BERG RIVER BASELINE MONITORING PROGRAMME

FINAL REPORT - VOLUME 5: Synthesis

DWAF Report No. P WMA 19/G10/00/2107

Edited by: BARRY CLARK and GEORDIE RACTLIFFE

October 2007
BERG RIVER BASELINE
MONITORING PROGRAMME

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Department of Water Affairs and Forestry
Directorate: Options Analysis

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# TABLE OF CONTENTS

**CHAPTER 1 - INTRODUCTION**

1.1 BACKGROUND .................................................................................................................. 2

1.2 OVERVIEW OF THE BERG RIVER CATCHMENT, HYDROLOGY AND GROUNDWATER ASSESSMENT ........................................................................................................ 2

1.3 DESCRIPTION OF THE ABIOTIC AND BIOTIC CHARACTERISTICS OF THE BERG RIVER .................................................................................................................. 2

1.4 ESTUARINE ASSESSMENT ................................................................................................. 2

1.5 SOCIAL AND RECREATIONAL ACTIVITIES ASSESSMENT ........................................... 3

1.6 CONTENT OF THIS REPORT VOLUME ............................................................................. 3

**CHAPTER 2 – RIVERINE ECOSYSTEM FUNCTIONING**

2.1 INTRODUCTION................................................................................................................. 5

2.1.1 Aims of this report ...................................................................................................... 5

2.2 CATCHMENT CHARACTERISTICS .................................................................................. 5

2.3 GROUNDWATER ............................................................................................................ 6

2.4 HYDROLOGY .................................................................................................................... 8

2.4.1 Flow variability ........................................................................................................ 9

2.4.2 The importance of the upper river to flows in the downstream reaches .............. 13

2.5 MAJOR ABIOTIC AND BIOTIC PATTERNS IN THE BERG RIVER AND THEIR RELATIONSHIP TO FLOW .................................................................................. 17

2.5.1 Longitudinal gradients in the Berg River ............................................................... 17

2.5.2 Channel characteristics and the influence of flow ................................................. 25

2.5.3 Water quality in the Berg River and the influence of flow ..................................... 27

2.5.4 Riparian vegetation in the Berg River and the influence of flow ......................... 34

2.5.5 Periphyton in the Berg River and the influence of flow ......................................... 35

2.5.6 Macro Invertebrates in the Berg River and the influence of flow ....................... 36

2.5.7 Fish in the Berg River and the influence of flow ............................................... 39

2.6 HABITAT INTEGRITY AND PRESENT ECOLOGICAL STATE OF THE BERG RIVER 41

2.7 IMPLICATIONS OF THE BERG RIVER DAM FOR ECOSYSTEM FUNCTIONING ... 45

2.6.1 Upper Foothill reach .............................................................................................. 46

2.6.2 Lowland river ......................................................................................................... 47

2.8 IMPLICATIONS FOR RESEARCH AND MONITORING ............................................. 49

2.9 REFERENCES .................................................................................................................. 49
CHAPTER 3 – ESTUARY CONCEPTUAL MODEL

3.1 INTRODUCTION

3.1.1 Background

3.1.2 Aims of the study

3.1.3 Approach

3.1.4 Structure of the report

3.2 WHAT IS A CONCEPTUAL MODEL?

3.3 THE BERG RIVER CATCHMENT AND ESTUARY

3.3.1 The Catchment

3.3.2 Location, shape and extent of the estuary

3.4 PATTERNS OF FLOW INTO THE ESTUARY

3.5 THE INFLUENCE OF FLOW ON PHYSICO-CHEMICAL CHARACTERISTICS

3.5.1 Water levels

3.5.2 Influence on sediments and bathymetry

3.5.3 Influence of flow on turbidity

3.5.4 Influence of flow on estuary water quality and nutrients

3.6 BIOTIC COMMUNITIES AND FLOW-RELATED DETERMINANTS OF THEIR STRUCTURE AND PRODUCTIVITY

3.6.1 Micro algae

3.6.2 Macrophytes

3.6.3 Invertebrates

3.6.4 Fish

3.6.5 Birds

3.7 A CONCEPTUAL MODEL OF THE ROLE OF FLOW IN DETERMINING ECOSYSTEM CHARACTERISTICS

3.7.1 The influence of flow on productivity, biomass and diversity

3.7.2 Influence of non-flow related biotic interactions

3.7.3 Influence of external factors on biotic communities

3.8 IMPLICATIONS FOR RESEARCH AND MONITORING

3.9 REFERENCES

CHAPTER 4 – RECOMMENDATIONS FOR FUTURE STUDY AND MONITORING REQUIREMENTS

4.1 INTRODUCTION

4.2 CHANGES IN HYDROLOGY AND SEDIMENT TRANSPORT RESULTING FROM THE BERG RIVER DAM

4.3 RECOMMENDATIONS REGARDING THE REFINEMENT OF THE IFR FOR THE BERG RIVER

4.4 RECOMMENDATIONS FOR REFINEMENT OF HYDROLOGICAL DATA AND MONITORING
4.5 RECOMMENDATIONS FOR GROUNDWATER MONITORING ........................................... 85

4.6 CONSOLIDATED MONITORING RECOMMENDATIONS FOR THE RIVER SYSTEM ............... 86

4.6.1 Hydrodynamics and sediment transport ................................................................. 86
4.6.2 Water chemistry ........................................................................................................ 88
4.6.3 Riparian vegetation ..................................................................................................... 89
4.6.4 Periphyton .................................................................................................................. 89
4.6.5 Invertebrates .............................................................................................................. 90
4.6.6 Fish ............................................................................................................................ 92

4.7 CONSOLIDATED MONITORING RECOMMENDATIONS FOR THE BERG RIVER ESTUARY .............................................................. 93

4.7.1 General monitoring recommendations ................................................................. 93
4.7.2 Hydrodynamics and sediment transport ................................................................. 93
4.7.3 Water chemistry ........................................................................................................ 94
4.7.4 Microalgae ................................................................................................................ 95
4.7.5 Macro algae and vegetation ...................................................................................... 95
4.7.6 Invertebrates .............................................................................................................. 96
4.7.7 Fish ............................................................................................................................ 96
4.7.8 Avifauna ..................................................................................................................... 97

