AFRICA

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## ABSTRACT

Knowledge about the availability and quality of habitats is vital for assessing overall riverine ecosystem health. Using the South African Index of Habitat Integrity for intermediate and rapid assessments (IHI), this study is a rapid assessment of the habitat integrity of three south-western Cape rivers. The following conclusions are drawn from this study.

(1) Although there is a general longitudinal decrease in habitat integrity downstream along the Hout Bay and Lourens Rivers, coinciding with an increase in anthropogenic activities, habitat integrity in the Palmiet River improves in the lower reaches in the Kogelberg Nature Reserve. Surrounding land use thus appears to be a major determinant of habitat integrity.

(2) Riparian zone habitat integrity appears to be primarily influenced by surrounding land use, whereas instream habitat appears to reflect upstream impacts.

(3) Assessments should be conducted during the dry season when the effects of stress factors are particularly apparent.

(4) The IHI was found to be subjective. It is suggested that the IHI scoring be categorised with scores assigned to particular descriptive categories.

(5) Overall, however, the IHI appears to be achieving its aim with the results being accepted during a peer review workshop.




***Key words:*** *river health, habitat integrity, rapid assessment, instream, riparian*

## 3.1 INTRODUCTION

### 3.1.1 River health assessment in South Africa

In South Africa water resources are limited (WRC 2001, 2002; RHP 2003, *in prep.*) and, consequently, South African Stream ecosystems are facing increasing stresses due to over-utilisation of water in an already over-stressed, drought-prone region (Davies and Day 1998). In South Africa rivers provide almost all of the water supply for a rapidly expanding population (Davies and Day 1998) and almost every permanent stream is regulated either by single or multiple impoundments (Davies and Day 1998; Kleynhans 1996). However, the natural water environment is not regarded as a user in competition with other users (e.g. domestic, agricultural, industrial) but rather as a resource base from which water originates and as an entity with its own intrinsic environmental value (Kleynhans 1996). In 1994 the South African Department of Water Affairs and Forestry (DWAF) initiated the National River Health Programme (RHP) as a tool to monitor the ecological state of rivers (Roux *et al.* 1999; WRC 2001, 2002; RHP 2003, *in prep.*), the results of which should be incorporated into a water resource management database system (Roux *et al.* 1999). To determine river health (condition) the RHP applies scientifically derived indices to assess ecological indicators considered to be representative of the wider river ecosystem (Chapter 1). The results are then used to class the river ecosystem in terms of its degree of modification relative to a natural benchmark (undisturbed) condition (Roux *et al.* 1999; Rowntree *et al.* 2000). One such index is the Intermediate Index of Habitat Integrity (Kemper 1999).



### 3.1.2 Habitat integrity assessment: Its role in river health on a global and local scale

Kleynhans (1996) defines the ecological integrity of a river as "its ability to support and maintain a balanced, integrated composition of physico-chemical and habitat characteristics, as well as biotic components on a temporal and spatial scale comparable to the natural characteristics of ecosystems of the region". Hence, it is the habitat and biotic integrities of a river that together determine its ecological integrity or ecological health (Kleynhans 1996).

In this sense, habitat integrity refers to the maintenance of a balanced, integrated composition of physico-chemical and habitat characteristics, on a temporal and spatial scale, that are comparable to the characteristics of natural habitats of the region (Kleynhans 1996). Assessment of habitat criteria determines the potential of aquatic habitats to support and maintain a balanced, integrated and adaptive community of organisms with a species composition and functional organisation comparable to that of the natural habitat of the region (Hall *et al.* 1996; Kleynhans 1996; Harper and Everard 1998; Muhar and Jungwirth 1998; Townsend and Riley 1999). Habitat integrity can thus be seen as a template for a certain level of biotic integrity to be realised (Kleynhans 1996; Harper and Everard 1998). Biotic integrity has been described "as the ability to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity and functional organisation comparable to that of the natural habitat of the region" (Karr and Dudley 1981).

Knowledge of the availability and quality of habitats is, therefore, considered to be vital for an assessment of the overall ecosystem health (Campbell 1994; CSIR 2002) and consequently, as can be seen in Table 3.1, habitat assessment has become an important part of evaluating ecological integrity internationally (Davies and Schofield 1994; Jackson and Anderson 1994; Kleynhans 1996; Harper and Everard 1998; Muhar and Jungwirth 1998; Kemper 1999; Kleynhans 1999; McQuaid and Norfleet 1999).

**Table 3.1.** Techniques developed world-wide to assess the habitat condition of rivers

| INDICES / TECHNIQUES | COUNTRY | SOURCE |
|---|---|---|
| Rapid Bioassessment Protocol for Habitat | United States of America (USA) | Plafkin *et al.* (1989) |
| Qualitative Habitat Evaluation Index | USA | Rankin (1995, in Muhar and Jungwirth 1998) |
| Visual Stream Assessment | USA | USDA/NRCS (1998) |
| River Habitat Survey | United Kingdom | Raven *et al.* (1997) |
| A rapid assessment technique for determining the physical and environmental condition of rivers in Queensland | Australia | Jackson and Anderson (1994) |
| Index of Instream Condition | Australia | Centre for Environmental Applied Hydrology (1997) |
| Index of Habitat Integrity | South Africa | Kleynhans (1996, 1999) |
| Index of Habitat Integrity for intermediate and rapid assessments | South Africa | Kemper (1999) |

Kleynhans (1996, 1999) and Kemper (1999) explain that the comprehensive Index of Habitat Integrity, developed in South Africa for comprehensive habitat assessments, is based on the qualitative assessment of a number of pre-weighted criteria indicating the integrity of instream and riparian zone habitats. Habitat integrity scores, derived by the application of a standardised formula, are sequentially determined for five kilometre segments of the river. The assessment of the criteria is largely achieved by careful scrutiny by the assessor of a continuous aerial video of the river taken at low level from a helicopter. Kemper (1999) explains that the Index of Habitat Integrity for intermediate and rapid assessments is a simplified procedure based on the above comprehensive method of Kleynhans (1996, 1999) but removing the reliance on costly aerial videos. It differs from the comprehensive method in that it is almost entirely based on available information of the river in question and assesses broad geomorphological river zones rather than specific five kilometre river segments. However, the Intermediate Habitat Integrity Index makes use of the same weighted criteria and standardised formula to arrive at habitat integrity scores.

### 3.1.3 Research aim

The aim of this study was to assess the habitat integrity of three south-western Cape rivers rapidly as part of the South African River Health Programme and to comment on the effectiveness of the Index of Habitat Integrity for intermediate and rapid assessments in determining riverine habitat integrity.

### 3.1.4 Study area

Three rivers, namely the Hout Bay, Lourens and Palmiet Rivers were studied in the south-western Cape, in the Fynbos Biome, South Africa (Chapter 1).



## 3.2 METHODS

The habitat integrity of the three rivers was determined by surveys based on two perspectives of the river, namely, the instream channel and the riparian zone. The instream channel is the river channel between the river banks. Instream habitat can be defined as a combination of biotopes making up the living space of an organism (Davies and Day 1998). According to Kemper (2000), the riparian zone is made up of vegetation found in close proximity to a river in a clearly defined zone. Riparian vegetation is dependent on the river for a number of functions; displays structural, compositional and functional characteristics, which are clearly distinct from the fringing vegetation; and is distributed according to clear inundation and other functional gradients. It is a vital component of river ecosystem functioning, as it provides shade, habitat, protection and food for the instream biota; filters sunlight (therefore regulating the instream temperature) and runoff pollutants; and binds the soil, preventing erosion of the river banks (Roth *et al.* 1996; Davies and Day 1998; Withers *in prep.*). Habitat integrity assessments were made separately for both aspects at sites considered to be representative of the geomorphological zones of each river (Chapter 2).

As already stated, the IHI assesses a series of criteria considered to be indicative of habitat integrity. These criteria, listed in Table 3.2, are assessed because anthropogenic modification of their characteristics can generally be regarded as the primary causes of the degradation of river habitat integrity (Kleynhans 1996).

**Table 3.2.** Criteria used in the assessment of habitat integrity assessments (taken from Kleynhans 1999)

| CRITERION | RELEVANCE |
|---|---|
| Water abstraction | Direct impact on habitat type, abundance and size. Also implicated in flow, bed, channel and water quality characteristics. Riparian vegetation may be influenced by a decrease in the supply of water. |
| Flow modification | Consequence of abstraction or regulation by impoundments. Changes in temporal and spatial characteristics of flow can have an impact on habitat attributes such as an increase in duration of low flow season, resulting in low availability of certain habitat types or water at the start of the breeding, flowering or growing season. |
| Bed modification | Regarded as the result of increased input of sediment from the catchment or a decrease in the ability of the river to transport sediment. Indirect indications of sedimentation are stream bank and catchment erosion. Purposeful alteration of the streambed, e.g. the removal of rapids for navigation is also included. |
| Channel modification | May be the result of a change in flow, which may alter channel characteristics causing a change in marginal in-stream and riparian habitat. Purposeful channel modification to improve drainage is also included. |
| Water quality modification | Originates from point and diffuse point sources. Measured directly or agricultural activities, human settlements and industrial activities may indicate the likelihood of modification. Aggravated by a decrease in the volume of water during low or no flow conditions. |
| Inundation | Destruction of riffle, rapid and riparian zone habitat. Obstruction to the movement of aquatic fauna and influences water quality and the movement of sediments. |
| Exotic macrophytes | Alteration of habitat by obstruction of flows and may influence water quality. Dependant upon the species involved and scale of infestation. |
| Exotic aquatic fauna | The disturbance of the stream bottom during feeding may influence the water quality and increase turbidity. Dependant upon the species involved and their abundance. |
| Solid waste disposal | A direct anthropogenic impact, which may alter habitat structurally. Also a general indication of the misuse and mismanagement of the river. |
| Vegetation removal | Impairment of the buffer forms to the movement of sediment and other catchment runoff products into the river. Refers to physical removal for farming, firewood and overgrazing. |
| Exotic vegetation encroachment | Excludes natural vegetation due to rigorous growth, causing bank instability and decreasing the buffering function of the riparian zone. Allochtonous organic matter will also be changed. Riparian zone habitat diversity is also reduced. |
| Bank erosion | Decrease in bank stability will cause sedimentation and possible collapse of the river bank resulting in a loss or modification of both instream and riparian habitat. Increased erosion can be the result of natural vegetation removal, overgrazing or exotic vegetation encroachment. |

The severity of the modification of these criteria was qualitatively assessed using information obtained during field assessments, from 1:50 000 topographic maps, historical data and from discussions held with authorities. The field assessments were conducted once during autumn (April-June) 2002 and then verified during a spring (September-November) 2002 site visit.

The severity of the impact of the modification of the criteria was then rated according to six descriptive classes laid out in Table 3.3, using the guidelines set out by Brown *et al.* (2001) (Appendix A) as an aid.

**Table 3.3.** Descriptive classes for the assessment of modifications to habitat integrity (taken from Kleynhans 1996)

| IMPACT CATEGORY | DESCRIPTION | SCORE |
|---|---|---|
| None | No discernible impact or the modification is located in such a way that it has no impact on habitat quality, diversity, size and variability. | 0 |
| Small | Modification limited to very few localities and the impact on habitat quality, diversity, size and variability is also very small. | 1-5 |
| Moderate | The modifications are present at a small number of localities and the impact on habitat quality, diversity, size and variability are also limited. | 6-10 |
| Large | The modification is generally present with a clearly detrimental impact on habitat quality, diversity, size and variability. Large areas are, however, not influenced. | 11-15 |
| Serious | The modification is frequently present and the habitat quality, diversity, size and variability in almost the whole of the defined area are affected. Only small areas are not influenced. | 16-20 |
| Critical | The modification is present overall with a high intensity. The habitat quality, diversity, size and variability in almost the whole of the defined section are influenced detrimentally. | 21-25 |

To arrive at the final habitat integrity scores for the instream channel and riparian zones, two weighting systems are applied in the IHI. Firstly, as seen in Table 3.4, each criterion in the IHI has been weighted according to its perceived influence on the habitat integrity of rivers. The rating given to each criterion is divided by the maximum value (i.e. 25) and multiplied by its respective weighting (Table 3.4). The estimated impacts of all criteria calculated in this way are then summed, expressed as a percentage and subtracted from 100 to arrive at a provisional assessment of habitat integrity for the instream and riparaian zones respectively. Kleynhans (1996) also describes how a second negative weighting is then applied to this score when the riparian zone criteria and the water abstraction, flow, bed and channel modification, water quality and inundation criteria of the instream component exceed ratings of large, serious or critical. The aim of this second negative

**Table 3.4.** Weighting of criteria used for the assessment of instream and riparian zone habitat integrity (taken from Kleynhans 1996)

| INSTREAM CRITERIA | WEIGHT | RIPARIAN ZONE CRITERIA | WEIGHT |
|---|---|---|---|
| Water abstraction | 14 | Indigenous vegetation removal | 13 |
| Flow modification | 13 | Exotic vegetation encroachment | 12 |
| Bed modification | 13 | Bank erosion | 14 |
| Channel modification | 13 | Channel modification | 12 |
| Water quality | 14 | Water abstraction | 13 |
| Inundation | 10 | Inundation | 11 |
| Exotic macrophytes | 9 | Flow modification | 12 |
| Exotic fauna | 8 | Water quality | 13 |
| Solid waste disposal | 6 | | |
| TOTAL | 100 | TOTAL | 100 |

weighting system is to accommodate possible cumulative and integrated negative effects of such impacts. The system is as follows:

- Impact = Large, lower integrity status by 33 percent of the weight for each criterion with such a rating
- Impact = Serious, lower integrity status by 67 percent of the weight for each criterion with such a rating
- Impact = Critical, lower integrity status by 100 percent of the weight for each criterion with such a rating

These negative weights are added for the instream and riparian facets respectively and the total additional negative weight is then subtracted from the provisionally determined integrity to arrive at a final habitat integrity estimate.

The scores given to each criterion were thus entered into Microsoft Excel spreadsheets supplied by Kleynhans (*pers. comm.* 2002) where, after combination with the above weighting systems, a final habitat integrity score was obtained separately for the instream channel and riparian zone of each site. These final scores were used to place the instream channel and riparian zone of the sites into a habitat integrity category according to Table 3.5. With Category A, in Table 3.5, representing an unmodified, natural condition and Category F, a critically modified habitat condition, these habitat integrity categories indicate the condition of the habitat of the instream channel and riparian zone of each site assessed. The habitat integrity of each site and the geomorphological zone which it is representing can, therefore, be determined according to Table 3.5.

**Table 3.5.** Habitat integrity assessment classes (taken from Kleynhans 1996)

| CATEGORY | DESCRIPTION | SCORE (% OF TOTAL) |
|---|---|---|
| A | Unmodified, natural. | 90-100 |
| B | Largely natural with few modifications. A small change in natural habitats and biota may have taken place but the ecosystem functions are essentially unchanged. | 80-89 |
| C | Moderately modified. A loss and change of natural habitat and biota have occurred but the basic ecosystem functions are still predominantly unchanged. | 60-79 |
| D | Largely modified. A large loss of natural habitat, biota and basic ecosystem functions has occurred. | 40-59 |
| E | The losses of natural habitat, biota and basic ecosystem functions are extensive. | 20-39 |
| F | Modifications have reached a critical level and the lotic system has been modified completely with an almost complete loss of natural habitat and biota. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible. | 0-19 |

## 3.3 RESULTS

### 3.3.1 Habitat integrity along the Hout Bay River

The habitat integrity scores obtained for the instream channel and riparian zone of each site sampled along the Hout Bay River are shown in Figure 3.1.

3.3.1.(i) Instream habitat integrity

Site 1 (Above Hely-Hutchinson Dam): The instream habitat integrity of Site 1 scored 100 or Category A (Figure 3.1) indicating that it is in a natural and unmodified condition (Table 3.5).

Site 2 (Orange Kloof Nature Reserve): On reaching Site 2 in Orange Kloof, the headwaters of the two main streams feeding the Hout Bay River have been impounded and diverted by five impoundments (Chapter 1) which, by affecting the downstream flow, are the main cause (Table 3.6) of the instream habitat integrity decreasing to 80 or Category B (slightly modified) at Site 2 (Figure 3.1; Table 3.5).

Site 3 (Disa Road Bridge): The IHI instream habitat integrity score decreases at Site 3 to 74 or Category C (moderately modified) (Figure 3.1; Table 3.5). This can mainly be attributed to a large

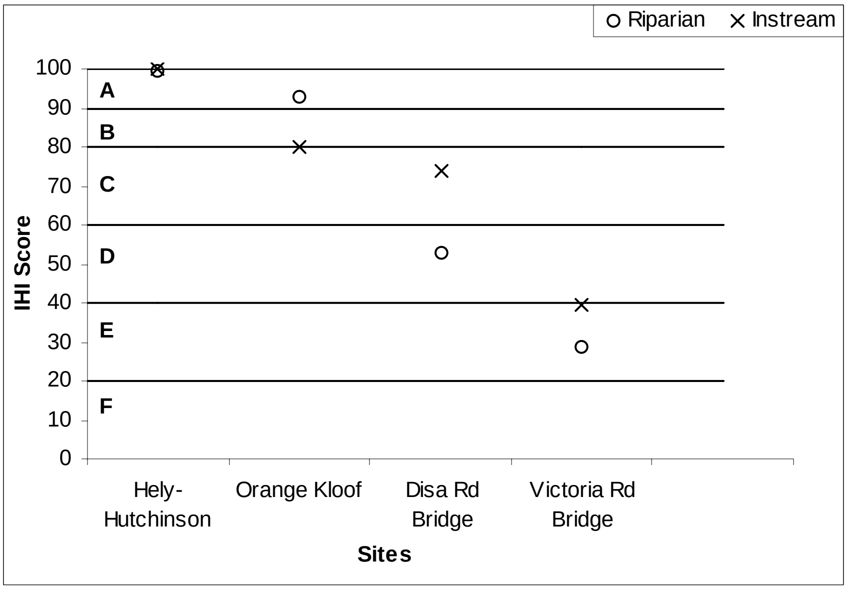


**Figure 3.1.** Instream and riparian habitat integrities along the Hout Bay River (where A-F represent the habitat integrity assessment classes, with A being unmodified or natural and F representing critically modified habitats)

amount of water abstraction, a decrease in water quality, probably due to runoff from the surrounding residential areas and horse paddocks and an increase in bed and channel modification (Table 3.6).



Site 4 (Victoria Road Bridge): The IHI score decreases further to 40 or Category D (largely modified) (Figure 3.1; Table 3.5) as the result of a number of modifications, the most prevalent being extreme channel modification (Table 3.6). The channel is modified by *Pennisetum clandestinum* grassed levees that are a result of dredging the river channel for flood control. The levees cut the river off from its adjacent floodplain. As indicated in Table 3.6, water abstraction and corresponding flow modification, due to upstream activities, still have an impact on the instream habitat integrity at Site 4. Due to the low oxygen saturation recorded, water quality is also considered poor.

3.3.1.(ii) Riparian zone habitat integrity

Site 1 (Above Hely-Hutchinson Dam): A distinct riparian zone was difficult to distinguish at Site 1 as the surrounding terrestrial fynbos extends down to the stream's edge. However, the vegetation fringing the stream and covering the instream islands was assessed as the riparian zone. With this

**Table 3.6.** Impact of various modifications on the instream habitat integrity of the Hout Bay River

| Criterion | Remarks | Score |
|---|---|---|
| Water abstraction | Site 1: None. | 0 |
| | Site 2: Large water abstraction due to major in-channel dams upstream. However, the site is low lying and, consequently, seepage adds to the flow. The change in flow volume from Site 1 was not severe. Dams occupy only a small area of the catchment. | 10 |
| | Site 3: Water abstraction is evident at the site. Large *Eucalyptus* spp. trees are present at the site and these transpire large volumes of water (Sunder 1993). | 11 |
| | Site 4: Abstraction increases a lot between Sites 3 and 4 perhaps due to use by riparian landowners. A small off-channel dam was visible immediately adjacent to the left bank just upstream of Site 4. Many irrigation sprinklers were seen to be watering the adjacent riparian properties. | 15 |
| Flow modification | Site 1: None. | 0 |
| | Site 2: Large. There are two major dams within 5 km upstream of the site, which modify the flow. | 13 |
| | Site 3: Upstream in-channel dams, Longkloof Weir and the apparent water abstraction cause modification to the flow. | 11 |
| | Site 4: The dams, Longkloof Weir and water abstraction upstream as well as established instream vegetation modify the flow. | 15 |
| Bed modification | Sites 1: None. | 0 |
| | Site 2: Some silt deposition evident. | 2 |
| | Site 3: Silt / gravel is in the interstitial spaces between the cobbles but the cobbles are still only minimally embedded. | 5 |
| | Site 4: Not determinable due to opaque water but erosion is evident. Sites in the Lowland River Zone naturally have river beds made up of fine materials like sand. . | 7 |
| Channel modification | Sites 1 and 2: None. | 0 |
| | Site 3: Slight modification, probably due to the surrounding urbanisation, is evident. | 5 |
| | Site 4: Extensive. A constructed levee cuts the river off from its floodplain. | 21 |
| Water quality | Site 1: Excellent. | 0 |
| | Site 2: Very good but slightly silty probably due to upstream inundation. TDS is greater than the TWQR (Chapter 5). | 1 |
| | Site 3: High $N_i$ and TDS concentrations. | 6 |
| | Site 4: $N_i$ and TDS concentrations are within their TWQR (Chapter 5), so the water quality at Site 4 is not as poor as was expected. However, dissolved oxygen is extremely low (Chapter 5) and when assessing water quality, dissolved oxygen concentrations should count 80% of the assessment (van Driel *pers. comm.* 2003). | 16 |

**Table 3.6 continued.** Impact of various modifications on the instream habitat integrity of the Hout Bay River

| Criterion | Remarks | Score |
|---|---|---|
| Inundation | Site 1: None. | 0 |
| | Site 2: Inundation occurs less than 5 km upstream. | 7 |
| | Site 3: Inundation occurs upstream . | 5 |
| | Site 4: A small percentage of the upstream channel is inundated. | 2 |
| Exotic macrophytes | Sites 1, 2 and 3: None. | 0 |
| | Site 4: No exotic macrophyte species present but it must be noted that the cosmopolitan reed *Phragmites australis* has colonised the sandbars in the river and the invasive *Lantana camara* is invading the channel. | 0 |
| Exotic fauna | Sites 1, 2, 3 and 4: According to Hayes (2002) no exotic fish species like *Onchorhyncus mykiss, Micropterus dolomieu, M. salamoides* or *Cyprinus carpio* were found to occur. Indigenous species such as *Sandelia capensis, Galaxias zebratus* and the estuarine species *Gilchristella aestuaria* were found. | 0 |
| Rubbish dumping | Sites 1 and 2: None. | 0 |
| | Site 3: A small amount of litter was found at the site. | 5 |
| | Site 4: 10-50 pieces of litter were seen in a 100 m stretch at the site. | 9 |

site experiencing minimal impacts (Table 3.7) the riparian zone of Site 1 scored 100 or Category A (Figure 3.1) indicating that it appears to be in a natural, unmodified condition (Table 3.5).