4.8 MONITORING PROGRAMME LOGISTICS AND REPORTING ........................................ 98
## LIST OF FIGURES

| Figure 2.1 | The Berg River catchment, showing major topographic features and drainage network feeding the main river. Aquifer monitoring points are also indicated | 6 |
| Figure 2.2 | Map of the Berg River catchment, showing the locations of DWAF gauging weirs (red text) on the mainstream Berg River and tributaries and additional sampling points (green text) used for water chemistry determinations | 9 |
| Figure 2.3 | Present day and naturalised mean annual runoff for sub-catchments in the Berg River Basin. Note only the portion of the total Berg River catchment included in the hydrological analysis (i.e. to Misverstand Dam) is presented | 11 |
| Figure 2.4 | Peak average daily flood flow at G1H004, as a percentage of the same flood peak at G1H013, regressed against flood size G1H013. Note that smaller floods at G1H013 have a substantially larger proportion of their flow contributed by G1H004 than do larger floods | 14 |
| Figure 2.5 | Scatter plot comparing flood peaks (peak average daily flow) at G1H004 with flood size in the lower river, represented by G1H013. The significant correlation coefficient (r-value) is indicated | 16 |
| Figure 2.6 | (a-c) Summary data for selected variables at major monitoring sites along the Berg River. Summer and winter data, for three time periods. Missing values arrowed on each graph. Site locations are indicated in green in Figure 2.2. | 22 |
| (d-f) | Summary data for selected variables at major monitoring sites along the Berg River. Summer and winter data, for three time periods. Missing values arrowed on each graph. Site locations are indicated in green in Figure 2.2. | 23 |
| Figure 2.7 | Longitudinal bed profile of the Berg River to Piketberg, showing chemical characteristics of major tributaries | 24 |
| Figure 2.8 | General and simplified relationship between increasing flow discharge and water level with hydraulic variables such as mean velocity, total wetted area etc | 25 |
| Figure 2.9 | Total dissolved solid load compared to runoff, from tributaries flowing into the Berg River: October 1988 to September 1989. Diagram after Bath (1993). Numbers refer to names of tributaries in the key | 29 |
| Figure 2.10 | Seasonal breakdown of total dissolved solid (TDS) loads from tributaries into the main channel of the Berg River: October 1988 to September 1989. Diagram after Bath (1993). Numbers refer to tributaries, listed in Figure 2.9 | 29 |
| Figure 2.11 | Summary (NO3+NO2)-N data from DWAF gauging weirs for data collected in the Berg River between January 2003 and December 2006. Data used as surrogate for total inorganic nitrogen. A. (NO3+NO2)-N concentrations B. Estimates of loading. NOTE: absence of data indicates missing values and not zero values | 33 |
Figure 2.12  Schematic showing generalised plant community zones perpendicular to the river channel and their relationship to various components of the flow regime (graphic supplied by JM King).  WSLF = Wet Seasonal Low Flow; DSLF = Dry Season Low Flow; four classes (1-4) described DRIFT intra-annual flood categories, whilst 1:2 and 1:20 describe inter-annual return-period floods.

Figure 3.1  (a) Conceptual, (b) deterministic and (c) statistical models and their accompanying predictions for the example of the effect of an increase in nitrogen on the biomass of deposit feeders. The first column shows a graphical representation of each model and the second column shows the probability densities of the predictions arising from the respective models. After Constable (1999).

Figure 3.2. The catchment of the Berg River. Main river flows south to north (Source: Parsons 2004)

Figure 3.3 Bathymetry of the Berg River estuary. (Source: Beck & Basson 2007).

Figure 3.4 Interannual pattern of flow at Misverstand (Source: Schuman 2007).

Figure 3.5 Relationship between annual rainfall and total annual volume of flow at Misverstand dam (Source: Schuman 2007).

Figure 3.6 Average flow rates at Misverstand (1974-2003) showing seasonal variation. Data from DWAF.

Figure 3.7 Measured water level relative to msl at Saldanha Bay, Laaiplek, Kliphoek and Jantjiesfontein. The blue lines show the longer-period fluctuations, while the red ellipse highlights an instance where the height of the high tide on one day is actually lower than the height of the low tide on the following day due to the longer period fluctuations in water level. (From Schumann 2007)

Figure 3.8 Relationship between salinity and turbidity (secchi depth) in the Berg estuary.

Figure 3.9  (a) Hypothetical build-up of sediments on intertidal areas and floodplain after a major flood, shown in cross-section, and (b) Build-up of and scouring of sediment at a particular spot over time under natural conditions (solid line) and under reduced-flow conditions (dotted line).

Figure 3.10 Relationship between salinity and turbidity (secchi depth) in the Berg estuary.

Figure 3.11 Salinity distribution during spring high tide and low freshwater flow (February) and during spring high tide and high flow (August). Source: Schuman (2007)

Figure 3.12 Relationship between NOx-N (NO3 + NO2 + NH3) concentrations and salinity measured in the Berg River Estuary during low flow (summer) and high flow (winter). Source: Clark & Taljaard (2007)

Figure 3.13 Simplification of the relationships between freshwater flow and physical parameters of the estuary. PON/POC is particulate organic nitrogen/carbon.

Figure 3.14 Dominant phytoplankton cells collected from the Berg estuary (A = large flagellate, B = small diatom and C = small flagellate). Source: Bate & Snow (2007).

Figure 3.15 Hypothetical relationships between nutrients, salinity and micro algal abundance (chlorophyll a concentration), ceteris paribus.
| Figure 3.16 | Salinity and degree of inundation as the main drivers of estuarine vegetation communities. | 69 |
| Figure 3.17 | Schematic diagram showing how the biomass per unit area and composition of different guilds of fish change in relation to salinity changes along the estuary. The relative contribution to biomass by the different groups is dynamic, but is roughly 80% micro algae/detritus feeders, 10% zooplankton feeders, 5% hyperbenthic/benthic invertebrate feeders and 5% piscivores. Species shown are dominant species within each guild. | 71 |
| Figure 3.18 | Conceptual model showing how riverine inflow influences physical and biotic components of the Berg River estuary. Only key components and relationships are depicted. Boxes with dotted edges are copies of variables elsewhere in the diagram to avoid excessive leader lines. | 74 |
LIST OF TABLES

Table 2.1 Comparison of 50th percentiles for low flow data at G1H004 for each month during the Baseline Monitoring period, against the longer-term low flow averages for two periods from the hydrological record. Flow values are in m³/s. Percentiles are based on low flows i.e. with floods removed from the flow record.  

Table 2.2 Comparison of 50th percentiles for low flow data at G1H013 (Drieheuwels) for each month during the Baseline Monitoring period, against the longer-term low flow averages from the hydrological record. Flow values are in m³/s. Percentiles are based on low flows i.e. with floods removed from the flow record.  

Table 2.3 Floods recorded at G1H004 in 2003-2005, compared with the longer term flood statistics (short record, 1980 – 1999, from Table 5.11). The number per annum (underlined), average peak daily flow (m³/s) and average volume per flood (Mm³) is provided in each case. The total number of floods per annum is also indicated, with, in brackets the total volume of flood flows per annum.  

Table 2.4 Floods recorded at G1H013 (Drieheuwels) in 2003-2005, compared with the longer term flood statistics. The number per annum (underlined), average peak daily flow (m³/s) and average volume per flood (Mm³) is provided in each case. The total number of floods per annum is also indicated, with, in brackets the total volume of flood flows per annum.  

Table 2.5 Summary of the percentage contribution of flood flows at G1H004 to the total flood passing through G1H013, averaged for various flood size classes. All inter-annual floods are included in the Band5 category.  

Table 2.6 Summary description of the geomorphological zones and reaches of the Berg River along with major riparian vegetation and in-stream invertebrate community characteristics.  

Table 2.7 Pearson’s correlation coefficients of 4th root transformed invertebrate densities and abiotic variables, for taxa in the Molenaars River (M) in June 2003 and the Berg River (B) in May 2004. Only significant relationships are presented. Results are given as the Pearson’s r-value. p-value is indicated as follows: * p <0.05; **p< 0.01; § p<0.001; † p< 0.000. Organic matter data were log-transformed to achieve normality.  

Table 2.8 Ecological Status classes from DWAF (1999).  

Table 2.9 PES / Ecostatus for ecosystem components.  

Table 2.10 Timing and magnitude of simulated artificial flood releases based on historical records, from the hydrodynamic modelling in the BRBMP.
CHAPTER 1 - INTRODUCTION

Geordie Ractliffe & Dr Barry Clark
1.1 BACKGROUND

The overall objectives of the Berg River Baseline Monitoring Programme (BRBMP) are presented in Volume 1 of this report series. Briefly, the aims of the programme were to describe the natural and present state, including the natural variability, of those chemical, physical and biological characteristics of the river and its hydraulically linked systems (i.e. estuary, floodplains and groundwater) that are most likely to be affected by changes imposed after the construction of the Berg River Dam.

The overall approach to the baseline monitoring programme, for river, estuary, groundwater, and socio-economic components was the initial sourcing and collation of a considerable volume of data and information already existing for the Berg River System, previously collected as part of other programmes and/or projects. Each specialist involved on the project was required to collate all available data within his/her field of expertise. The data were then used by the specialists to provide a series of situation assessments, each dealing with a different component of the Berg River or estuary. These assessments included an outline of the present ecological condition of the Berg River, as well as a description based on present knowledge of the structure and functioning of the ecosystem, both historically and in the present day. This was augmented by a field study component.

The final report for this study comprises five volumes. Volume 1 provides an introduction to the Berg River catchment and the groundwater environment, and an analysis of the natural and present-day flow regime. Volume 2 focuses on the riverine environment, Volume 3 on the Berg River estuary and floodplain and Volume 4 on social and cultural dependence on the Berg River and estuary. This, the fifth volume in the series, provides a synthesis of findings and recommendations for ongoing monitoring. Further details on where additional information on each of the four major components of the monitoring programme can be located is provided in the next four sections (sections 1.2-1.5).

1.2 OVERVIEW OF THE BERG RIVER CATCHMENT, HYDROLOGY AND GROUNDWATER ASSESSMENT

Results from the river monitoring studies are included in Volumes 1 and 2. Volume 1 provides a general introduction to the monitoring programme as a whole (Chapter 1), as well as detailed information on the Berg River catchment (Chapter 2), and management of water resources in the catchment (Chapter 3). Results of the geohydrological and hydrological studies are also included in this volume (Chapters 4 and 5, respectively).

1.3 DESCRIPTION OF THE ABIOTIC AND BIOTIC CHARACTERISTICS OF THE BERG RIVER

Volume 2 provides detailed information collected as part of each of the riverine monitoring studies including hydraulics and fluvial morphology (Chapter 2), sediment transport (Chapter 3), water chemistry (Chapter 4), riparian vegetation (Chapter 5), periphyton (Chapter 6), invertebrates (Chapter 7a), invertebrate responses to floods (Chapter 7b), and fish (Chapter 8).

Each chapter provides a detailed description of the current state of the system as revealed by survey activities conducted as part of the programme as well as a summary of any historical information available on the system. Each chapter also includes conclusions and statements from the various experts (authors) regarding the natural variability observed in the system during the baseline monitoring period and from historical data, its relevance to ecological sustainability, key processes that affect the physical or biotic component(s) in question, as well as key parameters that could be used as indicators to measure future changes in the system.

1.4 ESTUARINE ASSESSMENT

Results of the biophysical estuary monitoring studies are all contained in Volume 3 of this series.

This volume provides detailed descriptions of each of the physicochemical and biological components of the Berg River Estuary studied as part of the Berg River Baseline Monitoring Programme.
This includes the following components: Hydrodynamics and Sediment Transport (Chapter 2), Water Chemistry - Salinity, Temperature, Oxygen and Turbidity (Chapter 3), Nutrients (Chapter 4), Micro Algae (Chapter 5), Estuary and Floodplain Vegetation (Chapter 6), Submerged Macrophytes and Macroalgae (Chapter 7), Invertebrates (Chapter 8), Fish (Chapter 9) and Birds (Chapter 10).

1.5 SOCIAL AND RECREATIONAL ACTIVITIES ASSESSMENT

Results of the social and recreational assessments are all contained in Volume 4 of this series. The social and cultural aspects most likely to be affected by the Berg River Dam, in addition to those indirect effects felt through changes in ecosystem functions, are livelihoods, safety, and recreation. Two dedicated studies were designed and implemented to address these issues. The first focussed broadly on safety and recreation (Chapter 2), while the second focussed in more detail on livelihoods and recreation associated with the Berg Estuary, specifically recreational and subsistence fishing activities (Chapter 3).

1.6 CONTENT OF THIS REPORT VOLUME

The final volume of this report series is intended as a synthesis of the information provided in the preceding volumes, but focussing on the extent to which flow affects each ecosystem component directly, or modifies other biotic and abiotic relationships. Chapter 2 summarises our understanding of the role of flow in the ecological functioning of the Berg River itself, focusing in turn on each of the ecosystem components included in this BRBMP study. The Terms of Reference for this study further required that, for the Berg River estuary, a conceptual model be built to describe links between flow and fauna and flora of the estuary. Construction of the model required a succinct synthesis of the results of the monitoring programme including links between flow and all other physico-chemical parameters, between these physico-chemical parameters and the biota, as well as links between different biotic groups and feedback loops from the biota to physico-chemical parameters. This forms the substance of Chapter 3 of this volume. Finally, the detailed monitoring recommendations provided within each of the targeted specialist studies of this programme are synthesised into a single set of recommendations for monitoring, included here as Chapter 4.