Site 2 (Orange Kloof Nature Reserve): Although decreasing to a score of 93, the riparian habitat integrity of Site 2 still appears to be unmodified and in a natural condition (Category A) (Figure 3.1; Table 3.5). Heavy inundation between Sites 1 and 2 of the two headwater streams feeding the Hout Bay River (Table 3.9) probably, however, effects the lateral movement of water, the scouring effect of sediments and the variation in stress periods, which in turn effects the reproduction and overall 'health' of the riparian species (Kleynhans *pers. comm.* 2002).

Site 3 (Disa Road Bridge): The large removal of indigenous vegetation and increase in exotic vegetation encroachment (Table 3.7) has resulted in the riparian zone habitat integrity decreasing to 53 or Category D (largely modified) (Figure 3.1; Table 3.5).

Site 4 (Victoria Road Bridge): As indigenous vegetation removal and exotic vegetation encroachment increases, together with increasing channel modification (Table 3.7), so the integrity

**Table 3.7.** Impact of various modifications on the riparian habitat integrity of the Hout Bay River

| Criterion | Remarks | Score |
|---|---|---|
| Vegetation removal | Sites 1 and 2: None. | 0 |
| | Site 3: Considerable indigenous vegetation removal has occurred. | 13 |
| | Site 4: Severe indigenous vegetation removal is evident. | 19 |
| Exotic vegetation encroachment | Site 1: Evidence of 1 – 2 pine seedlings. | 1 |
| | Site 2: None. | 0 |
| | Site 3: There is severe exotic vegetation encroachment. The river margins are heavily invaded with *Echinochloa crus-galli*. *Acacia melanoxylon* are also evident in large numbers. | 17 |
| | Site 4: Almost no indigenous vegetation remains. *Paraserianthes lophantha* and *Lantana camara* are major invasive species here. | 20 |
| Bank erosion | Sites 1, 2: None. | 0 |
| | Site 3: Little erosion was visible. | 4 |
| | Site 4: Bank erosion is evident but alien vegetation covering the banks appears to control the severity. | 8 |
| Water abstraction | Site 1: None. | 0 |
| | Site 2: Inundation upstream can be seen to abstract water from Site 2. | 2 |
| | Site 3: Water abstraction appears to have a moderate effect on riparian vegetation. | 6 |
| | Site 4: Reduced water flow effects the riparian zone. Reeds are invading the instream channel. | 8 |
| Inundation | Site 1: None. | 0 |
| | Site 2: Large upstream inundation impacts on low and high flows. | 3 |
| | Site 3: Limited impact by upstream inundation. | 2 |
| | Site 4: Inundation appears to have no significant detrimental impact. | 0 |
| Flow modification | Site 1: None. | 0 |
| | Site 2: Upstream (within 5 km) inundation impacts the variation in flow. | 8 |
| | Site 3: Upstream inundation and Longkloof Weir probably effects the variation in flow. | 6 |
| | Site 4: Upstream dams, Longkloof Weir and water abstraction effect flow highs and lows. There is a high incidence of instream vegetation clogging the channel. | 8 |

**Table 3.7 continued.** Impact of various modifications on the riparian habitat integrity of the Hout Bay River

| Criterion | Remarks | Score |
|---|---|---|
| Water Quality | Sites 1 and 2: Water quality (Chapter 5) does not seem to be having an impact on the vegetation. | 0 |
| | Site 3: High $N_i$ concentration (Chapter 5) may have a slight effect. Phosphate concentration is, however, low. | 2 |
| | Site 4: Water quality (Chapter 5) does not seem to be having an impact on the vegetation. | 0 |

of the riparian zone at Site 4 decreases to a score of 29 or Category E (extensively modified) (Figure 3.1; Table 3.5). None of the *Prionium serratum* beds, which according to Brown *et al.* (1997) would naturally have occurred in this section, are evident today.

### 3.3.2 Habitat integrity along the Lourens River

The habitat integrity scores obtained for the instream channel and riparian zone of the sites sampled along the Lourens River are shown in Figure 3.2.

3.3.2.(i) Instream habitat integrity

Site 1(Picnic Bush): Although the site is dominated by the alien fish species *O. mykiss* (Table 3.8), the instream habitat integrity of Site 1 scored 97 and consequently, according to Table 3.5, fell into Category A (Figure 3.2) indicating that the site is unmodified and in a natural condition.

Site 2 (Vergelegen): The instream habitat integrity dropped to a score of 68 or habitat integrity Category C (Figure 3.2) indicating moderate instream habitat modification and a change in natural habitat and biota at Site 2 (Table 3.5). As can be seen from Table 3.6, this 30% decrease in the IHI score from Site 1 is attributable to the high water abstraction levels and large flow modification as well as a decrease in water quality observed between Sites 1 and 2.

Site 3 (Lower Radloff Park): The instream habitat integrity rating drops further to 57 or habitat integrity Category D (Figure 3.2) indicating a largely modified instream habitat (Table 3.5) at Site 3. Although, as seen in Table 3.8, the water abstraction is scored lower here and flow modification is not seen to increase from Site 2, they are still considered to have a large impact. Channel and bed modification, however, increased and water quality deteriorated. These factors are heavily weighted by Kleynhans (1996, 1999) (Table 3.5) and are the cause of the reduction in the habitat integrity score observed at this site.

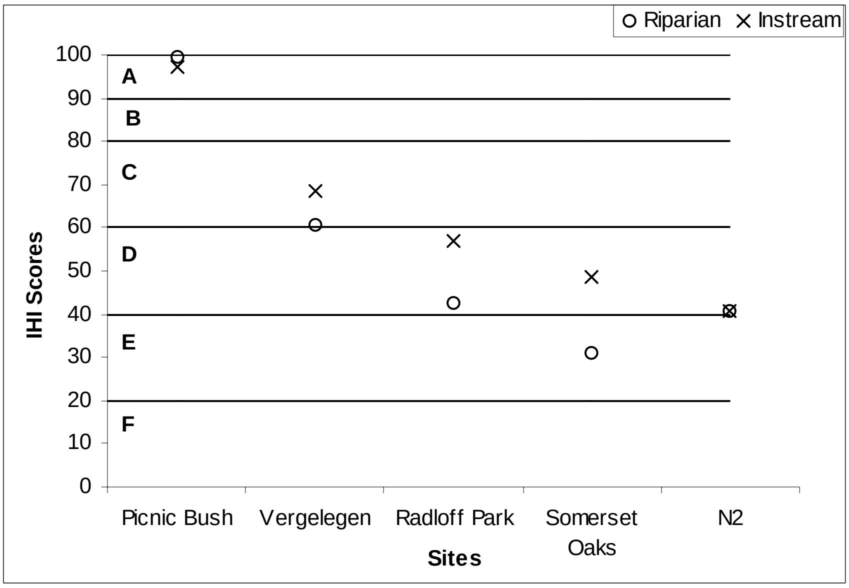


**Figure 3.2.** Instream and riparian zone habitat integrities along the Lourens River (where A-F represent the habitat integrity assessment classes, with A being unmodified or natural and F representing critically modified habitats)

Site 4 (Somerset Oaks): Although the physical instream habitat appears to be in a good condition, increased water abstraction and flow modification, together with large channel modification due to river confinement by gabions probably due to the encroaching urbanisation (Table 3.8), result in the largely modified habitat integrity of Site 4 (Score 49, Category D) (Figure 3.2; Table 3.5).

Site 5 (Open Space off Victoria Road, below the N2): Table 3.8 illustrates that the presence of a light industrial area upstream, together with storm water pipes discharging directly into the river may be the cause of the poor water quality at Site 5. The river bed was considered to be largely modified as extensive *Salix babylonica* root mats cover the substratum, which contains more cobble and exposed bedrock than is expected naturally for lowland river sites. The erosion at the site was also considered to be indicative of extensive bed modification. Large channel modification has occurred either due to rejuvenation as a result of natural uplift, or from increased runoff due to urbanisation, or due to bank stabilisation from the planting of *S. babylonica* for flood protection for the surrounding urban areas (Wadeson *pers. comm.* 2003). Water abstraction and flow modification from upstream activities are also still largely impacting on the instream habitat of Site 5. The IHI score was, therefore, seen to decrease to 41 or Category D (largely modified) (Figure 3.2; Table 3.5) at Site 5.

**Table 3.8.** Impact of various modifications on the instream habitat integrity of the Lourens River

| Criterion | Remarks | Score |
|---|---|---|
| Water abstraction | Site 1: None. | 0 |
| | Site 2: The flow dropped dramatically between Sites 1 and 2. This is probably due to abstraction upstream for irrigation use and the presence of farm dams. Most of the tributaries upstream are impounded. Blue Gum Dam (1.8 million $m^3$) and Rooiland Dam (2.3 million $m^3$) are two of the larger dams abstracting water from the Lourens River above Vergelegen. | 15 |
| | Site 3: Water abstraction upstream from two abstraction points (Wright *pers. comm.* 2002) and for farm dams decreases the natural flow at Site 3. However, the flow at Site 3 was similar to that observed at Site 2. | 11 |
| | Site 4: A severe drop in water flow from Site 3 is seen at Site 4. This decline may be attributed to water abstraction by one known abstraction point upstream (Wright *pers. comm.* 2002), by farm dams and by abstraction for agriculture, forestry and urban use. | 16 |
| | Site 5: Paardevlei on AECI land receives water from the Lourens River via a canal upstream of Site 5 (Wright *pers. comm.* 2002), decreasing the natural river flow. However, although water flow at Site 5 is low, it has not decreased much from Site 4. | 11 |
| Flow modification | Site 1: None. | 0 |
| | Site 2: There are no major in-channel impoundments along the Lourens River. Flow is only modified by the water abstraction described above. The river flows during all months where it naturally would have occurred (Wright *pers. comm.* 2002). | 10 |
| | Site 3: Refer to Site 2. | 10 |
| | Site 4: Refer to Site 2. | 11 |
| | Site 5: Refer to Site 2. | 10 |
| Bed modification | Site 1: None. | 0 |
| | Site 2: Silt and gravel found in the interstitial spaces slightly degrade the habitat available, however, although, the stones were embedded by 30-40%, the spaces between the particles were largely open. | 5 |
| | Site 3: Fine sedimentation filling the spaces between cobbles has moderately degraded the habitat available. | 9 |
| | Site 4: Fine sediment filling the interstitial spaces, moderately degrades the available habitat. Moderate fluvial bank and sub-aerial erosion was evident, further indicating bed modification. | 9 |
| | Site 5: Vast *S. babylonica* root mats alter the habitat diversity and availability to a large degree. These mats also trap sediment. The erosion evident at the site also indicates sedimentation and hence large bed modification is seen to have occurred. There is a larger degree of cobble and exposed bedrock than is expected for lowland river sites (Chapter 2), probably due to the channel modification and rejuvenation that has occurred (Wadeson *pers. comm.* 2003). | 16 |

**Table 3.8 continued.** Impact of various modifications on the instream habitat integrity of the Lourens River

| Criterion | Remarks | Score |
|---|---|---|
| Channel modification | Site 1: None. | 0 |
| | Site 2: A concrete retaining wall below the pedestrian bridge on the right bank is visible. Natural channel movement has been restrained by the planting of large trees. | 8 |
| | Site 3: A concrete berm lies across the river on the left bank diverting flow from its natural channel. A concrete retaining wall downstream on the right bank, to prevent the river from eroding into residential gardens, has resulted in the straightening of the river channel. Gabions occur upstream of the site. | 16 |
| | Site 4: The channel is confined by gabions, interspersed with vegetation in patches. | 16 |
| | Site 5: Where naturally the river would have migrated freely across its floodplain, channel incision has occurred. This may either be the result of rejuvenation from a natural phenomenon like the lowering of the sea level or upliftment of the upper reaches or it may be due to increased runoff from urbanisation (Wadeson *pers. comm.* 2003). The incision may also be the result of the *S. babylonica* planted to stabilise the river banks (Wadeson *pers. comm.* 2003). This down cutting of the channel has resulted in the protruding bedrock seen at the site (Wadeson *pers. comm.* 2003). | 18 |
| Water quality | Site 1: Good. | 0 |
| | Site 2: The water is well oxygenated but inorganic nitrogen ($N_i$) and total dissolved salts (TDS) are present in concentrations greater than the Target Water Quality Range (TWQR) (Chapter 5). However, productive systems are still expected at this N concentration (DWAF 1996). | 9 |
| | Site 3: Although still well oxygenated, $N_i$ and TDS concentrations have increased from Site 2 to above the TWQR (Chapter 5), degrading the water quality. However, productive systems are still expected in this N concentration (DWAF 1996). | 10 |
| | Site 4: Although the $N_i$ concentration has decreased, it is still greater than the TWQR and the TDS concentration has increased (Chapter 5), resulting in poor water quality. However, productive systems are still expected in this $N_I$ concentration (DWAF 1996). | 9 |
| | Site 5: In Chapter 5 it is seen that TDS is within the TWQR but the water is opaque with a high $N_i$ concentration. A dissolved oxygen saturation, below the TWQR was observed during spring. Therefore, water quality is considered to be poor. A storm water drain empties directly into the stream at the site. | 14 |
| Inundation | Sites 1, 2, 3, 4 and 5: None. | 0 |
| Exotic macrophytes | Sites 1, 2, 3, 4 and 5: None. | 0 |
| Exotic fauna | Site 1: *O. mykiss* dominated the site (Impson *pers. comm.* 2003). | 8 |
| | Sites 2 and 3: Alien species *Tilapia sparrmanii* found (Tharme *et al.* 1997). | 5 |
| | Site 4: Alien fish species *O. mykiss, T. sparrmanii* and indigenous species *S. capensis* recorded (Tharme *et al.* 1997). | 8 |
| | Site 5: Alien *C. carpio* and *T. sparrmanii* and indigenous *S. capensis* recorded (Tharme *et al.* 1997). | 13 |

**Table 3.8 continued.** Impact of various modifications on the instream habitat integrity of the Lourens River

| Criterion | Remarks | Score |
|---|---|---|
| Rubbish dumping | Sites 1 and 2: None. | 0 |
| | Site 3: 10 pieces of litter were counted within a 100 m stretch of river. | 5 |
| | Site 4: Between 10 and 50 pieces of litter were counted in a 100 m stretch of river. | 9 |
| | Site 5: More than 50 pieces of litter were counted in a 100 m stretch of river. | 14 |

3.3.2.(ii) Riparian zone habitat integrity

Site 1 (Picnic Bush): Scoring 100, Category A (Figure 3.2), the riparian habitat integrity of Site 1 is unmodified and in a natural condition (Table 3.5).

Site 2 (Vergelegen): Large indigenous vegetation removal and high exotic vegetation encroachment cause the riparian zone habitat integrity to decrease from Site 1 to a score of 60 or Category C at Site 2 (Figure 3.2; Table 3.9). This indicates a loss of natural habitat, biota and basic ecosystem functioning (Table 3.5). The right bank with a good amount of indigenous species recruitment, was, however, found to be in a better condition than the left, which is dominated by exotic vegetation (Table 3.9).

Site 3 (Lower Radloff Park): Extensive indigenous vegetation removal and exotic vegetation encroachment, recorded in Table 3.9, primarily result in the riparian zone at Site 3 scoring 43 or Category D (Figure 3.2). This indicates large habitat modification (Table 3.5). Channel modification is also considered to be large as urban properties extend to the edge of the steepened cement and gabioned banks (Table 3.9).

Site 4 (Somerset Oaks): The riparian zone at Site 4 scored 31 or Category E (severely modified) (Figure 3.2; Table 3.5). Extensive indigenous vegetation removal, together with an almost 100 percent cover of alien plants are the main reasons for this extremely poor condition (Table 3.9). Table 3.9 also shows that due to urban properties encroaching to the edge of the banks, channel modification was considered to be extensive.

**Table 3.9.** Impact of various modifications on the riparian zone habitat integrity of the Lourens River

| Criterion | Remarks | Score |
|---|---|---|
| Vegetation removal | Site 1: None. | 0 |
| | Site 2: Extensive indigenous vegetation has been removed on the left bank for the Vergelegen lawns and farm buildings. The right bank, with more indigenous species still occurring and good indigenous species recruitment, is in a better condition than the left bank, which is dominated by alien species. | 13 |
| | Site 3: Extensive indigenous vegetation removal for residential houses and gardens and for recreational areas. | 15 |
| | Site 4: Extensive with almost no indigenous species remaining. Where the right bank is steepened with gabions, almost no riparian zone is evident. | 17 |
| | Site 5: Little indigenous vegetation remains. | 15 |
| Exotic vegetation encroachment | Site 1: None. | 0 |
| | Site 2: Extensive invasion by exotic species, especially on the left bank. | 14 |
| | Site 3: Large degree of encroachment (60-70%), especially on left bank, which is overgrown and on the right where gardens extend to the edge of the river bank. | 16 |
| | Site 4: Almost all vegetation is exotic. | 19 |
| | Site 5: An estimated 60-70% of the riparian vegetation is exotic (e.g. *S. babylonica* and *P. clandestinum.*) | 16 |
| Bank erosion | Site 1: None. | 0 |
| | Site 2: No significant erosion is evident. | 0 |
| | Site 3: With bare roots visible along most of the site, it is estimated that about 10% or greater of the site (and therefore zone) is eroded. | 5 |
| | Site 4: Limited bank destabilisation is evident, with the rest of the banks being controlled by alien vegetation covering. | 5 |
| | Site 5: Erosion is present on the right bank but is controlled by alien grasses. | 9 |

**Table 3.9 continued.** Impact of various modifications on the riparian zone habitat integrity of the Lourens River

| Criterion | Remarks | Score |
|---|---|---|
| Channel modification | Site 1: A dirt farm road present on left bank. | 1 |
| | Site 2: Limited, resulting from invasion of Vergelegen gardens and agriculture. | 5 |
| | Site 3: The channel has been modified with concrete retaining walls and gabions forming the banks in places and gardens extending right up to the edge of these banks. | 12 |
| | Site 4: Paths, a dirt track and the remains of fires in the urban open space forming the riparian zone on the left bank. With urban properties extending to the edge of the river bank, the riparian zone on the right bank has disappeared almost completely. | 16 |
| | Site 5: It must be noted that the natural floodplain expected and associated riparian zone is no longer present. However, a riparian zone is still present at Site 5 and is not extensively impacted by the open space bordering the right bank and the tar road bordering the left. | 13 |
| Water abstraction | Site 1: None. | 0 |
| | Site 2: Despite a large amount of upstream abstraction, sufficient water still appears to be available for the riparian zone. No signs of mortalities. | 6 |
| | Site 3: Upstream abstraction and on-site abstraction, by alien vegetation, effect the amount of water available for riparian vegetation. | 6 |
| | Site 4: Moderate impact, with upstream abstraction and on-site abstraction, by alien vegetation, affecting the amount of water available for riparian vegetation. | 8 |
| | Site 5: Moderate impact. Large numbers of *S. babylonica* at site remove water, which would otherwise be available for indigenous species. | 6 |
| Inundation | Sites 1, 2, 3, 4 and 5: None. | 0 |
| Flow modification | Site 1: None. | 0 |
| | Site 2: Stress periods experienced by vegetation altered by upstream abstraction. | 4 |
| | Site 3: Upstream abstraction alters stress periods experienced by the riparian vegetation. | 4 |
| | Site 4: Moderate effect with upstream abstraction altering stress periods experienced by the riparian vegetation. | 6 |
| | Site 5: Flow is not altered extensively by upstream activities and hence there is only a limited impact on the riparian vegetation. | 4 |

**Table 3.9 continued.** Impact of various modifications on the riparian zone habitat integrity of the Lourens River

| Criterion | Remarks | Score |
|---|---|---|
| Water Quality | Site 1: No impact. | 0 |
| | Site 2: The $N_i$ concentrations greater than the TWQR (Chapter 5) are surmised to have an impact. However, phosphate concentrations are still low. | 4 |
| | Site 3: The $N_i$ concentrations greater than the TWQR (Chapter 5) are surmised to have an impact. However, phosphate concentrations are still low. | 6 |
| | Site 4: The $N_i$ concentrations greater than the TWQR (Chapter 5) are surmised to have an impact. However, phosphate concentrations are still low. | 4 |
| | Site 5: The $N_i$ concentrations greater than the TWQR (Chapter 5) are surmised to have an impact. However, phosphate concentrations are still low. | 5 |

Site 5 (Open Space off Victoria Road, below the N2): Scoring 41 or Category D (largely modified) (Figure 3.2; Table 3.5), the riparian zone at this site is in a better condition than that of Site 4. This improvement can be attributed to the fact that, although exotic vegetation still dominates the riparian zone, a reasonable amount of indigenous vegetation is still evident (Table 3.9). Riparian channel modification has also decreased at this site (Table 3.9).



### 3.3.3 Habitat integrity along the Palmiet River

The habitat integrity scores obtained for the instream channel and riparian zone of each site sampled along the Palmiet River are shown in Figure 3.2.

3.3.3.(i) Instream habitat integrity

Site 1 (Nuweberg): Scoring 100, or Category A (Figure 3.3), the instream habitat integrity here is unmodified and in a natural condition (Table 3.5).