Chapter 1 - Introduction
Chapter 2 - Riverine Ecosystem Functioning
Chapter 3 - Estuary Conceptual Model
Chapter 4 - Recommendations for future study & Monitoring Requirements
CHAPTER 2 – RIVERINE ECOSYSTEM FUNCTIONING

Geordie Ractliffe
2.1 INTRODUCTION

Many ecologists regard the hydrological regime of a river, which derives from such primary ecosystem characteristics as climate, geology and topography, as the master physical variable controlling ecosystem pattern and process. Hildrew & Giller (1994) assert that the forces of flow are “undoubtedly the major architects of physical patchiness in streams”, and physical heterogeneity, or patchiness, at a range of scales is part of the reason that rivers are complex and diverse ecosystems. Flows continually modify morphological features such as the channel bed and bars, due to processes of scour and deposition, and thus regulate the availability, spatial arrangement and condition of instream and floodplain aquatic habitats, and provided for the continued integration of different components of the riverine ecosystem. Poff et al. (1997) list five critical components of the flow regime that regulate ecological processes in river ecosystems: the magnitude, frequency, duration, timing (or predictability) and rate of change (flashiness) of hydrological conditions. On one hand, flow permanence, or the lack of it (the tendency for a system to undergo droughts) and on the other hand the nature of flooding, represent two of the major physical drivers defining the sorts and combinations of plant and animal species that characterise different river ecosystems. Similarly, all the flows in between these extremes play different roles in maintaining a river. Changing the nature of these “physical drivers” may have profound effects on the biological communities they support.

2.1.1 Aims of this report

This report provides a synthesis of our understanding of how the Berg River functions ecologically, particularly in response to flow as a driving factor. This understanding has been developed on the basis of each specialist’s theoretical knowledge of how flow affects river ecosystem functioning in general, but augmented by the relationships between flow and various ecosystem components highlighted during execution of the Berg River Baseline Monitoring Programme (BRBMP). What emerges from this synthesis is a simplified description of the linkages and interactions between different physical and biotic components of the system, with particular emphasis on the flow- and water quality-related linkages. Non-flow and anthropogenic influences are described as well, as they may at times override those of flow.

This report thus offers a brief outline of the spatial attributes of the catchment and the Berg River, followed by a summary of each component of the ecosystem, with emphasis on the factors that influence it. More detailed descriptions of the components are provided in the final baseline study report (Volumes 1 and 2). Finally, the linkages between the different components are discussed, along with the implications of the Berg River Dam for ecosystem integrity in the future.

2.2 CATCHMENT CHARACTERISTICS

The Berg River Catchment covers an area of almost 9000 km² in the Western Cape Province, and is subdivided into 12 quaternary catchments ranging in size from 125 km² near the headwaters to 2000 km² in the drier western parts of the catchment (Figure 2.1). The river runs northward for some 285 km, and drains into St. Helena Bay on the west coast of South Africa, where it interacts with the Benguela up welling system (Shillington 1998). Much of the catchment is relatively flat. However, a north-trending ridge of mountains in the centre of the catchment (Piketberg, Swartberg, Figure 2.1) divides the catchment in two, with the Berg River flowing through a poort between Koringberg and De Hoek. Mountains that reach in excess of 1 000 m elevation flank the north trending valley in the eastern part of the catchment, extending to the southern limit of the catchment, where the Berg River has its source (Figure 2.1).

A striking characteristic of the catchment is the low density of drainage channels in the western parts of the catchment underlain by unconsolidated sandy recent deposits (Figure 2.1). Significantly higher drainage densities are observed in the central and eastern parts underlain by weathered and fractured rocks, mostly of the Malmesbury and TMG.
The geology of the mountains and upland areas of the Berg River Basin comprise Table Mountain Sandstone (TMS) (in Day 2007). These rocks are old and well-weathered, and typically leach very few ions. As a result, the waters of the upper Berg River and its tributaries are naturally “pure” — that is, they are characterised by low concentrations of total dissolved solids, including nutrients. They are also acidic, largely as a result of humic acids leached from the surrounding fynbos vegetation, which occurs in the mountains of the south-western Cape. Downstream of Paarl, the remainder of the basin is dominated by Malmesbury Shale, with a number of granite hills surrounded by the clay soils typically derived from weathered granite. The overlying TMS has been increasingly eroded from these areas, with the exposed bedrock being mainly Malmesbury Shale, as far as the river mouth. Although shales, like TMS, are usually low in nutrients (Day and Dallas 1996), the rock formation is nevertheless almost always associated with mineralization of surface waters (Fourie and Görgens 1977). Thus the mineral content of the Berg River and its tributaries increases progressively with distance downstream. In the tributaries, this is exacerbated by the gentle gradients of the lower sections of the rivers, which cause pooling of water at the end of winter, as surface flows dry up. This promotes additional leaching from the rocks into the pools over the summer months.

Figure 2.1 The Berg River catchment, showing major topographic features and drainage network feeding the main river. Surface Water monitoring points are also indicated.

2.3 GROUNDWATER

Five distinct aquifer types occur in the Berg River Catchment — the Table Mountain Group Aquifer (TMGA), the Cape Granite Suite Aquifer (CGSA), the Malmesbury Group Aquifer (MGA), the Klipheuwel Group Aquifer (KGA) and Primary Aquifers (PA) comprising unconsolidated alluvial deposits and reworked marine deposits. The MGA is the dominant secondary aquifer system and underlies most of the area in the central and lower catchment. The TMGA predominantly occurs in the upper catchment and along the eastern and northern fringes of the catchment.
Most of the Berg River Dam site is underlain by the TMGA. The CGSA and KGA form a relatively small component of the total groundwater system in the catchment.

Secondary aquifers such as those found in the catchment owe their water-bearing properties to weathering, fracturing and faulting processes. However, the argillaceous nature of most of the rock and poor groundwater quality limit the exploitation potential of these aquifers.

Groundwater quality in the Berg River Catchment is generally quite poor, particularly in those areas underlain by rocks of the Malmesbury Group. Groundwater quality is controlled by, amongst other factors, lithology, residence time and rainfall. Good quality groundwater is found in the upper (southern and eastern) parts of the catchment that receive higher rainfall and are underlain by resistant and chemically inert quartzitic rocks. As one moves northwards, groundwater has been in contact with the aquifer material for longer, resulting in higher degrees of mineralization. Simultaneously, softer, argillaceous rocks of the Malmesbury Group are encountered in the vicinity of Paarl and northwards. Aquifers comprising rocks of the Malmesbury Group generally yield poor quality groundwater with a NaCl character and an EC ranging between 100 and 1 000 mS/m. Very poor quality groundwater is encountered in the drier western extremities of the Malmesbury Group Aquifer.