Site 2 (Grabouw): The instream habitat integrity decreases dramatically from Site 1 to score 36 or Category E (severely modified) at Site 2 (Figure 3.3; Table 3.5). Large water abstraction and flow modification together with very poor water quality and a considerable amount of litter (Table 3.10) degrade the instream habitat integrity at this site. During both autumn and spring the oxygen saturation levels recorded were also lower than those necessary for ecosystem functioning (Table 3.10).


**Figure 3.3.** Instream and riparian habitat integrities along the Palmiet River (where A-F represent the habitat integrity assessment classes, with A being unmodified, natural and F indicating critically modified habitats)

Site 3 (Arieskraal): The instream habitat integrity improves to score 53 or Category D (Figure 3.3; Table 3.5). Flow from the Klein Palmiet River tributary, just above Site 3, mitigates the upstream water abstraction and flow modification (Table 3.10). Although alien fauna scores highly at Site 3 (Table 3.10), this is not heavily weighted by Kleynhans (1996, 1999) and consequently it does not degrade the IHI score severely.

Site 4 (Kogelberg): After entering the Kogelberg Nature Reserve, the habitat integrity at Site 4 improves to score 75 or Category C, moderately modified (Figure 3.3; Table 3.5). Despite the decrease in water quality due to an increase in inorganic nitrogen and TDS concentrations, probably from the heavily agriculturalised catchments of the Huis and Krom Rivers, tributaries of the Palmiet River, water abstraction and flow modification decrease due to flow contributions from these tributaries and because, according to Byren and Davies (1989), Site 4 is beyond the flow recovery distance of the upstream impoundments (Table 3.10). This results in the improved IHI score (Figure 3.3). Sandbanks, which naturally would not have occurred in this region, are present (Table 3.10) indicating increased sedimentation and hence increased bed modification (Table 3.10).

**Table 3.10.** Impact of various modifications on the instream habitat integrity of the Palmiet River

| Criterion | Remarks | Score |
|---|---|---|
| Water abstraction | Site 1: None. | 0 |
| | Site 2: Extensive water abstraction occurs between Sites 1 and 2. The water is still flowing but under natural circumstances the river would have probably meandered more extensively between the macro-channel banks. | 16 |
| | Site 3: Water abstraction is still large but the confluence above Site 3 of the Klein Palmiet tributary, even though impacted itself, seems to be mitigating the effect of upstream abstraction. Arieskraal Dam, just upstream, is a constant bottom releasing dam (Byren and Davies 1989) and should be practising Instream Flow Requirement releases as specified in Brown and Day (1998), but cannot because the release valves are stuck (Boucher *pers. comm.* 2003). | 12 |
| | Site 4: The effect is reduced because of the confluence of the Krom and Huis tributaries, which, although disturbed themselves, contribute to the volume. | 6 |
| | Site 5: Water abstraction is slight, the confluence of the near-pristine (Day 1998) Dwars and Louws River tributaries contributing to the flow. | 3 |
| Flow modification | Site 1: None. | 0 |
| | Site 2: Nuweberg and Eikenhof Dams upstream and off-channel farm dams modify flow. | 18 |
| | Site 3: The effect of Arieskraal Dam, less than 5 km upstream of Site 3, is mitigated periodically by contributions from a major tributary, the Klein Palmiet (Byren and Davies 1989), entering the river between Arieskraal Dam and Site 3. | 16 |
| | Site 4: The normal seasonal flow regime has recovered at Site 4 from upstream impoundments (Byren and Davies 1989). However, big floods are still kept back and sediment volumes may be affected by dam releases. Tributary impoundments may modify the flow slightly. | 6 |
| | Site 5: This site is beyond the recovery distance from upstream impoundments, plus near-pristine tributaries contribute to the flow. | 3 |
| Bed modification | Site 1: None. | 0 |
| | Site 2: There is evidence of deposition in the runs and pools and it is estimated that the cobbles are embedded to a large degree. The water is opaque and silty. Erosion is also visible. | 10 |
| | Site 3: There is evidence of silt and gravel between the interstitial spaces, probably as the upstream dam is a bottom release dam (Byren and Davies 1989), but the spaces are still largely open. There is a landslide on the right bank at the site. Starting as a natural phenomenon, it has probably become larger and more severe due to a road cut into the hillside halfway down. | 7 |
| | Sites 4: Siltation is evident. Sandbanks downstream of the site are indicative of increased sedimentation. | 6 |
| | Site 5: Siltation is evident. | 4 |

**Table 3.10 continued.** Impact of various modifications on the instream habitat integrity of the Palmiet River

| Criterion | Remarks | Score |
|---|---|---|
| Channel modification | Site 1: None. | 0 |
| | Site 2: Some degree of channel modification is evident. | 5 |
| | Sites 3, 4 and 5: There is no evidence of channel modification. | 0 |
| Water quality | Site 1: Excellent. | 0 |
| | Site 2: The water quality is critically poor as oxygen saturations below that necessary for ecosystem functioning were recorded in both autumn and spring (Chapter 5). $N_i$ and TDS concentrations greater than the TWQR (Chapter 5) were observed. There is abundant litter at the site as well as an unpleasant odour. | 21 |
| | Site 3: There is a high TDS concentration but the overall water quality is good. | 4 |
| | Site 4: The water quality is reasonable but high $N_i$ and TDS concentrations were observed. An oxygen saturation below that necessary for ecosystem functioning was obtained in spring. | 9 |
| | Site 5: Good. | 0 |
| Inundation | Site 1: None. | 0 |
| | Site 2: A considerable percentage of the upstream channel is inundated. | 13 |
| | Site 3: A large percentage of the upstream channel is inundated. | 16 |
| | Site 4: Upstream inundation impacts this site, by holding back large floods and altering the sediment loads during dam releases. | 6 |
| | Site 5: Upstream inundation still impacts this site. | 4 |
| Exotic macrophytes | Sites 1, 2, 3, 4 and 5: None. | 0 |
| Exotic fauna | Site 1: None (Brown and Day 1998). | 0 |
| | Site 2: There is no record of any (Hayes 2002). | 0 |
| | Site 3: *M. dolomieu* is present (Brown and Day 1998). | 19 |
| | Site 4: *M. dolomieu, M. salamoides* and *L. macrochirus* are present (Brown and Day 1998). | 19 |
| | Site 5: Indigenous *Anguilla mossambica* present. The dominant fish is the exotic, *M. dolomieu* (Brown and Day 1998). | 19 |
| Rubbish dumping | Site 1: None. | 0 |
| | Site 2: More than 50 pieces of litter were counted in a 100 m section at the site. | 14 |
| | Sites 3, 4 and 5: No litter was observed. | 0 |

Site 5 (Post Box): The instream habitat integrity score at Site 5 improves further to 87 (Category B, slightly modified) (Figure 3.3; Table 3.5). The additional water added by the near-pristine Louws and Dwars Rivers mitigates the upstream effects of inundation and, combined with the decrease in the impacts of the other criteria, gives rise to an improved habitat integrity score (Table 3.10).

3.3.3.(ii) Riparian zone habitat integrity

Site 1 (Nuweberg): The riparian habitat integrity scores 100 or Category A (Figure 3.3) indicating that the riparian zone is in an unmodified, natural condition (Table 3.5).

Site 2 (Grabouw): The severe inundation between Sites 1 and 2 and the corresponding flow modification combined with extensive indigenous vegetation removal and exotic vegetation encroachment (Table 3.11) result in the riparian habitat integrity at Site 2 decreasing to 31 or Category E (extensively modified) (Figure 3.3; Table 3.5).

Site 3 (Arieskraal): The riparian zone habitat integrity improves to 60 or Category C (largely modified) (Figure 3.3; Table 3.5). Table 3.11 shows that, although the upstream inundation and consequent flow modification are considered to have an impact, the fact that there is minimal indigenous vegetation removal combined with a decrease in exotic vegetation encroachment, appears to result in improvement in the habitat.

Site 4 (Kogelberg): In the Kogelberg Nature Reserve, the riparian habitat integrity scores 85 or Category B (largely natural, few modifications) (Figure 3.3; Table 3.5). It can be seen in Table 3.11 that this improvement is due to the fact that near-pristine indigenous vegetation dominates the riparian zone and that the river has recovered from the effects upstream abstraction.

Site 5 (Post Box): The riparian zone, scoring 93 (Category A, natural, unmodified) (Figure 3.3; Table 3.5), consists almost completely of indigenous vegetation and the confluence and corresponding additional flow from the almost pristine tributaries, the Dwars and Louws Rivers (Day 1998), mitigates upstream flow modification (Table 3.11).

**Table 3.11.** Impact of various modifications on the riparian habitat integrity of the Palmiet River

| Criterion | Remarks | Score |
|---|---|---|
| Indigenous vegetation removal | Site 1: None. | 0 |
| | Site 2: It is estimated that more than half of the indigenous vegetation has been removed. | 15 |
| | Site 3: Very little removal of indigenous riparian vegetation. There is also evidence of upstream exotic *Pinus pinaster* tree removal. | 3 |
| | Sites 4 and 5: None. | 0 |
| Exotic vegetation encroachment | Site 1: A few juvenile *Acacia mearnsii* were found. | 1 |
| | Site 2: There is an estimated 60-70% exotic vegetation encroachment. | 19 |
| | Site 3: *P. pinaster* trees are invading into the riparian zone on the left bank, especially downstream of the site. | 11 |
| | Site 4: Recruitment of alien species (e.g. *A. mearnsii*) is evident. | 10 |
| | Site 5: Recruiting *A. longifolia* and *A. mearnsii* are present at the site. | 6 |
| Bank erosion | Site 1: None. | 0 |
| | Site 2: Limited erosion was evident. | 5 |
| | Site 3: Although the landslide evident on the right bank is a natural phenomenon, the road cut into the hillside halfway down worsens the erosion associated with it. | 5 |
| | Sites 4 and 5: None evident. | 0 |
| Channel modification | Site 1: None. | 0 |
| | Site 2: Minimal impact. | 3 |
| | Sites 3: None evident. | 0 |
| | Site 4: Sandbanks are visible downstream and upstream of the site, which is uncharacteristic. They are probably the result of increased sedimentation. Reeds invade these sandbanks. | 5 |
| | Site 5: None evident. | 0 |
| Water abstraction | Site 1: None. | 0 |
| | Site 2: Despite upstream water abstraction, there still appears to be sufficient water for the survival of the riparian zone. | 10 |
| | Site 3: Abstraction has a moderate impact on the riparian vegetation. | 9 |
| | Site 4: The impact of water abstraction was seen to be limited. | 5 |
| | Site 5: With the near-pristine Dwars and Louws River tributaries contributing their volumes, the impact of water abstraction was seen to be very limited. | 3 |

**Table 3.11 continued.** Impact of various modifications on the riparian habitat integrity of the Palmiet River

| Criterion | Remarks | Score |
|---|---|---|
| Inundation | Site 1: None. | 0 |
| | Site 2: Upstream inundation withholds water that would otherwise create a wider stream channel and a very different appearance to the site. | 12 |
| | Site 3: A large percentage of the upstream channel is inundated having a large impact on the riparian zone. | 13 |
| | Site 4: Upstream inundation has a moderate impact as tributaries are having a mitigating influence. | 5 |
| | Site 5: The effect of upstream inundation is slight. | 3 |
| Flow modification | Site 1: None. | 0 |
| | Site 2: Flow is modified by upstream inundation and water abstraction. | 12 |
| | Site 3: Arieskraal Dam, being a constant flow release dam, upstream probably results in flow constancy. However, the impact is mitigated probably by the flows from the Klein Palmiet River tributary. | 10 |
| | Sites 4: The flow has recovered from upstream inundation at Site 4 (Byren and Davies 1989). Tributary impoundment may also have a slight impact. | 5 |
| | Site 5: Slight impact. | 3 |
| Water Quality | Site 1: None. | 0 |
| | Site 2: $N_i$ concentration above the TWQR may have slight impact. | 3 |
| | Site 3: Limited if any impact. | 1 |
| | Site 4: Although a high $N_i$ concentration was recorded, water quality does not appear to impact the riparian vegetation. | 1 |
| | Site 5: None. | 0 |

## 3.4 DISCUSSION

### 3.4.1 Longitudinal patterns seen along the three rivers assessed

The general longitudinal decrease in habitat integrity as one moves downstream along the Lourens and Hout Bay rivers is expected because as one moves downstream into the flatter middle and lower reaches of rivers, one expects to find an increase in impacts associated with a transgression from natural, undisturbed mountainous areas to areas characterised by anthropogenic disturbances (e.g. agricultural and urban developments). However, the Palmiet River proves to be an exception. Although, like in the Lourens and Hout Bay Rivers, the habitat integrity deteriorates as the river moves from the pristine mountain reaches into the foothill reaches, it improves in the river's lower reaches downstream of Site 2. This is seen as the river seems to rejuvenate or restore itself as its lower reaches move through the Kogelberg Nature Reserve, which is characterised by natural undisturbed vegetation. Similar results were reflected by Roth *et al.* (1996) who noted that along the River Raisin in Midwestern USA, the highest habitat integrity scores were found where anthropogenically modified land use types like, agriculture, were less dominant than natural vegetation in the surrounding areas. Roy *et al.* (2003) also noted that changing land cover into anthropogenically modified uses degrades stream habitat. Specifically, they found that in urban areas a destruction of habitat occurred. Similar results are seen in this South African study, where the IHI scores decrease as the rivers flow through the urban areas of Hout Bay, Somerset West and Grabouw respectively. In his habitat integrity assessment of the Luvuvhu River, South Africa, Kleynhans (1996) found a similar pattern to that observed in this study along the Palmiet River. The bottom reaches studied by Kleynhans (1996) improved in habitat integrity from the middle reaches as the river passed from agricultural areas into the conservation areas of the Kruger National Park. However, the habitat integrity of the lower reaches, as is seen along the Palmiet River, still reflected the impacts of water abstraction and flow modification occurring in the upstream reaches. It, therefore, appears that the surrounding land use could be a major determinant of habitat integrity.

### 3.4.2 Instream habitat integrity versus riparian zone habitat integrity

Interesting contrasting conditions are found along the three rivers assessed. Firstly, the first sites on all three rivers are relatively unimpacted and represent pristine, near-natural conditions (i.e. the control situation). The Lourens River represents a river with no in-channel impoundments. In its middle and lower impacted reaches, where the river is surrounded by anthropogenically modified land uses (e.g. urban and agricultural areas), the riparian zone habitat score is lower than that of the instream habitat (Figure 3.2). This potentially indicates that the surrounding land use effects riparian habitat integrity to a greater extent than it does the instream. Site 2 on the Hout Bay River and Site 3 on the Palmiet River represent sites impacted by dams less than 5 km upstream but mainly surrounded by natural vegetation (Chapter 4). Here the riparian habitat is in a better condition than the instream habitat. This may indicate that the effects of upstream dams degrade instream habitats more severely than they do the riparian. However, Site 2 on the Palmiet River represents a site less than 5 km below a dam but dominated by anthropogenic disturbances. Here the riparian habitat scores less than the instream habitat. So it appears that, although, the upstream inundation affects both aspects, the occurrence of anthropogenically modified land use surrounding the site appears to degrade the riparian habitat more, thereby decreasing its score below that of the instream channel. Sites 3 and 4 on the Hout Bay River represent sites that have partially recovered from upstream inundation but are surrounded by modified land use types. As in the case of the Lourens River, these sites have a riparian habitat integrity score lower than the respective instream habitats. Sites 4 and 5 on the Palmiet River represent sites that have partially recovered from upstream inundation and are surrounded by natural near-pristine vegetation of the Kogelberg Nature Reserve. Here the instream habitat is degraded due to poor water quality from polluted tributaries upstream but the riparian habitat is good. It, therefore, appears that the riparian zone habitat integrity is effected primarily by on site effects (i.e. surrounding land use types), whereas the instream habitat integrity is affected by upstream effects which can originate at a substantial distance above the sampling site.

Both the instream and riparian components are, however, important for an overall habitat integrity assessment of a river. One component cannot be prioritised above the other as both effect the river condition (Kleynhans 1996; Davies and Day 1998). The instream conditions, in other words, the substrate and the water quality, provide habitats and living conditions for aquatic biota. The riparian zone vegetation provides shade, habitat and protection for the instream biota; filters sunlight (therefore regulating the instream temperature) and runoff pollutants; and binds the soil, preventing erosion of the river banks and thereby habitat degradation (Davies and Day 1998; Withers *in prep.*). Therefore, both components need to be assessed when determining the habitat integrity of rivers.

### 3.4.3 Management actions to improve the habitat integrity along the three rivers assessed

Using the results of the habitat assessments conducted in this study together with discussions held with members of the River Health Team (namely, Ms MJ Withers[1] and Mr DJ Ollis[1]), management actions can be suggested to improve and / or maintain the habitat integrity of the rivers assessed. A few such management actions are discussed below.

#### 3.4.3.(i) Hout Bay River

To improve the instream and riparian habitat integrity in the lower zones of the Hout Bay River, it is suggested, firstly, that the river channel between the levees should be widened. This will allow for the reconnecting of the channel with part of its floodplain, thereby restoring some of the natural structure and functioning of the river channel in this zone. It will also encourage the establishment of a zone of indigenous riparian and marginal vegetation, which will (1) act as a buffer against sediments and pollutants entering the river from surrounding areas as well as absorbing nutrients from the river and from run-off waters, (2) retain water after winter rains, (3) provide nesting areas

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for birds and cover for fish, (4) modulate water temperatures and (5) increase the flood absorption capacity of the river; all of which will aid in improving the habitat condition in these lower reaches (Brown *et al.* 1997). Secondly, the removal of alien vegetation along the river banks should be encouraged. This will reduce unnecessary water loss from the rivers and will provide the opportunity for indigenous species to recolonise the banks resulting in improved bank stability, improved buffering capacity of the riparian zone, an increase in riparian habitat diversity and a decrease in the foreign organic matter entering the stream (Davies and Day 1998). Alien vegetation clearing and reintroduction of indigenous species in the riparian zone should also occur along the entire length of the river and the major sources of water abstraction along the river, especially between Sites 3 and 4, should be identified and remedied.

3.4.3.(ii) Lourens River

To improve the habitat integrity of the Lourens River in its middle reaches, it is advised that, firstly, an indigenous riparian zone be established as a buffer between the river and the surrounding agricultural and urban activities. This would not only improve the riparian habitat integrity but by acting as a filter for nutrients and sediments, stabilising the river banks and regulating the water temperature, it would also improve the instream habitat integrity (Davies and Day 1998). Secondly, farming practices should be improved in the surrounding areas so as to reduce the $N_i$ concentrations recorded in the river (Hall *et al.* 1996; O'Keeffe *et al.* 1996; Sung-Ryong and Myung-Soon 2001; Evans 2002). The alien vegetation occurring at present in the riparian zone along the length of the river should be removed and indigenous species should be reintroduced, which would improve the riparian habitat integrity of the river. In the urban areas, it is unreasonable to expect the channelisation of the river to be removed, however, it could be modified to improve the slopes and thus the habitat integrity. In the lower reaches (i.e. the reaches represented by Site 5), it is possible to landscape the built up banks to restore some of the natural shape of the river channel, which would improve the instream habitat integrity as well as the riparian zone integrity as a riparian zone, reminiscent of the natural zone expected there, could then be developed.

3.4.3.(iii) Palmiet River

Again, along the entire length of the river, alien vegetation should be removed and indigenous vegetation species should be reintroduced into the riparian zone. The dams must release the instream flow requirements determined in Brown and Day (1998) so as to ensure that sufficient water is available in the downstream reaches. The increased TDS and $N_i$ concentrations observed at Site 4 in the Kogelberg Nature Reserve should be investigated and the sources should be remedied.

It is suspected that the sources of these elevated concentrations are along the Huis and Krom River tributaries, which are heavily agriculturalised. In that case, agricultural practices along these rivers should be improved. Fishing of the alien fish species should be encouraged as the removal of species such as *M. dolomieu* and *M. salamoides* would improve the instream habitat integrity of the lower reaches.

### 3.4.4 Comments on the IHI: Criticisms and suggestions

Although Kleynhans (1996) points out that the total evaluation of ecosystem health will always be partly subjective, the IHI, which is designed to be used with ease by assessors with little experience or expertise, was found to be highly subjective. It was also difficult to conceptualise what constituted, in Table 3.3, the numeric difference between qualitative measures like a "large" versus a "serious" impact, for example. It was found that without the guidelines prepared by Brown *et al.* (2001) over-scoring of the criteria occurred. Although these guidelines (Appendix A) need verification and possible refinement and were, therefore, used with caution, they aided the assessor in putting the scoring of impacts into perspective. For example, the effect of *O. mykiss,* versus *M. dolomieu* on instream habitat integrity became clear using the guidelines. However, it must be noted that these guidelines need refinement and this would be an excellent and, in fact, vital future subject for study.

If this study had relied on inferring the water quality at the various sites instead of using the results of water quality measurements (Chapter 5), then the study would not have shown the unexpected increase in inorganic nitrogen at the Palmiet River Site 4 in the Kogelberg Nature Reserve, nor the unexpected decrease in inorganic nitrogen and total dissolved salts concentration at Hout Bay River Site 4. It is, therefore, suggested that, when assessing the water quality criterion of the index, water quality tests should be conducted rather than inferring the state of the water quality from the surrounding landscape.

It is suggested that the IHI need only be conducted at a lower than seasonal or annual frequency, as the effects of changes in the physical criteria assessed will only become noticeable over a longer time period. The index will not pick up short term fluctuations and, therefore, is not suited to biomonitoring, like the South African Scoring System (SASS), which can reflect such changes in river condition. However, like the Visual Stream Assessment (VSA) developed by the Natural Resources Conservation Service (NRCS) in the USA (USDA/NRCS 1998), it is a useful index in working with landowners (McQuaid and Norfleet 1999). Landowners and conservationists can use this index to recognise degraded areas of a stream and to identify the causes of this habitat degradation, so that appropriate conservation measures and management actions to address the areas of concern can be formulated. However, it is strongly suggested that, like the VSA, the scoring of the IHI is categorised so that the assessor chooses the score that fits the description best suited to the site. This will aid the assessor in allocating appropriate scores to the impact of the modification of the criteria assessed on the habitat integrity of rivers and will ensure that over- and/or under-scoring does not occur. It will also reduce the subjectivity of the index.

It is also suggested that the IHI assessments be conducted during the summer months in the south-western Cape as this is the dry season and, although, the other criteria will not be affected much, the effects of water abstraction, which according to Kleynhans (1996), is the most prominent modification to instream habitat integrity, will clearly be evident. The effects of water abstraction on the riparian vegetation will also be more evident as during this time the river is a vital source of moisture for the vegetation. In other words, the rivers should be assessed during the period when they are under natural stress.

It is felt that a criterion to measure algae should be added to the index. Algae should be scored here as not only do they indicate poor water quality but they also can potentially degrade the water quality by depleting the water oxygen levels via to photosynthesis and can affect the physical habitat available for aquatic biota.

Overall, the scores obtained for both components at the sites assessed reflected, what Kemper (2000) refers to as, the "gut" feel (the general feeling obtained from the site visit) of the assessor and have been accepted by experts in the Provincial River Health Team (championed by A. Belcher[6]), who reviewed the sites with the author at a River Health Assessment Peer Review Workshop (March 2003) at the DWAF offices in Bellville. Habitat integrity provides a template for a certain level of biotic integrity to be realised (Kleynhans 1996; Harper and Everard 1998) and the IHI is essentially assessing the ability of the river to provide suitable living conditions for biota (Kleynhans 1996). One can, therefore, conclude that conducted at the same sampling sites at the same time, the results of SASS (Ollis *in prep*.), which assesses aquatic invertebrates, should to some degree be similar to the instream habitat integrity results obtained in the IHI. At the River Health Workshop held at DWAF (Bellville, Cape Town, South Africa) in March 2003, it was indeed found that the results of the above two indices did correspond. It can, therefore, be

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concluded that the instream habitat integrity component of the IHI is successful in indicating the instream habitat condition of rivers. The RVI assesses the structural and morphological aspects of the riparian vegetation in the riparian zone, whereas the IHI looks at the ability of the riparian zone in functioning to provide suitable living conditions for biota. However, both indices are essentially assessing the condition of the riparian zone. For the riparian zone to function efficiently in providing suitable habitat conditions for biota, the riparian vegetation needs to be in good condition. Therefore, if the RVI conducted for the same sampling sites at the same time indicates degradation of the riparian vegetation at a site, then IHI should reflect a degraded habitat integrity score for the riparian zone of that site. At the same River Health Workshop mentioned above, it was found that the RVI (Withers *in prep.*) and IHI scores for the riparian zone were generally similar. In the instances where there was a large discrepancy between the scores, it was found that a fault lay with the RVI as in these cases overscoring of a component assessed in the RVI was occurring (Withers *in prep.*). The RVI is also only in its initial stages of development and is in the process of being refined. It, therefore, appears that the IHI is successful in reflecting the habitat condition of the riparian zone and one can conclude that overall, the IHI is succeeding in reflecting the habitat integrity or condition of rivers.

## 3.5 CONCLUSIONS

In South Africa, as is the case internationally, there is considerable concern regarding the health or general condition of aquatic ecosystems. In assessing overall ecosystem health, knowledge of the availability and quality of habitats is considered to be vital. Consequently, habitat assessment has become an important part of evaluating ecological health internationally and, for this purpose, the Index of Habitat Integrity (IHI), used in this study, was developed in South Africa. From the results it appears that the IHI is successful in identifying areas of habitat degradation (i.e. areas of concern) and gives a wide, general perspective of the changes that have occurred along the rivers on a macro habitat scale.

Kleynhans (1996) states that ultimately a suite of methods with an increasing degree of detail and quantification (depending on the information requirements) needs to be employed in the total assessment of ecological health. In light of this, the results of this study were designed to fit hand in hand with the results of simultaneous biological assessments, which examined other aspects of concern to river health (Hayes 2002; Ollis *in prep.*; Withers *in prep.*). Together, these four studies are essentially a scoping process giving an overarching indication of the ecological condition of the

Hout Bay, Lourens and Palmiet Rivers. Detailed specialist studies conducted on a smaller scale should now be carried out in the areas of concern identified by these studies, so that the exact causes of the degradation in the health of these rivers can be determined. Negative influences should then be remedied.

The results from this study, together with the other three mentioned above, have been combined to produce a State-of-Rivers Report (RHP *in prep.*). The data accumulated should also be incorporated into a water resource management system database (Roux *et al.* 1999), so that appropriate management strategies for the improvement of the health of the rivers assessed can be determined.

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# THE INFLUENCE OF SURROUNDING LAND USE ON RIVERINE HABITAT INTEGRITY: AN ASSESSMENT AT DIFFERING SPATIAL SCALES

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## ABSTRACT

Management of surrounding land use is necessary for the maintenance of good ecological river condition. This study attempts to determine the influence of surrounding land use, at a local and regional scale, on the habitat integrity of three south-western Cape rivers. The results indicate that:

1) riparian zone habitat integrity is affected primarily by local land use conditions, whilst instream condition is effected more by upstream land use;
2) the percentage of natural versus disturbed land use, occurring at either scale, is a good predictor of both instream ($r^2 = 0.83$, $r^2 = 0.81$, $p < 0.05$) and riparian ($r^2 = 0.87$, $r^2 = 0.78$, $p < 0.05$) habitat integrity;
3) along the three rivers assessed, local urban development and regional alien forestry plantations have strong negative influences on both instream ($r^2 = - 0.80$, $r^2 = 0.80$, $p < 0.05$) and riparian ($r^2 = - 0.83$, $r^2 = - 0.81$, $p < 0.05$) habitat integrity.

It, therefore, appears that different land use types effect the habitat integrity of streams at differing scales. River management must thus occur over various scales. These results can be used to design management strategies for improving habitat conditions in the three rivers assessed.

***Key words:*** *habitat integrity, land use, local / regional scales*

## 4.1 INTRODUCTION

### 4.1.1 The River Health concept

Fresh water resources in South Africa are limited (WRC 2001; RHP 2003) and consequently, South African stream ecosystems are facing increasing stresses due to over-utilisation of water in an over-stressed region (DWAF 1996; Davies and Day 1998). The natural water environment is not regarded as a user in competition with other users (e.g. domestic, agricultural, industrial) (DWAF 1996; Kleynhans 1996) but rather as a resource base from which water originates and as an entity with its own intrinsic environmental value (Kleynhans 1996). To ensure that South Africa's water resources remain fit for agricultural, domestic, recreational and industrial use on a sustainable basis, aquatic ecosystems as a resource base must, therefore, be effectively protected and managed (DWAF 1996).

The concept of 'river health' simply refers to the condition of a river (Roux *et al.* 1999; WRC 2001). An ideally healthy river is one that is in or very close to its natural (undisturbed) state (O'Keeffe *et al.* 1994). River health measures conditions that are necessary for proper ecosystem functioning and for the ability to supply good quality water for consumption, irrigation and industrial processes and services like shade, food, grazing, medicinal plants and denitrification (DWAF 1996; Tharme *et al.* 1997; CSIR 2002; WRC 2002; RHP 2003). Lack of water meeting the above needs will constrain human subsistence and development (CSIR 2002).



### 4.1.2 The River Health Programme

As custodian of water resources in South Africa, the Department of Water Affairs and Forestry (DWAF) is responsible for the protection of aquatic ecosystem health, thereby ensuring their ability to meet the utilisation requirements of present and future generations (DWAF 1996; WRC 2001). For this purpose, DWAF initiated the River Health Programme (RHP) in 1994 (Roux *et al.* 1999; WRC 2001, 2002; RHP 2003, *in prep.*). Such a programme is in compliance with the National Water Act (Act No. 36 of 1998) legislating the monitoring of the health of the nation's rivers (Republic of South Africa 1998; Rowntree *et al.* 2000; WRC 2001, 2002; RHP 2003, *in prep.*).

To determine river health (condition) the RHP uses scientifically derived indices to assess ecological indicators considered representative of the wider river ecosystem (WRC 2001, 2002; RHP 2003, *in prep.*; Chapter 1). The indices' results are then used to classify the river ecosystem in terms of its degree of modification relative to a natural benchmark (undisturbed) condition (Roux *et al.* 1999; Rowntree *et al.* 2000). One such index is the Index of Habitat Integrity for intermediate and rapid assessments (Kemper 1999; Chapter 3), which assesses the habitat integrity or condition of a river in terms of its ability to provide suitable living conditions for biota (Kleynhans 1996).

### 4.1.3 The influence of land use on river health

The surrounding land use of a catchment affects the water quality of and habitats available in a river (Nash 1993; Hall *et al.* 1996; Roth *et al.* 1996; Allan *et al.* 1997; Townsend and Riley 1999; Lyons *et al.* 2000). Allan *et al.* (1997) suggest that the influence of land use on stream habitat integrity is scale-dependent, with instream habitat structure being determined primarily by local conditions and nutrient supply and channel characteristics being influenced by regional conditions, including land use at some distance upstream and lateral to the sites assessed. Management of the surrounding land uses at multiple spatial scales is, therefore, necessary for the maintenance of good ecological conditions in rivers (Nash 1993). Understanding the relationship between the health of rivers and land use surrounding the rivers is important in determining management strategies to maintain and / or improve river health, so that once riverine areas of poor ecological health are identified, new management strategies for land use activities surrounding these areas can be determined. A cyclical, continuous process of rapid assessment leading to a management plan, then reassessment, followed by revision of the management plan needs to be practised (Roux *et al.* 1999).

This study will attempt to determine the possible influence of surrounding land use on the habitat integrity of three south-western Cape rivers. Previous studies by Roth *et al.* (1996) found that habitat integrity correlated strongly with regional land use throughout the catchment upstream of a site. Lammert (1995 in Allan *et al.* 1997), on the other hand, found that the local scale of land use (defined as 150 m to 1 500 m upstream of a site) was the best predictor of stream condition. Allan *et al.* (1997) suggest that catchment management needs to occur at a regional scale because, whilst concentrating on only the local conditions will offer some benefit to river condition, it appears that land use occurring at a regional scale is more important. This study will, firstly, determine and compare the influence of land use at a local and regional scale on the habitat integrity of the three rivers assessed.

The Index of Habitat Integrity for intermediate and rapid assessments (Kemper 1999) used in Chapter 3 assesses the habitat of a riverine ecosystem from two perspectives, namely, the instream channel and the riparian zone (Kleynhans 1996; Kemper 1999). The instream channel is the river channel between the river banks. Instream habitat can be defined as a combination of biotopes making up the living space of an organism (Davies and Day 1998). The riparian zone is made up of vegetation found in close proximity to rivers in a clearly defined zone. This riparian vegetation is dependent on the river for a number of functions; displays structural, compositional and functional characteristics, which are clearly distinct from the fringing vegetation; and is distributed according to clear inundation and other functional gradients (Kemper 2000). It is a vital component of river ecosystem functioning as it provides shade, habitat, protection and food for the instream biota; it filters sunlight (therefore regulating the instream temperature) and runoff pollutants; and it binds the soil, preventing erosion of the river banks (Roth *et al*. 1996; Davies and Day 1998; Withers *in prep.*). This study will also, secondly, compare the influence of surrounding land use at a local and regional scale on the riparian and instream habitat integrities respectively.

### 4.1.4 Study area

Three rivers, namely the Hout Bay, Lourens and Palmiet Rivers were studied in the south-western Cape, in the Fynbos Biome, South Africa (Chapter 1).

## 4.2 METHODS

Firstly, the habitat integrity scores for the sites assessed along the Lourens, Hout Bay and Palmiet Rivers were obtained from Chapter 3.

Secondly, up-to-date land use coverages for the catchments assessed were not available (Lewarn *pers. comm.* 2003; de Klerk *pers. comm.* 2003). Land use coverages, therefore, needed to be digitised from a digital satellite image of the areas. From discussions with experts (Boucher *pers. comm.* 2002; Dallas *pers. comm.* 2002; Van der Merwe *pers. comm.* 2002) it was decided that a 1 km buffer on either side of the river channel would be sufficient to pick up the major land use types influencing the habitat integrity of a river. A 1 km buffer was, therefore, created around each river in the Geographical Information Systems (GIS) programme ArcView (ESRI 2003). Along each river the major land use types within the 1 km buffer were identified, according to both the differing impacts they exert on rivers and to their areas occupied, and were digitised from a digital satellite image in ArcView. A land use map of each river was thus created.

Along each of the three rivers, the following nine land use types were identified and mapped.

- ‘Natural’ comprises areas that are under natural indigenous vegetation or natural rock. These areas are unmodified and are mostly managed by the Western Cape Nature Conservation Board. Most natural areas are located in the Mountain Stream Zones (Chapter 2) of the rivers, except in the case of the Palmiet River, where the natural areas of the Kogelberg Nature Reserve surround the lower Rejuvenated Foothill Zone (Chapter 2).

- ‘Forestry’ areas include dense stands of the alien plants *Pinus pinaster* and / or *Eucalyptus* spp.
- ‘Off-channel dams’ are dams not impounding the main river channel. They have been constructed mainly for irrigation purposes.
- ‘Urban’ areas are built-up areas. Urban areas include residential and commercial areas and also large farmsteads incorporating fruit-packing infrastructure.
- High-intensity ‘agriculture’ occurs along the Lourens and Palmiet Rivers and includes cultivated areas of mostly orchards and vineyards.
- The Hout Bay River has no extensive agricultural development, hence a ‘peri-urban’ land use type was created to include the large homesteads ‘in a low density, rural setting’ (BOLA&EP *et al.* 1996) with large horse paddocks that are found along the river.
- An ‘informal settlement’, Imizamo Yetho, is also present along the Hout Bay River. Such an area is characterised by persons living in “shacks” with little sanitary infrastructure.
- A further three land use types were identified along the Lourens River.
  - The ‘recreation’ category was created to include the large 'open' urban areas occupied by golf courses and Radloff Park.
  - The ‘light industrial’ category was identified to include the light industrial zone of paint shops, car workshops, wood works and other small factories below the N2 national road.
  - An ‘industrial’ category was identified for the heavy industry occurring on the African Energy and Chemical Industry (AECI) land along the river.

Thirdly, the areas occupied by each land use type in the stretch (1) 1.5 km upstream and (2) over the entire stretch upstream of each site were calculated in ArcView. The areas of each land use unit were expressed as a percentage of the total area (1) 1.5 km upstream and (2) of the entire length upstream of each site respectively. Statistical correlation tests were then performed to determine whether significant relationships exist between the percentages of various land use types occurring at the two scales upstream of each site and the habitat integrity scores of each site.

## 4.3 RESULTS AND DISCUSSION

### 4.3.1 Land use classifications of the rivers assessed

4.3.1.(i) Hout Bay River

As shown in Figure 4.1, the Hout Bay River flows through areas characterised by natural vegetation before entering alien forestry plantations and areas consisting of peri-urban properties with large gardens and horse paddocks extending down to the river bank. The river then flows through the urban areas of Hout Bay village, including the informal settlement Imizamo Yetho. In the lower reaches, the river appears to be buffered by natural areas occurring between it and the surrounding urban areas. Small patches of alien forestry still occur in the 1 km buffer area towards the lower reaches of the Hout Bay River.

4.3.1.(ii) Lourens River

In Figure 4.2 it can be seen that after initially flowing through natural fynbos areas, the Lourens River enters the commercial alien *Pinus pinaster* plantations and agricultural areas (dominated by orchards and vineyards) on the Lourensford and Vergelegen Estates. The river then meanders through the urban areas of Somerset West encountering recreational areas and urban open spaces along its way. Below the N2 road, a light industrial area is found to the south of the river, whilst near its estuary, land owned by the AECI is found to the north.

4.3.1.(iii) Palmiet River

Figure 4.3 illustrates that the Palmiet River originates in the Nuweberg Mountains of the Hottentots Holland Nature Reserve. It flows through natural vegetation in the reserve before entering areas characterised by alternating forestry and natural parts. The river then enters the Elgin Valley and flows through agricultural areas, dominated by orchards, and further forestry plantations. On route it passes through the urban areas of Grabouw. The lower rejuvenated reaches then enter the Kogelberg Biosphere Reserve, where, after travelling through natural fynbos vegetation, the Palmiet River enters the Atlantic Ocean between the towns Kleinmond and Betty’s Bay.