Surface-groundwater interaction in the Berg River Catchment has not previously been quantified. Using information gathered at the catchment scale it appears that groundwater contributes to base flow in the headwaters of the catchment and along its lower reaches. If it is assumed groundwater discharges into rivers in areas where the groundwater level is within 2.5 m of the surface, then it is deduced that the Berg River is generally effluent in character (i.e. receives groundwater inflow). It is only in some parts of the catchment that the river appears to be influent (i.e. contributes surface flow to groundwater), namely:

- a ca 14km length of river upstream of Paarl
- a ca 7km length of river downstream of the confluence with the Doring River, and
- a ca 20km length of river in the northern portion of the catchment, including the section of river where the Matjies River confluences with the Berg.

By contrast, many of the tributaries of the Berg River are believed to be largely influent in character- that is, they discharge into the subsurface.

In terms of volume, the largest quantity of groundwater flows into the Berg River in the upper mountainous reaches near Franschhoek and, to a lesser degree, in the lower reaches of G10M, including the Vredenburg area. The shallow depth to groundwater and capillary action result in groundwater providing a source of water to river ecosystems in low-lying areas. Prevalence of groundwater-dependent ecosystems in low-lying areas adjacent to the river and its tributaries could hence be expected.

The rugged topography, steep hydraulic gradients and fractured nature of the rocks suggest springs and seeps in the mountainous areas result in groundwater continually feeding the river. This source of good quality base flow could play a crucial role in sustaining riverine ecosystems during dry summer months. In general, the contribution of groundwater to base flow is most significant during periods of low flow i.e. during summer.

However, the summer flow characteristics of the Berg River have been significantly altered by releases for irrigation from the Voëlvlei, Wemmershoek and Theewaterskloof Dams and by irrigation return flows. This has altered the ecological dependence on groundwater in the riverine areas and it is concluded that these anthropogenic influences override the role of groundwater in the hydrological functioning of the Berg River, except at a very localised scale.

Groundwater level response to individual rainfall events indicates that water in the river may discharge into the subsurface during individual rainfall events, but the duration of this exchange is limited - the direction of flow reverses as soon as the water level of the river recedes back to base flow conditions.
The extent of this exchange also appears to be very localised, and is restricted to the area directly adjacent to the river. Recharge of the groundwater system by the river is thus expected to be of limited importance.

While the groundwater contribution to base flow is small, groundwater quality can be a controlling factor of the quality of water in the river during periods of low flow. Groundwater quality is strongly influenced by geology, and the quality of groundwater discharging into the upper reaches of the Berg River is characteristically low in dissolved salts, as indicated by Electrical Conductivity (EC) values well below 70 mS/m. By contrast, concentrations of dissolved salts in groundwater increase substantially in the middle and lower reaches of the Berg River. However, surface water in these reaches does not appear to respond proportionally to increases in groundwater EC, suggesting other controls on surface water, in addition to lithology, and in particular, controls exerted by low EC groundwater discharging into the upper reaches from the Table Mountain Group aquifer. Groundwater quality (as measured by EC) increases in the lower reaches of the river, within the Langebaan Road aquifer system, where groundwater shows mean EC values of 100 mS/m, as compared to EC values of 700 mS/m some 75km upstream, near Piketberg. The saline character of tributaries such as the Moorreesburg Spruit is directly attributable to the quality of groundwater found in that part of the catchment.

2.4 HYDROLOGY

Total natural runoff from the Berg River Catchment amounts to 931 MCM/a, 45% of which is generated in quaternary catchments G10A, G10B and G10C. These three catchments make up only 7% of the total area of the Berg River catchment. The Berg River has nineteen major tributaries (Figure 2.2). Those tributaries rising on the eastern side of the river tend to be perennial, deriving their source waters from the Cape Fold Mountains that run along the eastern side of the catchment while tributaries draining from the western side are semi-perennial or seasonal. Thus the Franschoek, Wemmershoek, Dwars, Klein Berg, Kuilders and Twenty Four Rivers are perennial systems, although they all experience drastic reductions in summer flows (Dallas 1992). The remaining rivers naturally run dry in summer (Fourie and Görgens 1977).
Two major dams have been built in the catchment. The Wemmershoek Dam south east of Paarl has a surface area of 3 km² and a storage capacity of 66 MCM/a. The Voëlvlei Dam west of Tulbagh covers an area of 15 km² and has a storage capacity of 170 MCM/a. Numerous smaller farm dams are found throughout the east part of the catchment. DWAF (1993) estimated present-day annual runoff of the Berg River amounted to 682 MCM/a, with the modified flow attributed to direct abstraction from the river for irrigation, storage and abstraction for urban water supply; development of forestry within the basin; irrigation return flows; and releases from the Voëlvlei, Wemmershoek and Theewaterskloof Dams (the latter via the Berg River IBT). The natural and present day MAR for each quaternary catchment is provided in Figure 2.3.

The hydrological analysis identified two major features of the Berg River: the variability of flow, and the disproportional importance of the upper river in relation to small floods and winter base flows in the downstream reaches.

### 2.4.1 Flow variability

The Berg River displays considerable natural variability in all aspects of flow, including base flows and the range of different magnitudes (size classes) of floods.
This variability operates on a longitudinal and seasonal basis as well as inter-annually. This is highlighted by comparison of the long-term average low flows and floods, with those recorded over the three-year BRBMP period. The data are provided for the Berg River Dam site (DWAF gauge G1H004) and the lowest part of the river for which reliable data are available (Drieheuwels, DWAF gauge G1H013) in Tables 2.1 and 2.2 (low flows) and Tables 2.3 and 2.4 (floods).

Increasing from the upper to lower reaches, natural low flows in the Berg River have varied from 0.2 to 2.0 m$^3$.s$^{-1}$ in the low flow period (November-April), although not so much in recent years with IBT releases, and from 4 to 15 m$^3$.s$^{-1}$ in winter (May-Aug) (Tables 2.1 and 2.2). During floods, (average daily) flows in the lower river may reach as much as 550 m$^3$.s$^{-1}$ and up to 80 m$^3$.s$^{-1}$ in the upper reaches. Floods of the same size class may last for anything from 3 to 9 days, in the upper and lower reaches. On an hourly basis, instantaneous flood peaks are approximately 2.5 times the magnitude of the average flood discharge for that day in the upper reaches (detailed analysis in Volume 1 of this report series).

In relation to interannual variability in base flow, Table 2.1 also shows how variable a single year (e.g. any individual year 2002-2005) can be relative to a long term average (shaded portions highlight the driest months, compared with long term values). This variability is not demonstrated in the summer months owing to releases from Theewaterskloof and Voelvlei Dams which maintain flow in a steady state, except for abrupt changes at weekends when releases may be discontinued.