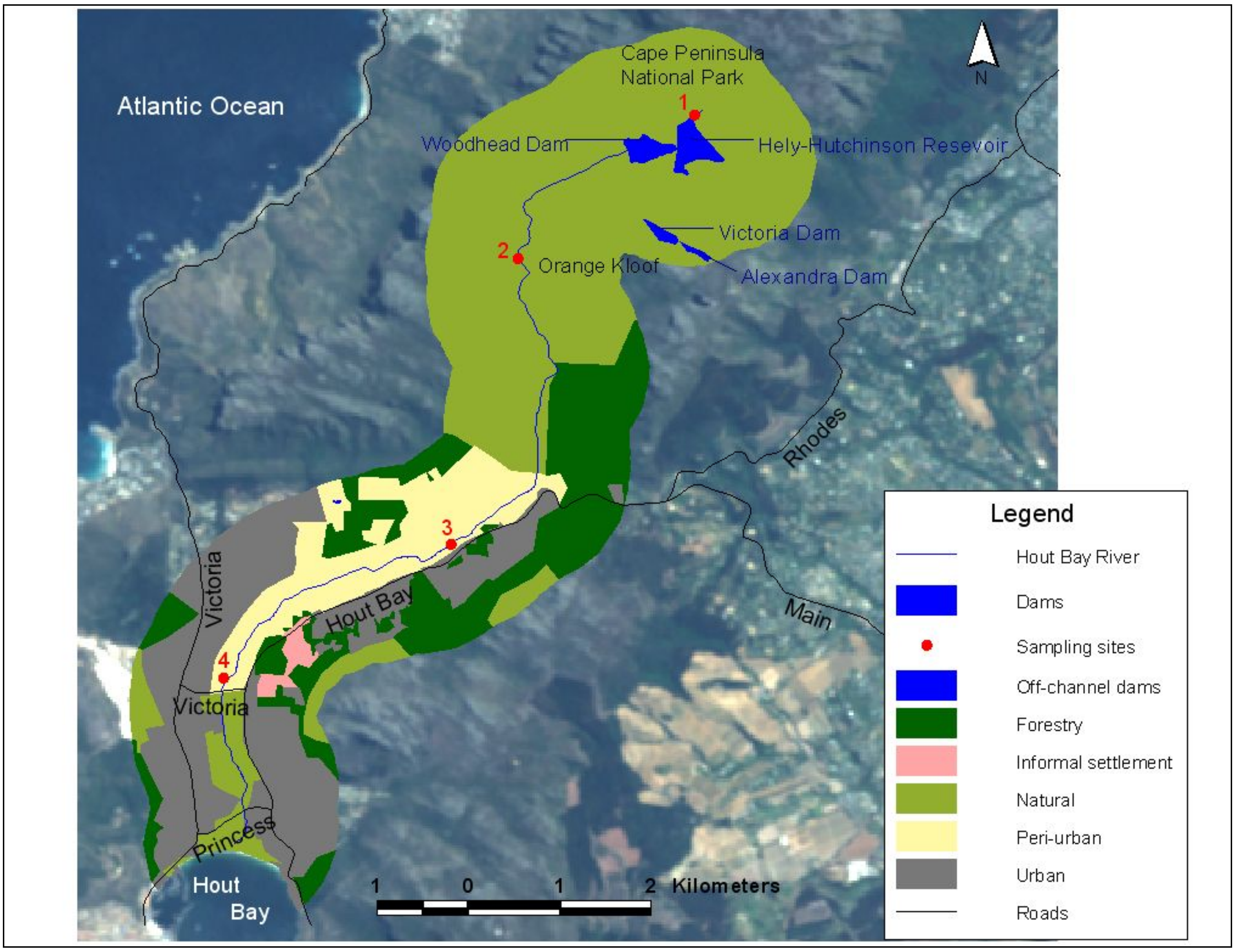


**Figure 4.1.** Land use along the Hout Bay River

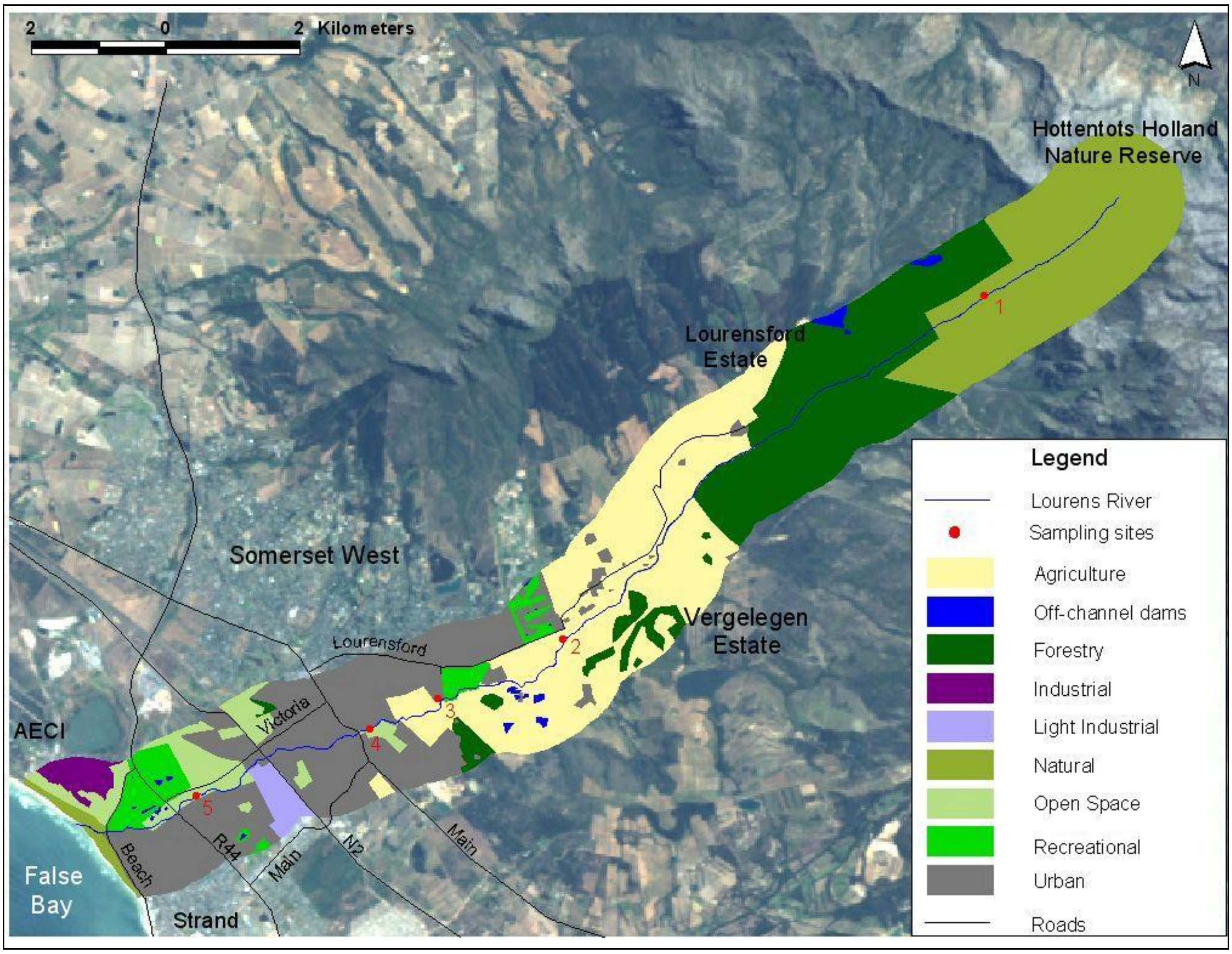


**Figure 4.2.** Land use along the Lourens River

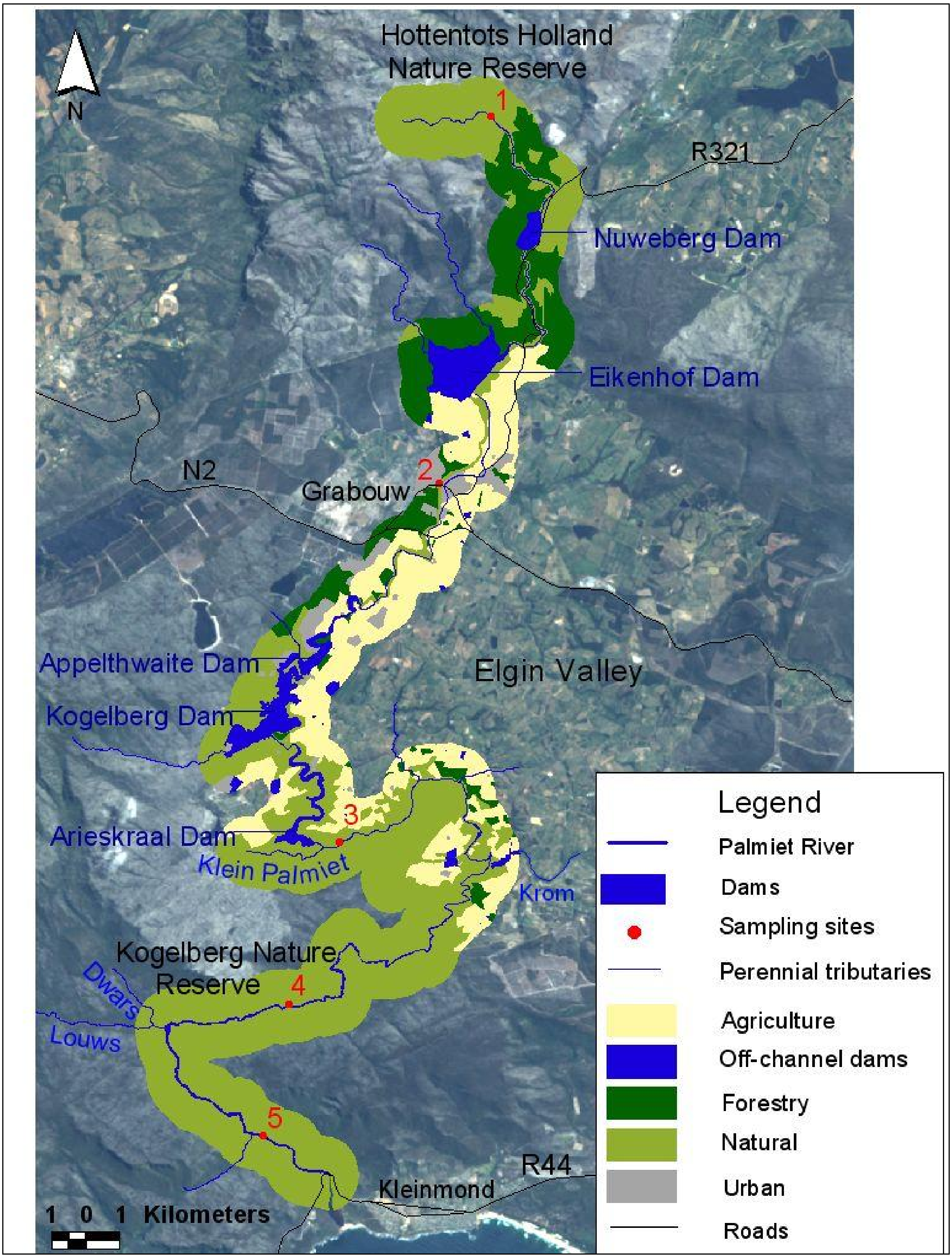


**Figure 4.3.** Land use along the Palmiet River

### 4.3.2 The influence of natural versus disturbed land use types on habitat integrity

Table 4.1 and Figures 4.4, 4.5, 4.6 and 4.7 indicate that there appears to be a strong positive and significant ($p<0.05$) relationship between the percentage of surrounding natural, undisturbed land cover, at both the local and regional scales studied, and the instream and riparian habitat integrities.

**Table 4.1.** Correlations ($r^2$ ) between the Index of Habitat Integrity (IHI) and the extent of natural (unmodified) and disturbed (modified) land cover measured at two spatial scales in a 1 km buffer strip along the three rivers assessed (The relationship is significant where $p < 0.05$)

| Land cover | Spatial Scale | IHI (instream) | | IHI (riparian) | |
|---|---|---|---|---|---|
| | | $r^2$ | P | $r^2$ | p |
| Natural | Regional | 0.81 | <0.01 | 0.78 | <0.01 |
| | Local | 0.83 | <0.01 | 0.87 | <0.01 |
| Disturbed | Regional | - 0.81 | <0.01 | - 0.78 | <0.01 |
| | Local | -0.83 | <0.01 | -0.87 | <0.01 |

There are indications, however, in Table 4.1, that the percentage of surrounding natural, undisturbed land cover occurring at a local scale is the best predictor of instream ($r^2$ = 0.83) and riparian ($r^2$ = 0.87) habitat integrity. The same negative significant correlations ($p<0.05$) can be seen between the percentage surrounding disturbed land use and habitat integrity (Table 4.1).



With habitat integrity improving with increasing surrounding natural land cover or decreasing disturbed land use types, one can conclude that the amount of natural or disturbed land cover surrounding a site at both a regional and local is a good predictor of riverine habitat integrity.

### 4.3.3 The relationship between natural vegetation cover and riparian versus instream habitat integrity

Although the sample size used is small, there are indications from Table 4.1 that at a local scale the percentage of surrounding natural or disturbed land use has a stronger relationship with riparian ($r^2$ = 0.87 and $r^2$ = –0.87 respectively) habitat integrity than with instream habitat integrity ($r^2$ = 0.83 and $r^2$ = –0.83 respectively). Although again similar, it also appears that at the regional scale the percentage of surrounding natural or disturbed land use has a stronger relationship with the instream ($r^2$ = 0.81 and $r^2$ = –0.81 respectively) habitat integrity than with riparian habitat integrity ($r^2$ = 0.78 and $r^2$ = –0.78 respectively). This indicates that the riparian zone is affected primarily by local land

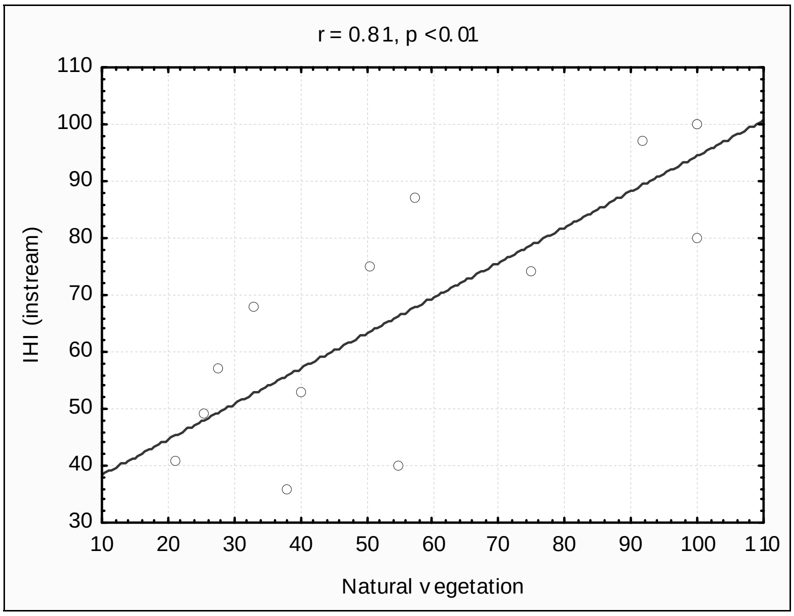


**Figure 4.4.** Correlation between instream habitat integrity and natural vegetation occurring at a regional scale

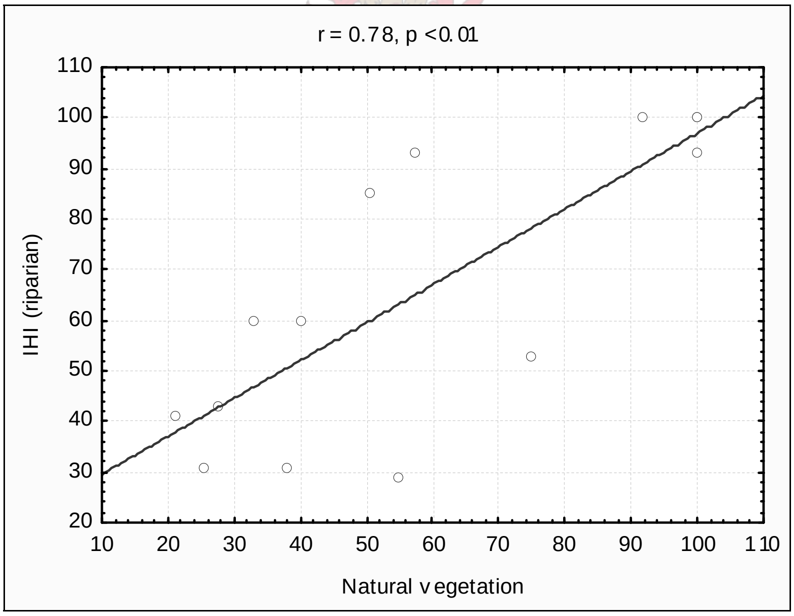


**Figure 4.5.** Correlation between riparian habitat integrity and natural vegetation occurring at a regional scale

use conditions; in other words, local land use types have a stronger impact on the riparian zone than they do on the instream condition. This can probably be expected as land use disturbance can be translated simply as indigenous vegetation removal, which, together with exotic vegetation encroachment, is seen as the largest contributor to riparian habitat degradation along the three rivers

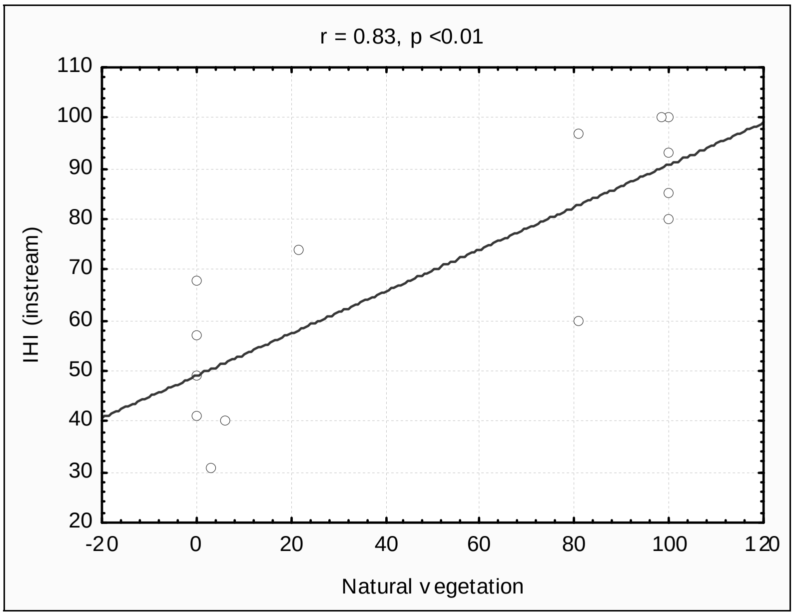


**Figure 4.6.** Correlation between instream habitat integrity and natural vegetation occurring at a local scale

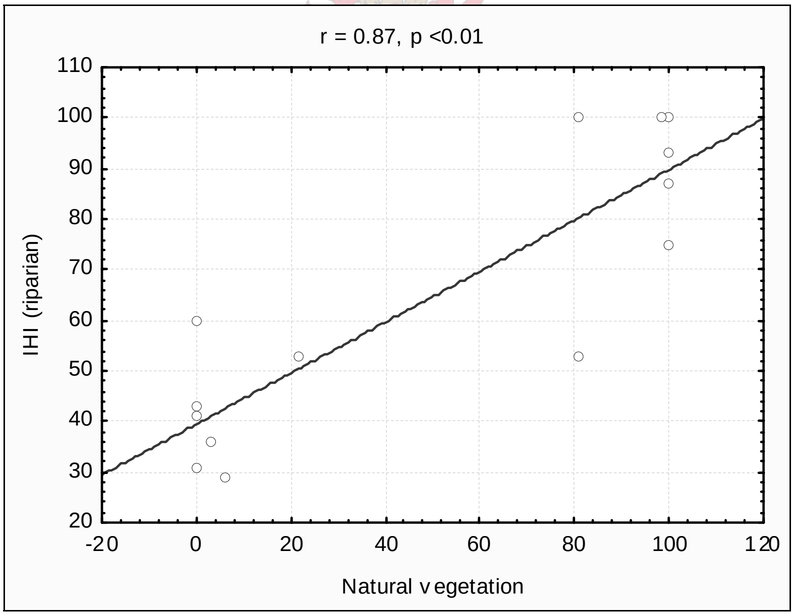


**Figure 4.7.** Correlation between riparian habitat integrity and natural vegetation occurring at a local scale

assessed (Chapter 3). The instream condition, on the other hand, appears to be effected more by upstream land use conditions. This can be explained by the river being a longitudinal continuum with downstream reaches being affected by local as well as upstream activities (Byren and Davies 1989; Davies and Day 1998). In other words, the instream condition at a site is probably still reflecting the upstream impacts of erosion or nutrient additions from agriculture, for example. Additional data is needed, however, to substantiate these indications.

### 4.3.4 The complexities of disturbed land use types

'Disturbed land use' incorporates many different land use types (agriculture, forestry, off-channel dams, urban areas, industrial and light industrial areas, recreational areas, open spaces, rural areas and informal settlements). Only the modified land use types of forestry, urban development, agriculture and off-channel dams occur with sufficient frequency along the three rivers assessed to calculate meaningful correlations and draw conclusions about their effects on riverine habitat integrity. It follows from Table 4.1, and is consequently apparent from Table 4.2, that all the disturbed land use types studied here have a negative detrimental effect on riverine habitat integrity.

**Table 4.2.** Correlations ($r^2$) between the Index of Habitat Integrity (IHI) and the extent of modified land use types measured at two spatial scales in a 1 km buffer strip along the three rivers assessed (The relationship is significant where $p < 0.05$)

| Land use type | Spatial Scale | IHI (instream) | | IHI (riparian) | |
|---|---|---|---|---|---|
| | | $r^2$ | P | $r^2$ | p |
| Agriculture | Regional | - 0.51 | 0.06 | - 0.44 | 0.11 |
| | Local | -0.45 | 0.11 | -0.43 | 0.13 |
| Forestry | Regional | - 0.80 | <0.01 | - 0.81 | <0.01 |
| | Local | -0.15 | 0.62 | -0.28 | 0.33 |
| Urban | Regional | - 0.75 | <0.01 | - 0.70 | <0.01 |
| | Local | -0.80 | <0.01 | -0.83 | <0.01 |
| Off-channel Dams | Regional | - 0.29 | 0.31 | - 0.17 | 0.57 |
| | Local | -0.64 | 0.013 | -0.52 | 0.06 |



From Table 4.2, it appears that at a local scale, the amount of urban development surrounding a site has the greatest negative influence on riparian habitat integrity ($r^2$ = -0.83) and instream habitat integrity ($r^2$ = -0.80). Both these relationships are significant ($p<0.05$). At a regional scale, alien forestry is the best predictor of instream ($r^2$ = -0.80, $p<0.05$) and riparian habitat integrity ($r^2$ = -0.81, $p<0.05$). Overall, however, it appears that the amount of forestry at a regional scale has a strong, significant negative impact on instream ($r^2$ = -0.80, $p<0.05$) and riparian habitat integrity ($r^2$ = -0.81, $p<0.05$) (Figures 4.8 and 4.9), whilst the degree of urbanisation occurring at a local scale has the largest impact on the instream ($r^2$ = -0.80, $p<0.05$) and riparian ($r^2$ = -0.83, $p<0.05$) habitat integrity (Figures 4.10 and 4.11).

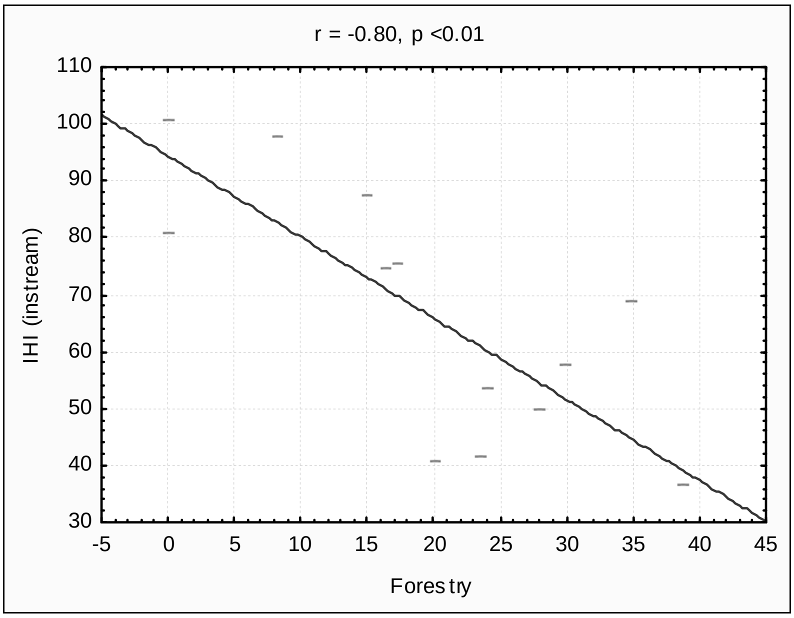


**Figure 4.8.** Correlation between instream habitat integrity and alien forestry occurring at a regional scale

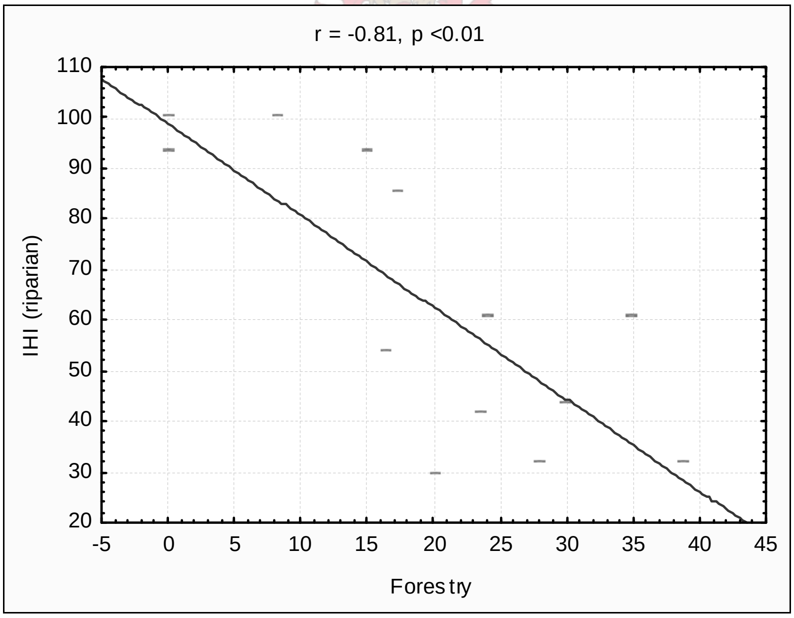


**Figure 4.9.** Correlation between riparian habitat integrity and alien forestry occurring at a regional scale

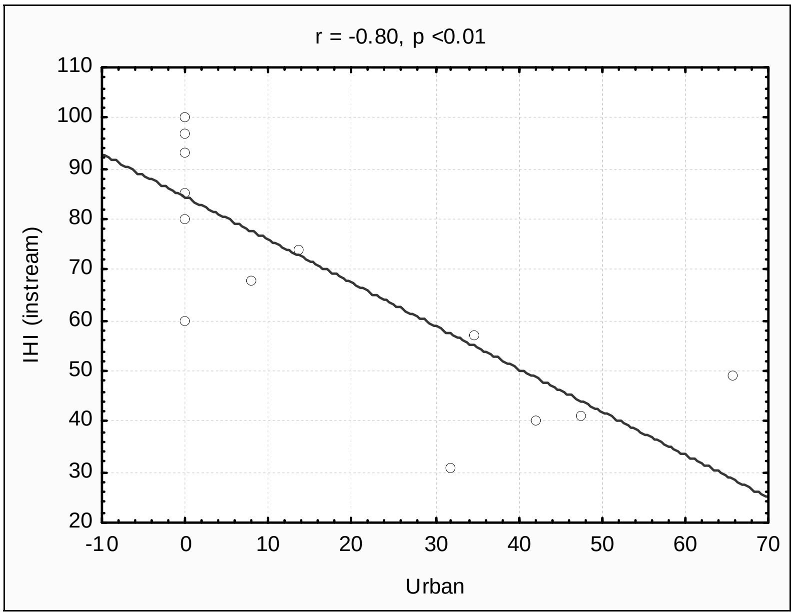


**Figure 4.10.** Correlation between instream habitat integrity and urban development occurring at a local scale

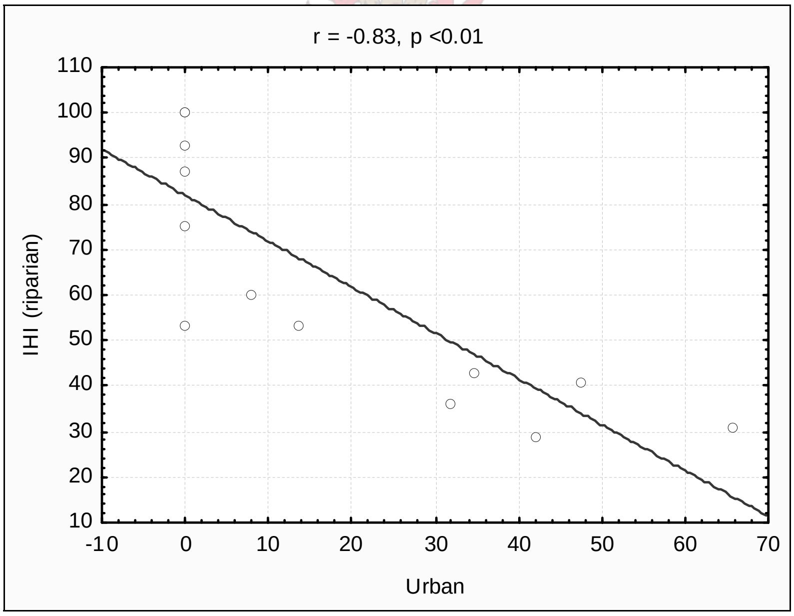


**Figure 4.11.** Correlation between riparian habitat integrity and urban development occurring at a local scale

Water abstraction is considered by Kleynhans (1996) to be the overall criterion with the most significant impact on riverine habitat integrity. Calder (1999) explains that forests evaporate more water than shorter vegetation because they are tall and have deeper root systems. Forests also reduce runoff (Calder 1999) and Sunder (1993) showed that extensive *Eucalyptus* spp. and *Pinus* spp. plantations substantially lowered the water yield from catchments. It can, therefore, be concluded that because all three rivers studied had large areas under alien forestry (Figures 4.1, 4.2 and 4.3), alien forestry, by directly increasing the impact of water abstraction from the rivers, was found to have a significant negative impact on their instream habitat integrity. By directly reducing the water yield from these catchments forestry can be seen to be acting over a regional scale affecting the river reaches at a distance downstream.

On a local scale, urbanisation has the greatest effect on the instream and riparian habitat integrity (Table 4.2; Figures 4.10 and 4.11). This can probably be explained by urban areas directly affecting the channel shape with river banks being gabioned and straightened for flood control and, with gardens extending down to the river banks, responsible for alien vegetation dominating the riparian zone. The impacts of urbanisation, therefore, appear to have more localised effects than that of alien forestry discussed above.

These results add further evidence to the debate on whether local or regional land use conditions affect riverine habitat more. From the results it appears that different land use types effect the habitat integrity of streams at differing scales. This supports the idea of Allan *et al.* (1997) and Lyons *et al.* (2000) that human alteration of the landscape affects riverine ecosystems via multiple processes operating at different spatial scales. River catchment management is, therefore, an action that needs to occur over various spatial scales and consequently, according to Allan *et al.* (1997), managers and planners must think in terms of catchments.



It must be noted that the GIS land use analysis in this study did not include analysis of the tributaries of the rivers. This is perhaps a limitation of the study as major tributaries were found to have a significant effect on river condition. It is recommended that similar future studies include tributary analysis, especially when upstream effects are being considered. The good correlations observed between land use and habitat integrity are not surprising and were expected. Although the author took care to avoid inferring the scoring of habitat integrity criteria from surrounding land use types, a possible problem of the analysis as it is presented is that the scoring of the habitat integrity may have been influenced by the surrounding land use and thus the correlation between habitat integrity and natural and disturbed land use respectively may have been affected. In future similar studies, the assessor must be careful not to infer riverine habitat condition from surrounding land use types. In such instances correlation tests between the habitat integrity and land use would be spurious.

## 4.4 CONCLUSIONS

Nash (1993) argues that the global trends in water quality are the result of large scale changes in land use. Non-point pollution sources, affecting the habitat condition of rivers world-wide, are difficult to monitor and, therefore, the regulation of land use is considered to be the principle tool for protecting the quality of the world's water resources. Along the three rivers assessed in this study it appears that the amount of natural or disturbed land use occurring at both a regional and local scale is a good predictor of riverine habitat integrity. The rivers all flow through urban areas and are also all impacted by alien forestry along sections. Interestingly, it appears that the amount of alien forestry occurring at a regional scale upstream of a site has a significantly large negative impact on riverine habitat integrity, whereas urbanisation on a local scale has the strongest effect on the instream and riparian habitat integrity. It, therefore, appears that different land use types effect the habitat integrity of streams at differing scales. River catchment management is thus an action that needs to occur over various scales and therefore, according to Allan *et al.* (1997), managers and planners must think in terms of catchments.

To reach an overall conclusion about the impacts of the various modified land use types on riverine habitat integrity in general, further similar studies need to be conducted on a number of different rivers. Further study could also be conducted into determining the optimum buffer distance for representing the major land use types impacting on a river. It is hoped that the results of this study will contribute to the development of management strategies for the Hout Bay, Lourens and Palmiet Rivers.

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# AN ASSESSMENT OF THE PRESENT WATER QUALITY CONDITION OF THREE SOUTH-WESTERN CAPE RIVERS ASSESSED AS PART OF THE NATIONAL RIVER HEALTH PROGRAMME

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## ABSTRACT

South African stream ecosystems are facing increasing stresses due to water over-utilisation in a drought-prone region. The National River Health Programme and Target Water Quality Ranges (TWQR) are tools providing guidelines to measure the ecological state of rivers. Run in conjunction with river health assessments, the aim of this study was to assess the water quality of three south-western Cape rivers at the time of the assessments.

The results indicate that:

(1) There appears to be a filtering system (e.g. wetland) functioning between the Hout Bay River's middle and lower reaches.

(2) High total dissolved salts, conductivity and inorganic nitrogen concentrations found along the Lourens River middle reaches are cause for concern.

(3) The water quality in the Palmiet River at Grabouw is extremely poor; there was insufficient oxygen to support most aquatic life forms. Downstream impoundments appear to act as salt and nutrient sinks, however, the Huis and Krom Rivers then appear to degrade the water quality of the reaches extending into the Kogelberg Nature Reserve.

The results of this study can be used in the SASS, FAII and IHI assessments and can be added to long-term data sets for comparison with the TWQR.



***Key words:*** *water quality, river health, Target Water Quality Ranges*

## 5.1 INTRODUCTION

### 5.1.1 River health assessment in South Africa

South Africa is a semi-arid country, with an annual rainfall below the world average and high evaporation rates (DWAF 1996), consequently, water resources in South Africa are limited (WRC 2001). In South Africa, rivers provide almost all of the water supply for the population (Davies and Day 1998) and almost every permanent stream is regulated either by single or multiple impoundments (Davies and Day 1998; Kleynhans 1996). South African stream ecosystems are thus facing increasing stresses due to over-utilisation of water in an already over-stressed, drought-prone region (DWAF 1996; Davies and Day 1998).

The natural water environment is not regarded as a user in competition with other users (e.g. domestic, agriculture, industry) (DWAF 1996; Kleynhans 1996) but rather as a resource base from which water originates and as an entity with its own intrinsic environmental value (Kleynhans 1996). Man depends on many ‘services’ provided by aquatic ecosystems (e.g. waste assimilation self-purification, provision of an aesthetically pleasing environment, use as a recreational resource and provision of a livelihood to communities) (DWAF 1996). To ensure that South Africa’s water resources remain fit for agricultural, domestic, recreational and industrial use on a sustainable basis, aquatic ecosystems, as a resource base, must be effectively protected and managed. For this purpose the South African Department of Water Affairs and Forestry (DWAF), in 1994, initiated the National River Health Programme (RHP) as a tool for monitoring the ecological state of rivers (Roux *et al.* 1999; WRC 2001, 2002; RHP 2003, *in prep.*). The results of this programme are intended to be incorporated into a national water resource management database system (Roux *et al.* 1999).

### 5.1.2 The relevance of water quality to river health

Water quality is a human construct used to describe the combined effect of the physical attributes and chemical constituents of a water sample (Tharme *et al.* 1997; Dallas 1998; Pegram and Gorgens 2001) based on its fitness for (1) a variety of uses and (2) the protection of the health and integrity of aquatic ecosystems (DWAF 1996; Pegram and Gorgens 2001). Water quality is dependent on numerous factors, which alter the chemical composition of the water body normally through activities within the catchment (Tharme *et al.* 1997; Dallas 1998).

The chemical composition of a river is one of the main factors determining the characteristics of the system (Tharme *et al.* 1997). Each river has an intrinsic chemical composition, which, to a certain extent, is dependent on the geographic location of the river (Tharme *et al.* 1997; Dallas 1998; McCartan *et al.* 1998). Geographic or regional differences arise from differences in climate (i.e. temperature, mean annual precipitation, mean annual evaporation), geomorphology (i.e. gradients, erosion) and geology (Tharme *et al.* 1997; Dallas 1998; McCartan *et al.* 1998). The maintenance of a certain standard or range of water quality is a precondition to the maintenance of almost all the biotic components of the system (Dallas 1998). A change in water quality may result in changes in the ecological status of the riverine ecosystem (Tharme *et al.* 1997; Dallas 1998), thereby affecting the health of the river.

### 5.1.3 Water Quality Guidelines

The policy of DWAF is to strive to protect South Africa's water resources (DWAF 1996; Tharme *et al.* 1997; Dallas 1998). The South African Water Quality Guidelines for Aquatic Ecosystems were published by DWAF (1996) to meet this goal and are essentially specifications of the instream water quality required to protect aquatic ecosystems (Dallas 1998). They are based on the establishment of a Target Water Quality Range (TWQR) for each physical and chemical constituent (Tharme *et al.* 1997; Dallas 1998). A TWQR is a management objective derived from numerical and narrative criteria and can be seen as a 'no effect range', i.e. such that there is no detrimental effect on the aquatic ecosystem (DWAF 1996).



### 5.1.4 Research aim

Run in conjunction with river health assessments performed as part of the River Health Programme in the Western Cape (Chapter 1), the aim of the present study is to determine the water quality of three south-western Cape rivers at the time of the health assessments.

### 5.1.5 Study area

Three rivers, namely the Hout Bay, Lourens and Palmiet Rivers were studied in the south-western Cape, in the Fynbos Biome, South Africa (Chapter 1).

## 5.2 METHODS

### 5.2.1 Determining water quality

According to Dallas (1998), it is primarily system variables (temperature and dissolved oxygen), non-toxic inorganic constituents (pH, electrical conductivity, total dissolved salts / solids, turbidity and total suspended solids) and nutrients (nitrite, nitrate, ammonium and soluble reactive phosphorous) that are taken into account when characterising the water chemistry of a river. Toxic constituents like heavy metals or biocides, although potentially lethal to many aquatic organisms, are difficult and expensive to measure and consequently data on these constituents is not readily available.

Instantaneous measurements of seven water quality constituents (temperature, pH, dissolved oxygen, total dissolved salts / solids, electrical conductivity, inorganic nitrogen and phosphate) were taken in conjunction with 2002 river health assessments conducted once during autumn (March - May) and repeated the following spring (September - November) at sampling sites considered to be representative of each geomorphological zone (Chapter 2) along the Hout Bay, Lourens and Palmiet Rivers. pH was measured using a Wissenschaftkich-Technische Werkstatten (WTW) pH 330-meter; with electrical conductivity, total dissolved salts and dissolved oxygen being measured using a Corning Checkmate 90 apparatus with dissolved oxygen and conductivity sensors. Water samples were taken, frozen and sent to the Stellenbosch Department of Soil Science, Stellenbosch University, to determine nitrate, nitrite, ammonium and phosphate concentrations and to Bemlab in Somerset West to measure ammonia concentrations.

The results obtained were used to determine the water quality of each site sampled and to deduce longitudinal trends along the rivers at the time of sampling. In Dallas (1998) and Dallas *et al.* (1998) expected or natural ranges for water quality constituents are specified for the geomorphological zones (Chapter 2) found along south-western Cape rivers. Each site sampled in this study had been chosen to represent a specific geomorphological river zone for the river health assessments (Chapter 2). The water quality results of each site sampled were, therefore, compared to the expected or natural conditions for the zone which the site represented. Findings were also compared to previous water quality data for the three rivers assessed. Applying the specifications laid out in the South African Water Quality Guidelines (DWAF 1996) to the background median values expected for each water quality constituent measured, in the respective geomorphological zones of south-western Cape rivers (Dallas 1998; Dallas *et al.* 1998), TWQR's for each constituent were also calculated. Where it was possible the results of this study were then compared to their respective TWQR.

### 5.2.2 General importance of measured physical attributes and chemical constituents for riverine ecosystems.

5.2.2.(i) Temperature

Temperature regulates the rates of chemical reactions, the solubility of dissolved oxygen, the metabolic rates of organisms and essential ecosystem processes such as spawning and migration (Covich 1993; Tharme *et al.* 1997; Dallas 1998). Dallas (1998) notes that aquatic organisms are usually adapted to natural diel and seasonal variations in water temperature. Changes in the amplitude, frequency and duration of these variations may cause severe disruptions to the ecological and physiological functions of aquatic organisms. Anthropogenic causes of temperature changes in river systems include those resulting from thermal pollution, discharge of water from impoundments and the removal of vegetation cover (Dallas and Day 1993).

5.2.2.(ii) Dissolved Oxygen

With reference to Covich (1993), DWAF (1996), Tharme *et al.* (1997) and Dallas (1998), dissolved oxygen (DO) is required for the respiration of all aerobic organisms and, therefore, the maintenance of adequate DO concentrations is critical for the survival and functioning of aquatic biota. DO is also needed for the microbial decomposition of dead plants and the chemical oxidation of sediments. There is a natural diel variation in DO associated with the 24-hour cycle of photosynthesis and respiration by aquatic biota. In unpolluted surface waters, DO concentrations are usually close to saturation but organic wastes and suspended material may reduce this concentration, which in turn may exacerbate the effects of toxic substances if present.

5.2.2.(iii) pH

According to DWAF (1996), Tharme *et al.* (1997) and Dallas (1998), the relative proportions of major ions and hence the pH of natural waters is determined by geological and atmospheric influences. Most fresh waters in South Africa are well buffered and near-neutral. However, water draining catchments dominated by fynbos in the south-western and southern Cape typically have low acidic pH values due to the influence of organic acids (e.g. humic and folic acids) present. pH affects the availability and toxicity of constituents such as trace metals (e.g. lead), non-metallic ions (e.g. ammonium) and essential elements (e.g. selenium). Lowering the pH (acidification) mobilises aluminium, a potentially lethal element to aquatic biota and decreases the solubility of certain essential elements such as selenium. At pH values greater than 8, non-toxic ammonium ions ($NH_4^+$) are converted into highly toxic, un-ionised ammonia ($NH_3$). So, although pH is potentially harmful in its own right, it is most important with respect to its influence on other physico-chemical variables that could have detrimental effects on a system. Natural diel and seasonal pH variations occur naturally in systems such as those present in the Fynbos Biome.

5.2.2.(iv) Electrical conductivity and Total Dissolved Salts / Solids

Electrical conductivity (Ec) is the measure of the water's ability to conduct an electrical current (Day 1990; Tharme *et al.* 1997; Dallas 1998). This ability is due to the presence of ions such as carbonate / bicarbonate, sulphate, chloride, sodium, potassium, magnesium and calcium, all of which carry an electrical charge (Tharme *et al.* 1997; Dallas 1998). According to DWAF (1996), total dissolved solids (TDSolids) concentration is a measure of the quantity of all compounds dissolved in water. Total dissolved salts (TDSalts) concentration is a measure of all dissolved compounds in water that carry an electrical charge. Since most dissolved substances in water carry an electrical charge, TDSalts concentration is usually used as an estimate of the concentration of TDSolids in water and it is common practice to use TDSalts concentration as a measure of the TDSolids. TDSalts is directly proportional to Ec, whilst, although the TDSolids reading is often positively correlated with Ec, TDSolids also includes organic compounds that do not dissociate into ions and, therefore, do not carry an electrical charge (Day 1990; Tharme *et al.* 1997; Dallas 1998). Being dependent on the geological formations the water is in contact with, total dissolved salts / solids (TDS) and Ec often vary regionally (Tharme *et al*. 1997; Dallas 1998). Physical processes like rainfall and evaporation also affect TDS (DWAF 1996). The proportion of major ions in the water affects the buffering capacity of water and hence the metabolism of aquatic organisms (DWAF 1996; Tharme *et al.* 1997; Dallas 1998). Changes in TDS concentration also affect community structure as well as ecological processes like nutrient cycling (DWAF 1996). Return-flow irrigation water often leads to elevated Ec in the receiving water body (Tharme *et al.* 1997; Dallas 1998) as does domestic and industrial effluent discharges and surface runoff from urban, industrial and cultivated areas (DWAF 1996). TDS cannot economically be removed or reduced, meaning that once added to water, minerals represent a permanent form of degradation (Van Ginkel *et al.* 1996).

5.2.2.(v) Nutrients

Nutrient enrichment of water bodies stimulates the rapid plant growth of micro- and macrophytes (Braden and Lovejoy 1990). DWAF (1996) explains that, due to their stimulatory effect on aquatic plant growth and algae, inorganic phosphorous and inorganic nitrogen (nitrate + nitrite + ammonium + ammonia) are of primary concern for aquatic ecosystems. In South Africa, however, phosphorous is considered to be the principle nutrient controlling the degree of eutrophication in aquatic ecosystems. In unimpacted waters, inorganic nitrogen and inorganic phosphorous concentrations are seldom high as they are rapidly taken up by plants for growth and reproduction (DWAF 1996; Tharme *et al.* 1997; Dallas 1998).

According to DWAF (1996), phosphorous is an essential macronutrient having a major role in the building of nucleic acids and in the storage and use of energy in cells. Although phosphorous can occur in many organic and inorganic forms, soluble reactive phosphate or orthophosphate species $H_2PO_4$ and $HPO_4^{2-}$ are the only forms of soluble inorganic phosphorous utilisable by aquatic biota. With the weathering of rocks and the decomposition of organic matter being sources of natural phosphorous, phosphorous concentrations vary with regional geology. Point-source discharges (e.g. domestic and industrial effluents) and diffuse sources (e.g. atmospheric precipitation, urban runoff and drainage from agricultural land, especially on which fertilisers have been applied) are probable sources of elevated phosphorous concentrations.

In high concentrations, nitrite and ammonia may be toxic to aquatic organisms; the toxicity of ammonia increasing with increasing pH and temperature (Tharme *et al.* 1997; Dallas 1998). Elevated inorganic nitrogen concentrations may result from point discharges (e.g. organic industrial effluents, effluents containing human or animal excrement) and diffuse sources (e.g. urban and agricultural runoff) (DWAF 1996; Tharme *et al.* 1997; Dallas 1998).



## 5.3 RESULTS AND DISCUSSION

All measurements taken were instantaneous and, as such, while they do provide an indication of water quality in the river at the time of sampling, they cannot reliably be used to deduce trends over time (Brown *et al.* 1997). The data can, however, be used to show longitudinal trends down the river at the time of sampling.

### 5.3.1 Temperature

The TWQR stipulates that water temperature should not vary from the background (considered to be ‘natural’) average daily water temperature by > 2$^{o}$C or by > 10% (DWAF 1996).

Water temperature experiences diel variation and, therefore, it is difficult to draw any conclusions about longitudinal trends along each river, as sites were sampled instantaneously at different times of the day. This data, however, can be taken into account when discussing South African Scoring System (SASS) (Ollis *in prep.*) and Fish Assemblage Integrity Index (FAII) (Hayes 2002) results.

**Table 5.1.** Expected (or natural) temperature conditions compared to the observed average instantaneous autumn and spring temperatures for sites sampled along the Hout Bay, Lourens and Palmiet Rivers (MSZ = Mountain Stream Zone, UFZ = Upper Foothill Zone, RFZ = Rejuvenated Foothill Zone, Med = Median Temperature, Min = Minimum Temperature, Max = Maximum Temperature, TWQR = Target Water Quality Range, AUT = Autumn, SPR = Spring)

| **TEMPERATURE ($^{o}$C)** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ***Expected or Natural*** | | ***Observed*** | | | | | | | | |
| | | | | **Hout Bay River** | | | **Lourens River** | | | **Palmiet River** | | |
| ***ZONE*** | | AUT | SPR | ***SITE*** | AUT | SPR | ***SITE*** | AUT | SPR | ***SITE*** | AUT | SPR |
| ***MSZ*** | Med | 15.00 | 15.00 | ***1*** | 12.75 | 12.92 | ***1*** | 17.18 | 16.37 | ***1*** | 18.78 | 17.02 |
| | Min | 10.00 | 9.00 | ***2*** | 13.15 | 11.85 | | | | | | |
| | Max | 21.50 | 22.50 | | | | | | | | | |
| | TWQR | 13.50 - 16.50 | 13.50 - 16.50 | | | | | | | | | |
| ***UFZ*** | Med | 18.00 | 17.00 | ***3*** | 17.07 | 19.24 | ***2*** | 19.00 | 18.82 | ***2*** | 19.15 | 15.62 |
| | Min | 13.00 | 12.00 | | | | ***3*** | 18.35 | 18.92 | ***3*** | 16.80 | 19.14 |
| | Max | 27.50 | 32.00 | | | | ***4*** | - | 16.77 | | | |
| | TWQR | 16.20 - 19.80 | 15.30 – 18.10 | | | | | | | | | |
| ***RFZ*** | Med | 18.00 | 17.00 | | | | | | | ***4*** | 16.38 | 16.12 |
| | Min | 13.00 | 12.00 | | | | | | | ***5*** | 17.83 | 18.45 |
| | Max | 24.50 | 32.00 | | | | | | | | | |
| | TWQR | 16.20 - 19.80 | 15.30 – 18.10 | | | | | | | | | |

According to DWAF (1996), in order to compare temperature results to the TWQR, the average daily temperatures, instead of average instantaneous readings, would need to be calculated.