Table 2.1 Comparison of 50th percentiles for low flow data at G1H004 for each month during the Baseline Monitoring period, against the longer-term low flow averages for two periods from the hydrological record. Flow values are in m$^3$/s. Percentiles are based on low flows i.e. with floods removed from the flow record.

<table>
<thead>
<tr>
<th>Year / Month</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre 1970</td>
<td>0.32</td>
<td>0.21</td>
<td>0.20</td>
<td>0.66</td>
<td>1.52</td>
<td>2.75</td>
<td>3.22</td>
<td>4.17</td>
<td>2.64</td>
<td>1.92</td>
<td>1.05</td>
<td>0.49</td>
</tr>
<tr>
<td>Post 1980</td>
<td>3.23</td>
<td>2.69</td>
<td>2.25</td>
<td>1.17</td>
<td>1.28</td>
<td>2.68</td>
<td>3.98</td>
<td>2.99</td>
<td>2.91</td>
<td>1.43</td>
<td>1.81</td>
<td>2.75</td>
</tr>
<tr>
<td>2002</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.22</td>
<td>2.37</td>
<td>3.72</td>
</tr>
<tr>
<td>2003</td>
<td>4.03</td>
<td>4.03</td>
<td>3.59</td>
<td>0.89</td>
<td>0.63</td>
<td>0.63</td>
<td>0.71</td>
<td>2.30</td>
<td>1.67</td>
<td>1.49</td>
<td>2.57</td>
<td>3.19</td>
</tr>
<tr>
<td>2004</td>
<td>3.96</td>
<td>3.48</td>
<td>1.19</td>
<td>0.45</td>
<td>1.35</td>
<td>1.20</td>
<td>2.99</td>
<td>0.78</td>
<td>0.81</td>
<td>0.57</td>
<td>3.30</td>
<td>2.37</td>
</tr>
<tr>
<td>2005</td>
<td>4.12</td>
<td>3.29</td>
<td>3.17</td>
<td>0.87</td>
<td>0.66</td>
<td>3.52</td>
<td>1.14</td>
<td>3.21</td>
<td>1.35</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 2.3  Present day and naturalised mean annual runoff for sub-catchments in the Berg River Basin. Note only the portion of the total Berg River catchment included in the hydrological analysis (i.e. to Misverstand Dam) is presented.
Table 2.2  Comparison of 50th percentiles for low flow data at G1H013 (Drieheuwels) for each month during the Baseline Monitoring period, against the longer-term low flow averages from the hydrological record. Flow values are in m$^3$/s. Percentiles are based on low flows i.e. with floods removed from the flow record.

<table>
<thead>
<tr>
<th>Month</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long term</td>
<td>1.55</td>
<td>1.60</td>
<td>1.44</td>
<td>2.33</td>
<td>5.44</td>
<td>13.27</td>
<td>22.86</td>
<td>24.64</td>
<td>15.72</td>
<td>8.45</td>
<td>3.41</td>
<td>1.77</td>
</tr>
<tr>
<td>2002</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9.05</td>
<td>4.34</td>
<td>2.93</td>
<td></td>
</tr>
<tr>
<td>2003</td>
<td>1.91</td>
<td>2.65</td>
<td>2.27</td>
<td>1.97</td>
<td>2.14</td>
<td>2.56</td>
<td>2.12</td>
<td>7.52</td>
<td>11.09</td>
<td>6.30</td>
<td>1.93</td>
<td>2.61</td>
</tr>
<tr>
<td>2004</td>
<td>2.65</td>
<td>2.34</td>
<td>2.26</td>
<td>2.86</td>
<td>2.02</td>
<td>4.95</td>
<td>5.85</td>
<td>15.23</td>
<td>4.40</td>
<td>6.60</td>
<td>2.04</td>
<td>3.02</td>
</tr>
<tr>
<td>2005</td>
<td>2.38</td>
<td>1.64</td>
<td>1.06</td>
<td>1.14</td>
<td>3.01</td>
<td>20.36</td>
<td>9.06</td>
<td>19.72</td>
<td>11.88</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The comparison of flood flows in individual years with average data for the long-term record (Tables 2.3 and 2.4) further demonstrates this large variability from year to year. In terms of total flood volume – that is, combining the volume of all floods in a year, compared to the total volume of the average floods in a year (bottom row in Tables 2.3 and 2.4) - 2003 was the driest of the years in the BRBMP. At G1H004 this was not as pronounced as in the downstream section of the river, where at G1H013 the total flood volume in 2003 was 123 Mm$^3$, only some 50% of the average volume in the long term record of 248 Mm$^3$.

The floods that were most affected in the dry years recorded in this “snapshot” comparison were the Class 3 and 4 floods, which were either fewer in number, or had lower peak flows and volumes, or both, than the long-term average. Class 1 floods were generally more numerous, but mostly smaller than their long term average size. These patterns may be reflecting either or both a decline in the intensity of rain and less saturated catchment conditions. In 2003, the larger floods also only began in August, some two months later than usual.

Thus, a given total flood volume may be split quite differently between various intra-annual flood classes from one year to the next, and in “dry” years there may be a considerably greater proportion of flows occurring as Class 1 and 2 floods. This is another form of intra-annual variability that maintains the stochastic nature of flow in the Berg River.

Table 2.3  Floods recorded at G1H004 in 2003-2005, compared with the longer term flood statistics (short record, 1980 – 1999, from Table 5.11). The number per annum (underlined), average peak daily flow (m$^3$/s) and average volume per flood (Mm$^3$) is provided in each case. The total number of floods per annum is also indicated, with, in brackets the total volume of flood flows per annum.

<table>
<thead>
<tr>
<th>DRIFT Category</th>
<th>Flood size interval (based on peak average daily discharge)</th>
<th>Average number per annum / peak / volume in record</th>
<th>Number / peak / volume in 2003</th>
<th>Number / peak / volume in 2004</th>
<th>Number / peak / volume in 2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:2-year Exceeding 70 m$^3$/s</td>
<td>0.5 by definition</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Class 4 floods</td>
<td>35 – 70 m$^3$/s</td>
<td>3.2 / 46.4 / 10.7</td>
<td>2 / 41.7 / 6.9</td>
<td>2 / 53.4 / 11.6</td>
<td>3 / 53.7 / 12.1</td>
</tr>
<tr>
<td>Class 3 floods</td>
<td>17.5 – 35 m$^3$/s</td>
<td>3.1 / 25.8 / 5.7</td>
<td>3 / 23.7 / 5.2</td>
<td>2 / 26.1 / 6.3</td>
<td>6 / 25.4 / 4.3</td>
</tr>
<tr>
<td>Class 2 floods</td>
<td>8.7 - 17.5 m$^3$/s</td>
<td>2.7 / 13.8 / 3.0</td>
<td>2 / 11.4 / 1.5</td>
<td>4 / 11.6 / 2.0</td>
<td>5 / 11.4 / 1.9</td>
</tr>
<tr>
<td>Class 1 floods</td>
<td>&lt; 8.5 m3/s</td>
<td>1.3 / 6.7 / 1.4</td>
<td>18 / 5.2 / 0.9</td>
<td>9 / 5.5 / 0.9</td>
<td>9 / 5.7 / 1.0</td>
</tr>
<tr>
<td>Total floods (total flood volume) for all intra-annual classes</td>
<td>10.8 (57.5)</td>
<td>25 (49.8)</td>
<td>17 (52.1)</td>
<td>23 (80.1)</td>
<td></td>
</tr>
</tbody>
</table>
Table 2.4  Floods recorded at G1H013 (Drieheuwels) in 2003-2005, compared with the longer term flood statistics. The number per annum (underlined), average peak daily flow (m$^3$/s) and average volume per flood (Mm$^3$) is provided in each case. The total number of floods per annum is also indicated, with, in brackets the total volume of flood flows per annum.