### 5.3.2 Dissolved Oxygen

According to DWAF (1996), dissolved oxygen (DO) concentrations of less that 100% saturation indicate oxygen depletion, whilst results in excess of saturation usually indicate eutrophication of a water body. The TWQR specifies that 80% - 120% oxygen saturation will protect all life stages of most southern African aquatic biota endemic or adapted to aerobic warm water habitats. This saturation range is always applicable to aquatic ecosystems of high conservation value.

**Table 5.2.** Expected or natural and the observed average instantaneous autumn and spring Dissolved Oxygen for sites sampled along the Hout Bay, Lourens and Palmiet Rivers (MSZ = Mountain Stream Zone, UFZ = Upper Foothill Zone, RFZ = Rejuvenated Foothill Zone, LRZ = Lowland River Zone, TWQR = Target Water Quality Range, AUT = Autumn, SPR = Spring)

| **DISSOLVED OXYGEN (% saturation)** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ***TWQR*** | ***Observed*** | | | | | | | | |
| | | **Hout Bay River** | | | **Lourens River** | | | **Palmiet River** | | |
| ***ZONE*** | | ***SITE*** | AUT | SPR | ***SITE*** | AUT | SPR | ***SITE*** | AUT | SPR |
| MSZ | 80-120% | ***1*** | 89.00 | 112.50 | ***1*** | 76.00 | 87.75 | ***1*** | 85.00 | 94.50 |
| | | ***2*** | 88.00 | - | | | | | | |
| *UFZ* | 80-120% | ***3*** | 89.00 | 96.80 | ***2*** | 88.00 | 94.00 | ***2*** | 66.00 | 62.67 |
| | | | | | ***3*** | 94.00 | 98.50 | ***3*** | 100.00 | 82.50 |
| | | | | | ***4*** | - | 92.00 | | | |
| *RFZ* | 80-120% | | | | | | | ***4*** | 99.00 | 76.00 |
| | | | | | | | | ***5*** | 101.00 | 89.00 |
| *LRZ* | 80-120% | ***4*** | 66.00 | 82.60 | ***5*** | 97.00 | 63.50 | | | |

Due to this study being part of a river health assessment with the primary aim of determining the habitat integrity of the three rivers, water chemistry testing was conducted in conjunction with the site visits for the river health assessments. DO saturations were therefore measured at various times of the day and so, as with the other earlier studies conducted on these rivers by Brown *et al.* (1997), Tharme *et al.* (1997) and Dallas (1998), interpretation of the data is limited. Ideally the expected DO range should be determined by measurement at a site over consecutive 24-hour cycles (Dallas 1998) and the lowest or 06h00 reading should be compared to the TWQR (DWAF 1996).

Nevertheless, at most sites in Table 5.2, DO saturation is below 100% indicating oxygen depletion from the theoretical equilibrium concentration (DWAF 1996). Along the Hout Bay River, there definitely appears to be a longitudinal decrease in DO saturation downstream during both autumn and spring. Of concern is the low DO saturation recorded at Site 4 during autumn, as this, according to DWAF (1996) is below the 80% saturation necessary to protect aquatic life forms.

Unexpectedly, autumn DO saturation appears to increase downstream along the Lourens River, which is contradictory to the River Continuum Concept (Davies and Day 1998) and previous studies (Tharme *et al.* 1997). In spring no discernible pattern is evident. DO saturation shows a diel variation (DWAF 1996) and the fact that measurements were taken at various times of the day along the rivers may explain the unexpected spring results. The average instantaneous DO saturation recorded at Lourens River Site 5 during spring is cause for concern, as 63% is far below the minimum acceptable 80% saturation. The 76% saturation recorded at Lourens River Site 1 in autumn is unlikely as this site is in near-pristine condition and is in an unimpacted mountain stream (Chapter 3) with fast-flowing water. This reading could, therefore, perhaps be due to an instrument error.

DO saturation along the Palmiet River appears to be sufficient except at Site 2 in Grabouw (Table 5.2). During both autumn and spring oxygen saturation is only 66% and 62.7% respectively, which are far below the necessary 80% needed to protect all aquatic life (DWAF 1996).

Occasional short-lived depletion of oxygen is less important than repeated exposures (DWAF 1996). The frequency of the low DO saturations recorded at the above-mentioned sites, therefore, needs to be determined, in order to assess the severity of the situation.

### 5.3.3 pH

The TWQR stipulates that pH values should not vary from the range of background (considered to be 'natural') pH values for a specific site and time of day by > 0.5 of a pH unit or by > 5% and should be assessed by which ever estimate is the more conservative (DWAF 1996). All pH measurements for a site assessed should be within the TWQR (DWAF 1996).

The Hout Bay River has a longitudinal decrease in acidity down its length (Table 5.3). Like the results of Brown *et al.* (1997), these results contradict those of King and Grindley (1982 in Brown *et al.* 1997) who found the river to be distinctly acidic from source to sea. This increase in pH may be attributable to increased contamination, perhaps, as suggested by Brown *et al.* (1997), due to urbanisation.

Where Tharme *et al.* (1997) recorded a longitudinal increase in pH downstream along the Lourens River during their autumn study, in the autumn sample of this study the Lourens River appears to be near neutral along its entire length (Table 5.3). The near-neutral pH recorded at Site 1 in autumn and spring is unusual for near-pristine streams draining fynbos dominated catchments, which are characteristically acidic (DWAF 1996). The Lourens River is, however, atypical of south-western

**Table 5.3.** Expected or natural and the observed average instantaneous autumn and spring pH for sites sampled along the Hout Bay, Lourens and Palmiet Rivers (MSZ = Mountain Stream Zone, UFZ = Upper Foothill Zone, RFZ = Rejuvenated Foothill Zone, LRZ = Lowland River Zone, Med = Median pH, Min = Minimum pH, Max = Maximum pH, TWQR = Target Water Quality Range, AUT = Autumn, SPR = Spring, a = background pH + / - 5% and b = background pH + / - 0.5 of pH unit)

| **pH** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ***Expected or Natural*** | | ***Observed*** | | | | | | | | |
| | | | | **Hout Bay River** | | | **Lourens River** | | | **Palmiet River** | | |
| ***ZONE*** | | | | ***SITE*** | AUT | SPR | ***SITE*** | AUT | SPR | ***SITE*** | AUT | SPR |
| ***MSZ*** | Med | 5.50 | | ***1*** | 4.20 | 4.25 | ***1*** | 7.10 | 6.70 | ***1*** | 5.80 | 6.30 |
| | Min | 3.60 | | ***2*** | 4.50 | - | | | | | | |
| | Max | 7.90 | | | | | | | | | | |
| | TWQR | [a] 5.23 – 5.78 | [b] 5.00 – 6.00 | | | | | | | | | |
| ***UFZ*** | Med | 6.00 | | ***3*** | 7.00 | 6.62 | ***2*** | 6.90 | 6.40 | ***2*** | 6.30 | 5.60 |
| | Min | 4.00 | | | | | ***3*** | 7.00 | 5.80 | ***3*** | 6.40 | 6.40 |
| | Max | 7.20 | | | | | ***4*** | - | 6.40 | | | |
| | TWQR | [a] 5.70 - 6.30 | [b] 5.50 - 6.50 | | | | | | | | | |
| ***RFZ*** | Med | 6.00 | | | | | | | | ***4*** | 7.20 | 6.80 |
| | Min | 4.00 | | | | | | | | ***5*** | 7.20 | 6.90 |
| | Max | 7.20 | | | | | | | | | | |
| | TWQR | [a] 5.70 - 6.30 | [b] 5.50 - 6.50 | | | | | | | | | |
| ***LRZ*** | Med | 7.30 | | ***4*** | 7.30 | 6.30 | ***5*** | 6.90 | 6.30 | | | |
| | Min | 6.50 | | | | | | | | | | |
| | Max | 8.50 | | | | | | | | | | |
| | TWQR | [a] 6.94 - 7.67 | [b] 6.80 - 7.80 | | | | | | | | | |

Cape fynbos streams, as it only has a short section of its upper mountain stream zone (Chapter 2) above Site 1 passing through Table Mountain Group sandstones (Moolman 2002). The river, including Sites 1 and 2, then passes through Cape Granites which have a higher salt content and generally a more neutral pH (Boucher *pers. comm.* 2003). This explains the near-neutral pH recorded at Site 1 during both autumn and spring. It also explains the pH recorded at Site 2 being higher than the expected median of pH 6.00 for upper foothill streams in the south-western Cape. The readings obtained in spring have a lower pH than those recorded for the same sites during autumn (Table 5.3). This could be due to an increase in organic acids from runoff from the surrounding fynbos areas in the upper catchment after the winter rains. In spring a longitudinal increase in acidity downstream was also seen. This again is unusual for streams draining fynbos-dominated catchments where normally the lowest pH is recorded at the near-pristine top sites draining Mountain Fynbos areas like Site 1. Acidic runoff and / or discharges, perhaps from the surrounding fruit and wine farming activities, may be causing this downstream elevation. The sharp drop in pH to pH 5.8 at Site 3 indicates that acidic discharge is probably occurring upstream of this site. After passing through the urban areas the pH increases sharply again, which is, as Brown *et al.* (1997) suggested along the Hout Bay River, probably due to contamination from the urban areas. The lower reaches of the river pass through Malmesbury Group shales (Moolman 2002) and hence saline conditions are expected at Site 5 (Boucher *pers. comm.* 2003). The pH recorded is more acidic than expected perhaps from extensive vegetation contributing organic material.

In Table 5.3, there is a general longitudinal increase in pH downstream along the Palmiet River, supporting Dallas's (1998) findings. However the pH recorded in the Kogelberg Nature Reserve (Sites 4 and 5) is considerably higher than expected and compared to the TWQR. Sites 4 and 5 are surrounded by natural near-pristine fynbos vegetation and as already stated, rivers draining fynbos dominated catchments in the southern and south-western Cape are generally acidic (DWAF 1996). The pH recorded at Sites 4 and 5 is approximately neutral and as such is notably higher than the median and TWQR. This elevated pH is, therefore, indicative of upstream contamination.

Only on one occasion along each river, was the pH found to be within the TWQR (Table 5.3). There appears to be no pattern to these findings and surprisingly these sites are generally the most polluted sites along the rivers. Dallas *et al.* (1998) found that the upper regions of rivers in the south-western Cape are often poorly buffered and, therefore, experience considerable fluctuation in pH. The findings of this study support their suggestion that the TWQR may need to be modified for south-western Cape mountain stream and foothill sites, which exhibit considerable fluctuation in pH and that regional quality guidelines should be established.

### 5.3.4 Total Dissolved Solids / Salts

The TWQR specifies that total dissolved salts / solids (TDS) concentrations should not change by > 15% from the normal cycles of the water body under unimpacted conditions at any time of the year, and the amplitude and frequency of natural cycles in TDS concentrations should not change (DWAF 1996).

From Table 5.4 it can be seen that along all three rivers there is the expected longitudinal downstream increase in TDS. The largest increase in TDS concentration along all three rivers is

**Table 5.4.** Expected or natural total dissolve salts / solids (TDS) readings compared to the observed average instantaneous autumn and spring TDS for sites sampled along the Hout Bay, Lourens and Palmiet Rivers (MSZ = Mountain Stream Zone, UFZ = Upper Foothill Zone, RFZ = Lower Foothill Zone, LRZ = Lowland River Zone, Med = Median TDS, Min = Minimum TDS, Max = Maximum TDS, TWQR = Target Water Quality Range, AUT = Autumn, SPR = Spring)

| **TOTAL DISSOLVED SALTS / SOLIDS (mg/l)** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***Expected or Natural*** | | ***Observed*** | | | | | | | | |
| | | | **Hout Bay River** | | | **Lourens River** | | | **Palmiet River** | | |
| ***ZONE*** | | | ***SITE*** | AUT | SPR | ***SITE*** | AUT | SPR | ***SITE*** | AUT | SPR |
| ***MSZ*** | Med | 26.30 | ***1*** | - | 55.53 | ***1*** | 22.00 | 17.50 | ***1*** | 25.70 | 9.90 |
| | Min | 5.90 | ***2*** | - | 62.60 | | | | | | |
| | Max | 105.50 | | | | | | | | | |
| | TWQR | 22.36-30.25 | | | | | | | | | |
| ***UFZ*** | Med | 32.00 | ***3*** | - | 111.67 | ***2*** | 56.30 | 51.53 | ***2*** | 59.50 | 87.35 |
| | Min | 2.00 | | | | ***3*** | 58.50 | 61.70 | ***3*** | 40.20 | 45.00 |
| | Max | 109.40 | | | | ***4*** | - | 82.70 | | | |
| | TWQR | 27.20-36.80 | | | | | | | | | |
| ***RFZ*** | Med | 32.00 | | | | | | | ***4*** | 80.00 | 86.73 |
| | Min | 2.00 | | | | | | | ***5*** | 82.00 | 75.30 |
| | Max | 109.40 | | | | | | | | | |
| | TWQR | 27.20-36.80 | | | | | | | | | |
| ***LRZ*** | Med | 183.00 | ***4*** | - | 138.33 | ***5*** | 71.50 | 84.60 | | | |
| | Min | 65.00 | | | | | | | | | |
| | Max | 640.00 | | | | | | | | | |
| | TWQR | 55.55-210.45 | | | | | | | | | |

seen between the top pristine sites and the next site, which is influenced by the first anthropogenic activities impacting the river system. Along the Hout Bay River this occurs between Sites 2 and 3 after the appearance of forestry plantations and peri-urban properties; along the Lourens River between Sites 1 and 2, coinciding with the onset of the forestry and agricultural activities of Lourensford and Vergelegen Estates; and at Palmiet Site 2, in Grabouw, again after the appearance of forestry, agricultural and urban activities. Similar increases were encountered in rivers in agricultural areas studied by Braden and Lovejoy (1990), Nash (1993) and Hall *et al.* (1996) and in urban rivers according to Roy *et al.*'s (2003) study.

Interestingly a drop in TDS is seen at Palmiet River Site 3, after the Appelthwaite, Kogelberg and Arieskraal Dams (Table 5.4). This supports the findings of Byren and Davies (1989) who indicate that these dams are possibly acting as a sink for TDS. A similar pattern was seen by O'Keeffe *et al.* (1996) along the Buffalo River, where the concentration of TDS was found to decrease downstream of the Laing Dam. Even though TDS is expected to increase naturally downstream (Davies and Day 1998), the TDS recorded during autumn and spring at Palmiet River Sites 4 and 5 are 60 – 63% greater than the expected natural median TDS concentration (Table 5.4). This is of concern as it indicates that, despite being situated in the Kogelberg Nature Reserve, surrounded by natural Mountain Fynbos vegetation (Boucher 1978; Gale 1992; Day 1998), these sites are polluted probably by upstream sources and possibly by adjoining tributaries like the heavily agriculturalised Krom and Huis Rivers.

### 5.3.5 Conductivity

There is no TWQR specified specifically for conductivity (Ec) (DWAF 1996). Instead, because Ec can be used as a surrogate measure for TDS, after converting the Ec reading to the equivalent TDS concentration, the TWQR for TDS can be applied (DWAF 1996).

Ec is closely related to TDS and, therefore, along all three rivers patterns similar to those seen for TDS are evident in Table 5.5. In brief, there is a general longitudinal increase in Ec downstream along each river, with the largest increases tending to occur between the near-pristine top sites and the following site affected by the onset of forestry and agriculture (Lourens River), forestry, agriculture and urban development (Palmiet River) or forestry and peri-urban properties (Hout Bay River). Although an increase a downstream increase in Ec is expected, the high Ec values recorded in the upper foothill zones of the three rivers assessed are cause for concern as they are far above the maximum expected values. Although, as in the case of TDS, after large impoundments, Palmiet River Site 3 experiences a drop in Ec but the Ec increases to levels much higher than the expected median value at Sites 4 and 5. Again this indicates upstream pollution as Sites 4 and 5 are situated in the near-pristine Kogelberg Nature Reserve.

### 5.3.6 Inorganic nitrogen

Inorganic nitrogen ($N_i$) concentrations below 0.5 mg/l are considered to be sufficiently low enough to limit eutrophication and reduce the likelihood of nuisance growths of blue-green algae and other aquatic plants (DWAF 1996). The TWQR states that ($N_i$) concentrations should not change by more

**Table 5.5.** Expected or natural conductivity (Ec) readings compared to the observed average instantaneous autumn and spring Ec for sites sampled along the Hout Bay, Lourens and Palmiet Rivers (MSZ = Mountain Stream Zone, UFZ = Upper Foothill Zone, RFZ = Rejuvenated Foothill Zone, LRZ = Lowland River Zone, Med = Median, Min = Minimum Ec, Max = Maximum Ec, TWQR = Target Water Quality Range, AUT = Autumn, SPR = Spring)

| **CONDUCTIVITY ($uSm^{-1}$)** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Expected or Natural*** | | | ***Observed*** | | | | | | | | |
| | | | **Lourens River** | | | **Hout Bay River** | | | **Palmiet River** | | |
| ***ZONE*** | | | ***SITE*** | AUT | SPR | ***SITE*** | AUT | SPR | ***SITE*** | AUT | SPR |
| ***MSZ*** | Med | 3.00 | ***1*** | 11.00 | 11.10 | ***1*** | 4.53 | 3.99 | ***1*** | 4.56 | 3.80 |
| | Min | 0.90 | ***2*** | 12.00 | 13.29 | | | | | | |
| | Max | 21.50 | | | | | | | | | |
| ***UFZ*** | Med | 3.10 | ***3*** | 17.00 | 22.27 | ***2*** | 10.00 | 10.13 | ***2*** | 10.37 | 19.21 |
| | Min | 1.50 | | | | ***3*** | 9.00 | 11.79 | ***3*** | 9.00 | 8.63 |
| | Max | 11.20 | | | | ***4*** | - | 17.75 | | | |
| ***RFZ*** | Med | 3.10 | | | | | | | ***4*** | 17.81 | 17.22 |
| | Min | 1.50 | | | | | | | ***5*** | 19.99 | 15.07 |
| | Max | 11.20 | | | | | | | | | |
| ***LRZ*** | Med | 21.00 | ***4*** | 26.00 | 25.93 | ***5*** | 11.51 | 17.16 | | | |
| | Min | 4.50 | | | | | | | | | |
| | Max | 107.00 | | | | | | | | | |

than 15% from the water body under local unimpacted conditions at any time of the year (DWAF 1996).

The low nutrient concentration observed at the first sites along all three rivers, is characteristic of the naturally acidic waters of south-western Cape Rivers (Covich 1993). $N_i$ does not appear to be a problem along the Hout Bay River as all sites, except for Site 3 where the $N_i$ is slightly higher than 0.5 mg/l, $N_i$ concentration is lower than 0.5 mg/l (Table 5.6). The increase at Site 3 may possibly be attributed to runoff from surrounding paddocks and stables bordering the river as well as from garden fertiliser runoff (Brown *et al.* 1997). With the occurrence of more paddocks and stables between Sites 3 and 4, it was expected that an increase in $N_i$ concentration between these sites would be seen. However, as with the TDS and Ec, a drop between these sites is actually seen (Tables 5.4, 5.5 and 5.6). This indicates that the water is being filtered between these two sites. What the filtering mechanism is needs to be investigated.

**Table 5.6.** Observed average instantaneous autumn and spring inorganic nitrogen concentrations for sites sampled along the Hout Bay, Lourens and Palmiet Rivers (SPR = Spring)

| **INORGANIC NITROGEN (mg/l)** | | | | | |
|---|---|---|---|---|---|
| | | ***Observed*** | | | |
| **Hout Bay River** | | **Lourens River** | | **Palmiet River** | |
| *SITE* | SPR | *SITE* | SPR | *SITE* | SPR |
| *1* | 0.252 | *1* | 0.047 | *1* | 0.101 |
| *2* | 0.008 | *2* | 1.324 | *2* | 0.703 |
| *3* | 0.519 | *3* | 1.57 | *3* | 0.495 |
| *4* | 0.187 | *4* | 1.091 | *4* | 0.595 |
| *5* | | | 1.4 | *5* | 0.256 |

It appears that $N_i$ is a cause for concern along the Lourens River as at all sites, except for the top near-pristine Site 1, $N_i$ concentration is considerably higher than 0.5 mg/l (Table 5.6). This corresponds with the findings of Tharme *et al.* (1997) and is probably due to runoff from surrounding agricultural and urban activities. The greatest increase in $N_i$ concentration is seen between Sites 1 and 2 where a 28-fold increase occurs. With the additional impacts of further agriculture and the occurrence of urbanisation, Site 3 has the highest $N_i$ concentration recorded (more than three times greater than the desirable 0.5 mg/l). This is probably due to agricultural practices and urban fertiliser runoff. As the river passes through the urban Somerset West Area, $N_i$ concentration decreases at Site 4 but then increases again by 1.3-fold between Sites 4 and 5. This indicates that there is a contamination source between these two sites, which may possibly be contamination from the light industrial zone bordering the Lourens River below the N2 national road just upstream of Site 5.

At Palmiet River Site 2, $N_i$ is higher than 0.5 mg/l, probably due to runoff from surrounding agriculture and urbanisation activities (Table 5.6). But again like with TDS and Ec, $N_i$ concentration drops at Site 3, further indicating that the upstream inundation is acting as a sink. This is contradictory to the findings of Byren and Davies (1989) who found nutrient concentrations to increase slightly below the dams. The increase then seen at Site 4 is surprising as Site 4 is in the Kogelberg Nature Reserve. However, as with TDS and Ec (Tables 5.4 and 5.5), this indicates the presence of upstream pollution sources (possibly from runoff in the heavily agriculturalised tributaries, the Huis and Krom Rivers) are impacting this site. After flowing through more of the near-pristine Kogelberg Nature Reserve this concentration drops (Table 5.6).

The increase in $N_i$ concentration seen in the reaches of the Hout Bay, Lourens and Palmiet Rivers that flow through agricultural and urban areas is in agreement with the findings of a number of local and international studies. For example, Hall *et al.* (1996), in their study of Maryland streams in the USA, found a considerable increase in nutrient concentration in river reaches passing through agricultural areas. Loigu and Leisk (1996) found the highest nutrient concentrations in rivers draining agricultural areas and found that the concentration of nutrients like nitrogen increased in the urban areas. Evans (2002) found that the concentrations of $N_i$ in rivers in England and Wales directly related to the amount of cultivation occurring in the catchment, indicating that cultivated areas are the main source of $N_i$ pollution. Sung-Ryong and Myung-Soon (2001) show that an increase in the average nitrogen concentration in Korean Rivers is due to an increase in urban and cultivated land areas. O'Keeffe *et al.* (1996) found that in the middle reaches of the Buffalo River (South Africa) nitrate concentrations were seen to increase as the river flowed through areas characterised by agriculture.

Although $N_i$ concentrations elevated above the desirable 0.5 mg/l were recorded along all three rivers, $N_i$ is still between 0.5 and 2.5 mg/l (Table 5.6). This indicates mesotrophic conditions normally associated with high levels of species diversity and productive systems (DWAF 1996). Nuisance growth of aquatic plants and blooms of blue-green algae can occur but the algal blooms are seldom toxic (DWAF 1996). $N_i$ concentrations at all sites were never high enough (2.5 – 10 mg/l) to cause eutrophication of the river (Table 5.6).

Occasional increases in $N_i$ concentration are less important than continuously high concentrations (DWAF 1996). More frequent readings are necessary to determine the frequency of increases above 0.5 mg/l and consequently the severity of the nutrient contamination in these rivers. Weekly $N_i$ concentrations over at least a four-week period should rather be compared to the TWQR, whilst average summer $N_i$ concentrations are the best basis for estimating the likely biological consequences of $N_i$ (DWAF 1996).

### 5.3.7 Phosphate

Inorganic phosphorous ($P_i$) is seldom measured (Dallas 1998). However, DWAF (1996) stipulates that weekly inorganic concentrations averaged over at least four weeks should be compared to the TWQR and that the average summer $P_i$ concentration is the best predictor of the biological consequences of phosphorous. A concentration of 0.005 mg/l is found in unimpacted, aerobic South African waters (DWAF 1996). Thus phosphorous measurements should ideally occur at a detection limit of at least 0.005 mg/l (DWAF 1996). However, detection limits available in this study were only to 0.1 mg/l. Soluble reactive phosphate levels at all sites along all three rivers were undetectable as all were less than 0.1 mg/l. According to Brown *et al.* (1997), failure to detect nutrients at concentrations greater than 0.1 mg/l, indicates that levels, along all three rivers assessed, are low and therefore, not cause for serious concern. These results are surprising as Evans (2002) and Loigu and Leisk (1996) found that the greatest proportion of phosphorous entering rivers was from agriculture and Roy *et al.* (2003) and O'Keeffe *et al.* (1996) observed an increase in phosphorous with an increase in urban land cover. The fact that phosphorous did not appear to be of concern in either of the three rivers assessed is perhaps indicating that effluent from these urban areas is being well managed and large amounts are not entering the rivers. The levels encountered along the rivers also indicate that spills from sewerage and reticulation systems are not occurring. It is suggested, however, that additional studies be conducted at a more sensitive detection limit in order to substantiate this.

### 5.3.8 The overall condition of the Lourens, Hout Bay and Palmiet Rivers

Along all three rivers assessed, a drastic reduction in water quality is seen between the near-pristine mountain stream sites (Lourens River Site 1, Hout Bay Sites 1 and 2, Palmiet River Site 1) and the consecutive sites assessed in the Upper Foothill Zones (Lourens River Site 2, Hout Bay River Site 3, Palmiet River Site 2). This reduction is seen as the river passes from near-pristine, unimpacted surroundings to areas characterised by anthropogenic disturbances like forestry (Lourens, Hout Bay and Palmiet Rivers), agriculture (Lourens and Palmiet Rivers), urban (Palmiet River) and peri-urban (Hout Bay River) activities. Similarly, O'Keeffe *et al.* (1996) found that the water quality in the upper reaches of the Buffalo River in the Eastern Cape was in a good condition, as these reaches had not been impacted by development. However, water quality deteriorated as the Buffalo River passed into the middle and lower reaches impacted by agriculture and urbanisation. The water quality aspects that are cause for particular concern or interest along the three rivers assessed in this study are highlighted below.

5.3.8.(i) <u>Hout Bay River</u>

(a) $N_i$ is slightly elevated at Site 3 probably due to runoff from the surrounding horse paddocks and stables and garden fertilisers. Due to the longitudinal nature of river systems, Site 4 experiences the cumulative effects of the impacts experienced by Site 3 as well as being exposed to additional paddocks, stables and gardens between Sites 3 and 4. It is, therefore, expected that $N_i$ concentration should increase at Site 4. However, it was seen to decrease. TDS shows a similar pattern between Sites 3 and 4. It can, therefore, be concluded that the water is being filtered or the nutrients and salts are being trapped between Sites 3 and 4, by, for instance, resetting by flowing through a wetland. The determination of the exact mechanism, however, was beyond the scope of the present project and is a topic for future investigation.

(b) Ec and TDS concentrations are higher than expected at Site 3. TDS is three times greater than expected and greater than the maximum expected value, whilst Ec is considerably higher than the maximum expected value. Investigation into the reasons for these elevated values should be conducted and management actions to decrease these levels should be taken.

(c) At Site 4, as at Site 5 along the Lourens River, the low dissolved oxygen saturation level is of concern. However, it does improve in spring, indicating that it is perhaps not of too long a duration. However, the frequency, timing and duration of these lows must be investigated to ascertain the severity of the condition.

5.3.8.(ii) Lourens River

(a) Exceptionally high TDS and Ec readings were obtained at Sites 2, 3 and 4. These TDS readings are 1.6 to 2.5 times greater than the desired concentration and consequently exceed the TWQR by on average 25.27 mg/l. Similarly, the conductivity levels of these sites are 2.9 to 5.7 times greater than desired. The frequency of these elevated states should, firstly, be determined in order to ascertain the severity of the condition. Secondly, the source(s) of contamination should be identified and appropriate management actions should be determined to decrease the salt contamination at these sites.

(b) The elevated levels of $N_i$, downstream of Site 1 are probably caused by runoff from the agricultural, urban and light industrial areas. Although it does not appear that levels are high enough during autumn and spring to result in eutrophication of the system, average summer concentrations should be obtained to ascertain the likely biological consequences of $N_i$. Nevertheless, $N_i$ levels are reasonably high and should be monitored to ensure that they do not increase to levels responsible for eutrophication.

(c) The low DO saturation levels recorded during spring at Site 5 on the Lourens River must be highlighted. According to DWAF (1996) DO levels are characteristically lowest at dawn (06h00), increasing during the day. The 06h00 saturation should be between 80 – 120%. Site 5 was assessed after dawn and thus it is assumed that the oxygen level should have risen from its theoretical lowest concentration at dawn. The 63.5% recorded, therefore, indicates that there was a severe shortage of oxygen at this site during spring. The frequency, timing and duration of this shortage should be determined, however, in order to ascertain the severity of the condition, as continuous exposure to saturations lower than 80% are more severe than short-lived oxygen depletion (DWAF 1996).

5.3.8.(iii) Palmiet River

(a) Site 2, in Grabouw, has the poorest water quality along the Palmiet River. The elevated TDS, conductivity and $N_i$ levels can probably be attributed to runoff from the surrounding agricultural, forestry and urban activities.

(b) In both autumn and spring Site 2 also has DO saturations that are considerably lower than the minimum 80% saturation required to protect aquatic ecosystems (DWAF 1996). However, again the frequency, timing and duration of this depletion should be determined to ascertain the severity of the condition.

(c) The impoundments occurring between Sites 2 and 3 appear to be acting as sinks for TDS, Ec and $N_i$. However, these values increase at Site 4 to levels 2.5 to 2.7 times greater than the expected value and TWQR. This is surprising and of concern as Site 4 is in the Kogelberg Nature Reserve surrounded by natural, conserved, near-pristine fynbos vegetation. It was, thus, expected that the water quality would improve. The increase seen at Site 4 is, therefore, indicative of upstream contamination perhaps from the heavy agriculturalised Huis and Krom River tributaries, which join the Palmiet River just above Site 4. After flowing through most of the near-pristine Kogelberg Nature Reserve, the TDS concentration is still 2.5 times greater and conductivity 1.7 times greater than their expected values at Site 5. This indicates that the water quality of the Palmiet River within the Kogelberg Nature Reserve is not as good as was expected. Upstream sources of this contamination should be investigated and management actions should be undertaken to improve the condition of the lower reaches of the Palmiet River as well as of Site 2 in Grabouw.

## 5.4 CONCLUSIONS

Although the results do not allow for the deduction of trends over time or for most to be compared to the calculated TWQR, they do give an indication of the condition of the river at the time that the river health assessments were undertaken. The results have been used in the Index of Habitat Integrity (IHI) assessment (Chapter 3) and can also be used for the SASS and FAII assessments conducted by Ollis (*in prep.)* and Hayes (2002) respectively. The data can also be added to long term data sets to assess the quality of the rivers on a temporal scale. DWAF (Diedricks *pers. comm.* 2003) and the Cape Metropolitan Council (Haskins *pers. comm.* 2003) have long-term data sets for some of the same sites assessed in this study and, in some instances, data for sites near to those assessed here. Sites in this study were chosen for their suitability in conducting river health assessments (Chapter 2) and not all the sites with long-term water quality data sets were found to be suitable for river health assessments. If the project was purely a water quality survey, the design would need to have been different and tests would have been carried out at sites for which long-term data is available. However, it is suggested that future river health assessments be conducted at the sites used in this study (Chapter 2) and as such long-term water quality data sets can be built up for them. The data obtained in this study are the first entries in such data sets and provide the baseline conditions for future assessments.

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# GENERAL CONCLUSIONS

## 6.1 INTRODUCTION

Like rivers throughout the world, South African rivers are increasingly suffering disturbance from water resource development (Kleynhans 1996; Rowntree *et al.* 2000). The assessment of the environmental condition of rivers and their rehabilitation is thus being promoted internationally. For example, in Australia the Council for Australian Governments promotes the legal protection of environmental flows and in England and Wales the National Rivers Authority gives explicit recognition to the ecological needs within water resource management (Rowntree *et al.* 2000). The South African National Water Act (Act No. 36 of 1998) brings South Africa in line with these international trends by recognising and protecting an ecological reserve in rivers and legislating for the monitoring of river health (Republic of South Africa 1998). As custodian of water resources in South Africa, the Department of Water Affairs and Forestry (DWAF) is responsible for the protection of aquatic ecosystem health, thereby ensuring the ability of these systems to meet utilisation requirements of present and future generations (DWAF 1996; WRC 2001, 2002; RHP 2003, *in prep.*). For this purpose DWAF initiated the River Health Programme (RHP) in 1994 (Roux *et al.* 1999; WRC 2001, 2002; RHP 2003, *in prep.*). The goals of this programme are to:

1. Measure, assess and report on the ecological state of riverine ecosystems;
2. Detect and report on spatial and temporal trends in this ecological state; and
3. Identify and report on emerging problems regarding this ecological state (Roux *et al.* 1999).

## 6.2 THE SUCCESS OF THE RIVER ZONATION AND SITE SELECTION FOR THE RHP PERFORMED DURING THIS STUDY

The RHP is essentially a scoping process assessing sites representative of broad geomorphological zones to identify areas of poor ecological health. An aim of this study was, therefore, to zone the three rivers assessed and select representative sites in each zone. Using the desktop method of Rowntree *et al.* (2000), which relies on gradient for the longitudinal zonation of South African rivers, it was found that each river could be successfully zoned provided that field verification of the desktop analysis occurs. However, the results also indicate that the notion that one gradient classification system will be applicable nationally throughout South Africa, with its diverse geology and climate, is unlikely. Rather this classification system needs to be modified for various physiographic and hydrological regions or features, or according to a factor based on the length of the river. More information and data is needed, however, before such a concept can be implemented. In the meantime this method generally appears to be successful in the longitudinal zonation of South African rivers for the RHP provided that field verification of the desktop analysis is conducted.

Along each river sites representing the various substrates, hydraulic biotopes, vegetation and impacts experienced by a zone could be found. However, the idea of assessing one site representative of each geomorphological river zone is not always feasible as zones can cover large distances and experience diverse impacts. It was found that in these instances along the three rivers assessed in this study two sites were needed in a zone. It is up to the discretion of the assessor to determine the number of sites that is sufficient in representing the condition of a zone.

## 6.3 THE HABITAT INTEGRITY OF THE HOUT BAY, LOURENS AND PALMIET RIVERS AND THE SUCCESS OF THE HABITAT INTEGRITY STUDY IN FULFILLING THE PRIMARY GOALS OF THE RHP

Conducted simultaneously with the biological assessments of Hayes (2002), Ollis (*in prep.*) and Withers (*in prep.*), this study forms part of a south-western Cape river health assessment by focussing on the habitat integrity and water quality of the Hout Bay, Lourens and Palmiet Rivers assessed. Habitat integrity assessments have become important in assessing the ecological integrity (or health) of rivers internationally (Campbell 1994; Davies and Schofield 1994; Jackson and Anderson 1994; Kleynhans 1996; Muhar and Jungwirth 1998; Kemper 1999; Kleynhans 1999; McQuaid and Norfleet 1999). In South Africa, the Index of Habitat Integrity (IHI) is used (Kleynhans 1996, 1999). By using the Index of Habitat Integrity for intermediate and rapid assessments (Kemper 1999), this study shows that the habitat integrity along the three rivers assessed tends to decrease longitudinally downstream. As in other studies conducted (Kleynhans 1996; Roth *et al.* 1996; Roy *et al.* 2003), this decrease corresponds with an increase in anthropogenic disturbances as the rivers flow from the steep mountainous upper catchment areas, covered in natural Mountain Fynbos, into the flatter middle and lower reaches where forestry, agriculture and urban activities dominate. The exception is the Palmiet River, where the habitat integrity of its lower reaches improves as it passes through the Kogelberg Nature Reserve. Similar results were seen by Kleynhans (1996) along the lower reaches of the Luvuvhu River passing through the Kruger National Park. By measuring, assessing and reporting on the habitat integrity of these rivers, this study also fulfils the first goal of the RHP.

Although sites were visited during the autumn and spring of 2002, no changes in the habitat integrity were observed. This indicates that the IHI could be conducted on a lower than seasonal or annual frequency, as the effects of changes in the physical criteria assessed will only become noticeable over a longer time period. The IHI should also be used during the season when the river is experiencing natural stress, as during this time the severity of criteria like water abstraction or flow modification will become most apparent. By reporting on the spatial and temporal trends in habitat integrity, this study serves in fulfilling the second goal of the RHP.

Areas of habitat degradation were identified along each river during this study. Firstly, extensive channel modification has occurred in the Lowland River reaches of the Hout Bay River, above and below Victoria Road. Here, grassed levees cut the river channel off from its floodplain. Riparian landowners also appear to be extracting large volumes of water between Hout Bay Road and Victoria Road. Secondly, due to channel modification with gabioned and cemented river banks built for flood control, poor water quality and alien vegetation species dominating the riparian zone, the middle and lower reaches of the Lourens River in and below Somerset West are cause for concern. Thirdly, the Palmiet River passing through the urban areas of Grabouw has an extensively modified habitat. Of concern are the oxygen saturations recorded, which were below those necessary to support most aquatic life forms. The high inorganic nitrogen and total dissolved salts concentrations and sandbanks indicate that the river reaches passing through the Kogelberg Nature Reserve have a modified habitat integrity. Alien vegetation was also evident in the riparian zone. These conditions should not be occurring in a conserved area and are a result of upstream contamination, perhaps from the heavy agriculturalised Huis and Krom River tributaries. Investigation into the exact causes of this habitat degradation along the three rivers should now be conducted and the negative influences should be remedied. By identifying the areas of habitat degradation, this study has fulfilled the third goal of the RHP. Various methods for improving the habitat integrity in the areas highlighted above are discussed in Chapter 3 of this study.

Although successful in indicating areas of habitat degradation along the rivers assessed and fulfilling the primary goals of the RHP, the IHI was found to be subjective. It is suggested that research be conducted into categorising the scoring used in the IHI. As in the American Visual Stream Assessment Index (USDA/NRCS 1998), the assessor could then choose the description best suiting the site and assign the corresponding score. This would reduce the risk of over- and / or under- scoring of habitat modifications. Brown *et al.* (2001) have developed such guidelines (Appendix A) but these need verification and possible refinement.

## 6.4 THE EFFECT OF LAND USE ON THE HABITAT QUALITY ALONG THE THREE RIVERS ASSESSED

Along the Hout Bay, Lourens and Palmiet Rivers it appears that the amount of natural or disturbed land use occurring at both a regional and local scale is a good predictor of riverine habitat integrity. It also appears that the amount of alien forestry occurring at a regional scale upstream of a site has a significantly large negative impact on riverine habitat integrity, whereas urbanisation has the greatest effect on instream and riparian habitat integrity at a local scale. It, therefore, appears that different land use types effect the habitat integrity of streams at differing scales. River management is thus an action that needs to occur over various scales and, therefore, according to Allan *et al.* (1997), managers and planners must think in terms of catchments.

## 6.5 WATER QUALITY

### 6.5.1 Areas of concern along the rivers assessed

As an aim of this study, the water quality of the Hout Bay, Lourens and Palmiet Rivers was assessed as part of the river health assessments. The results indicate the state of the river at the time of the river health assessments and were, therefore, used in the habitat integrity assessments of the rivers and can be used in the South African Scoring System (SASS) and Fish Assemblage Integrity Index (FAII) assessments (Ollis *in prep.*; Hayes 2002). Generally the results indicate that at the time of sampling, although inorganic nitrogen concentrations were elevated above the desired concentration along the Lourens River middle reaches, the concentration of nutrients was not high enough to cause eutrophication along any of the three rivers. The dissolved oxygen saturations in the Palmiet River in Grabouw were not high enough to support most life forms and the elevated inorganic nitrogen and total dissolved salts concentrations in the Palmiet River, in the Kogelberg Nature Reserve, indicated upstream contamination, perhaps from the heavily agriculturalised Huis and Krom River tributaries. The inundation along the middle reaches of the Palmiet River appears to be acting as a sink for total dissolved salts and inorganic nitrogen, whilst, along the Hout Bay River, the water is being filtered or the nutrients and salts are being trapped between Disa and Victoria Roads, by, for instance, resetting by flowing through a wetland.

### 6.5.2 The comparison of the water quality results with Target Water Quality Ranges

Due to the nature of the study, the majority of the constituents measured could not be compared to their respective National Target Water Quality Range, specified by DWAF (1996), as specific long term monitoring data is needed. However, the study does indicate that the TWQR specified for pH is not suitable for the unbuffered waters of the mountain and foothill zones in south-western Cape rivers, which experience large fluctuations in pH. This evidence supports the suggestion by Dallas *et al.* (1998) that regional water quality guidelines are needed.

## 6.6 COMMENTS AND CRITICISMS OF THE RHP

The RHP is in line with other similar international programmes, for example, the National River Health Programme (Environment Australia 2003) run in Australia. The RHP is a successful programme which can be used nationally to inform authorities, environmentalists and the public on the present state of South Africa's rivers. The idea of using water-related indicators / indices in the RHP to measure the quality of an ecosystem's well-being, is an idea that has accelerated in its use recently world-wide (Gleick 2002). The IHI, used in this study, is such an index that can be applied nationally. However, it appears that the zonation method and water quality guidelines used need modification for the various provinces or physiographic or hydrological regions. The value of the RHP lies in that it is a scoping process acting to identify areas of poor ecological health. As such it is not an expensive or time consuming exercise. It is important however, that the various RHP indices, working at different scales, be used to obtain an overall, complete picture of the health of the rivers assessed. Detailed studies should then be conducted at sites of poor ecological health, so as to identify and remedy the causes of this degradation. It is imperative that the results of the RHP assessments be incorporated into management actions to improve or maintain river health.

## 6.7 THE OVERALL SUCCESS OF THIS STUDY

It can be concluded that this study has not only reached its own aims (Chapter 1) but has also satisfied the primary aims of the RHP. The results of this study should be read in conjunction with the other three biotic assessments (Hayes 2002; Ollis *in prep.;* Withers *in prep.*) conducted simultaneously to obtain an overall picture of the health of the Hout Bay, Lourens and Palmiet Rivers. The results should be used to develop management plans for the three rivers and should be entered into a river management database system as baseline data for future river health assessments. Future river health assessments should be conducted at the sites chosen in this study because, as required by the RHP, they are considered to be representative of their respective geomorphological zones. The results of this study have been used in a State-of-Rivers report that will be published by DWAF (RHP *in prep.*).

It is hoped that this study will serve to inform the Western Cape public about the state of the Hout Bay, Lourens and Palmiet Rivers and that the results will be used by river catchment authorities to devise management actions for these rivers. It is also hoped that this study has highlighted and provided various avenues for future research to aid South Africa in protecting its water resources to ensure their sustainability for present and future generations.

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