<table>
<thead>
<tr>
<th>DRIFT Category</th>
<th>Flood size interval (based on peak average daily discharge)</th>
<th>Average number per annum in record</th>
<th>Number in 2003</th>
<th>Number in 2004</th>
<th>Number in 2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:2-year</td>
<td>Exceeding 281 m$^3$/s</td>
<td>0.5 by definition</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Class 4 floods</td>
<td>140.5 – 281 m$^3$/s</td>
<td>1.4 / 187.6 / 68.6</td>
<td>0</td>
<td>1 / 140.6 / 74.9</td>
<td>2 / 172.0 / 64.7</td>
</tr>
<tr>
<td>Class 3 floods</td>
<td>70.3 - 140.5 m$^3$/s</td>
<td>1.9 / 100.8 / 34.6</td>
<td>2 / 85.9 / 24.2</td>
<td>1 / 75.2 / 31.7</td>
<td>3 / 97.7 / 33.9</td>
</tr>
<tr>
<td>Class 2 floods</td>
<td>35.1 - 70.3 m$^3$/s</td>
<td>3.3 / 51.1 / 18.7</td>
<td>2 / 50.6 / 12.0</td>
<td>3 / 45.0 / 10.9</td>
<td>3 / 47.6 / 12.5</td>
</tr>
<tr>
<td>Class 1 floods</td>
<td>&lt; 35.1 m$^3$/s</td>
<td>3.4 / 21.4 / 7.2</td>
<td>20 / 10.1 / 2.5</td>
<td>8 / 14.5 / 3.7</td>
<td>10 / 13.6 / 3.1</td>
</tr>
<tr>
<td>Total floods (total flood volume) for all intra-annual classes</td>
<td>10.5 (248.3)</td>
<td>24 (123.0)</td>
<td>13 (169.0)</td>
<td>18 (299.3)</td>
<td></td>
</tr>
</tbody>
</table>

2.4.2  The importance of the upper river to flows in the downstream reaches

The second feature of the hydrological regime is the high relative importance of the upper river - the Berg River Dam sub catchment - to winter low flows and small floods in the lower river during the autumn – spring period. (Summer flows in the river are highly altered from the natural state, due to irrigation releases from Theewaterskloof and Voelvlei Dams.)

Base flow

In addition to the two major dams in the Berg River catchment, the impact of water abstraction and farm dams on river flow in many sub catchments is severe (Figure 2.3). For example summer run-off abstraction from the Franschhoek River has reduced the naturally perennial river to one that has zero flow for 50% of the time during the months of February and March. The extreme impact of the flow diversion and farming on the Twenty-four Rivers (G1H028) in all months is also clearly evident from the hydrological analysis, where more than 70% of the MAR has been abstracted for human use. In this context, the contribution to winter low flow from G1H004 to the lower river at Drieheuwels, G1H013, is significant and greater on a percentage basis than it was under natural conditions – this portion of the catchment presently contributes some 20% to the non-flood flows in the lower river during at least the early winter months. This is despite the fact that the present day winter low flows at G1H004 are themselves affected by abstractions at Wolwekloof.

Flood flows

In terms of flood flows, the analysis of hydrological data examined the contribution (as a percentage of peak flow or total volume) of each sub-catchment to base flow and to individual flood events, measured in the lower river (and passing into the estuary). The usefulness of this exercise was in establishing what might be some consequences for flows in the lower river, of the Berg River Dam and resulting altered flow regime.

This analysis showed that flood events originating in one sub-catchment can vary considerably in terms of size relative to the same event further downstream, as indicated by the scatter in Figure 2.4 for G1H004.
Colloquially, if one sub-catchment is "firing", other sub-catchments may or may not be "firing" simultaneously, or to the same extent. These same event comparisons also quite clearly indicate the important contribution to flood flow in the lower reaches emanating from G1H004 (the Berg River Dam sub-catchment), especially for the smaller floods (<100 m³/s) (Table 2.5).

The percentage contribution to small floods at G1H013 from the most upstream sub-catchments (e.g. the Franschhoek River and especially the upper Berg River) is much higher than their contribution to larger events. Table 2.5 shows that for the smallest flood categories (Bands 1 and 2 floods), G1H004 account for an average 72-53% of the peak flow at G1H013, and drops to 19% for floods above 200 m³/s. In contrast, the eastern and northern sub-catchments have a declining percentage contribution to smaller floods at G1H013.

Table 2.5 Summary of the percentage contribution of flood flows at G1H004 to the total flood passing through G1H013, averaged for various flood size classes. All inter-annual floods are included in the Band5 category.

<table>
<thead>
<tr>
<th>Band Numbers</th>
<th>Flood Category Interval</th>
<th>Median Volume (M.m³)</th>
<th>Average percent Volume</th>
<th>Median percent Volume</th>
<th>Median Volume Range (M.m³)</th>
<th>Median peak (m³/s)</th>
<th>Average percent Peak</th>
<th>Median percent Peak</th>
<th>Peak Range (m³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band 1</td>
<td>0-20</td>
<td>1.42</td>
<td>44%</td>
<td>39%</td>
<td>0.9-3.4</td>
<td>7.97</td>
<td>72%</td>
<td>65%</td>
<td>4.5-20.4</td>
</tr>
<tr>
<td>Band 2</td>
<td>21-50</td>
<td>3.24</td>
<td>35%</td>
<td>32%</td>
<td>1.1-10.0</td>
<td>16.48</td>
<td>53%</td>
<td>48%</td>
<td>3.7-41.7</td>
</tr>
<tr>
<td>Band 3</td>
<td>50-100</td>
<td>5.21</td>
<td>27%</td>
<td>24%</td>
<td>1.1-16.2</td>
<td>24.91</td>
<td>41%</td>
<td>35%</td>
<td>4.9-58.2</td>
</tr>
<tr>
<td>Band 4</td>
<td>100-200</td>
<td>8.24</td>
<td>20%</td>
<td>18%</td>
<td>3.7-25.8</td>
<td>37.00</td>
<td>29%</td>
<td>28%</td>
<td>12.5-85.6</td>
</tr>
</tbody>
</table>
| Band 5        | 200+                    | 14.55                | 14%                    | 15%                   | 2.8-33.8                   | 55.34             | 19%                 | 19%                | 10.1-79.2         

Figure 2.4 Peak average daily flood flow at G1H004, as a percentage of the same flood peak at G1H013, regressed against flood size G1H013. Note that smaller floods at G1H013 have a substantially larger proportion of their flow contributed by G1H004 than do larger floods.

The percentage contribution to small floods at G1H013 from the most upstream sub-catchments (e.g. the Franschhoek River and especially the upper Berg River) is much higher than their contribution to larger events. Table 2.5 shows that for the smallest flood categories (Bands 1 and 2 floods), G1H004 account for an average 72-53% of the peak flow at G1H013, and drops to 19% for floods above 200 m³/s. In contrast, the eastern and northern sub-catchments have a declining percentage contribution to smaller floods at G1H013.
For example, G1H028 (Twenty-four Rivers) accounts for only 1% of Band 1 floods at G1H013, increasing to 16% of Band 5 floods. This is to a degree a consequence of the diversion on the Twenty-four Rivers that targets low flows and small floods, but could also be a consequence of lower rainfall in these areas compared with the upper Berg. Indeed, in the more arid parts of the catchment, flooding may not always occur, as a result of a different rainfall distribution. A similar trend is evident for all the central sub-catchments and those in the arid parts of the catchment (e.g. Matjies). These effects (i.e. low rainfall and irregular flooding, as well as reduced small floods as a result of water resource development) cannot readily be distinguished in sub-catchments that are characterised by both.

It is noteworthy that “small events” (Band 1 and 2) at G1H013 are up to 50 m$^3$/s. In winter, the long term median low flow (i.e. excluding flood flows, Table 2.2) is between 15 and 20 m$^3$/s. Thus many of the small floods in the upper catchment, at G1H004 for example, probably simply translate into winter base flow in the lower river. Base flow has been shown to be one of the critical factors determining the extent of lateral flooding of the floodplain (see Chapter 3 of this report). The removal of minor floods at G1H004 will therefore have implications for the maintenance of winter base flow levels in the lower river and estuary.

**Annual flood volumes**

An examination of the long term average annual flood volumes (i.e. total flood volume for each year) shows that the flood volume at G1H004 is some 23% of the flood volume at G1H013 (58 Mm$^3$ out of 248 Mm$^3$: Tables 2.3 and 2.4). However, in the dry years of 2003 and 2004 this upstream portion of the river contributed 40 and 30% respectively of the flood volume at G1H013 – probably because of the extensive development and the greater proportional use of the water resource in the other sub-catchments. The implication of this, especially in an already over-exploited catchment, is that the Berg River Dam will quite probably remove this “buffer” provided by the upper river during dry or drought years.

**Synchronisation of floods within the catchment**

Correlations performed on the relationship between flood magnitude at all pairs of sub-catchments, based on the flood magnitude achieved at each gauge during each isolated flood “event” on record, shows that some catchments are more synchronised than others. Floods at G1H004 are better correlated with nearby sub-catchments (e.g. G1H003, Franschhoek; G1H019, Banhoek) and becomes progressively less correlated toward the central and northern parts of the catchment.

G1H004 is the dominant contributor to small and medium floods in the lower river – i.e. in many cases floods at G1H004 are not matched by any flood response in other sub-catchments, whilst the reverse does not occur. Figure 2.5 shows that G1H004 is highly synchronised with floods in the lower catchment ($r = 0.73$), but for larger floods, the scatter in the plot is high.
Figure 2.5  Scatter plot comparing flood peaks (peak average daily flow) at G1H004 with flood size in the lower river, represented by G1H013.  The significant correlation coefficient (r-value) is indicated.

For larger floods, therefore, G1H004 is not always a dominant or even substantial contributor to floods in the lower river. For example, whilst, on average, smaller floods at G1H004 are double the size of those in the Little Berg catchment (G1H008), there are a number of large floods at G1H008 which coincided with flows in the upper Berg River that were only or not even half as great. With regard to the production of larger flood flows in the lower Berg River, it is thus important to consider that:

a. Large events do not require synchronised flooding (all sub-catchments flooding to the same relative magnitude): Figure 2.5 shows that for large events at G1H013, G1H004 can produce significant amounts – or not, which would imply that other catchments are producing the bulk of flood volumes at these times.

b. Other sub-catchments may at times have a larger influence on big (inter-annual) floods in the lower river than G1H004.

Notwithstanding, flood routing analysis shows that the attenuation in floods along the length of the river is not as pronounced with elevated base flows, as would be the case with lower initial base flows. For example, a flood of 100 m$^3$/s at the Berg River Dam would be attenuated to less than 50 m$^3$/s in the midreaches and 20 m$^3$/s at the estuary if the “starting condition” in the river at these latter two points was only 2 m$^3$/s, but with an initial base flow of 20 m$^3$/s the flood would be just over 70 m$^3$/s in the midreaches and 50 m$^3$/s at the estuary. This is because the main channel along the length of the river needs to be filled and thus accommodates the flood. This shows that it is important to ensure that the future flood releases from the dam are made in phase with tributary floods, otherwise the flood attenuation is too great and the effectiveness of the managed flood releases at the dam is reduced significantly.
2.5 MAJOR ABiotic AND BIOTIC PATTERNS IN THE BERG RIVER AND THEIR RELATIONSHIP TO FLOW

2.5.1 Longitudinal gradients in the Berg River

The upper reaches of the Berg River are hydraulically very steep with an average bed slope of 0.67% down to Paarl. The river bed of this steep reach consists mainly of boulders and cobbles. From Paarl, the river profile flattens, with an average bed slope to the estuary of 0.045%. The river bed of this part of the river consists mainly of finer materials such as sands, silts and clayey materials. According to Bath (1989) this rapid fall in profile from the headwaters, the meandering of the main channel, and the multiple channels separated by low lying islands in the lower reaches are indications that the Berg River is geologically an old river system.

Geomorphological features, of which gradient is the most important (Rowntree and Wadeson 2000), are used to group rivers into different zones, within each of which a series of macro-reaches (a length of channel characterised by a particular channel pattern and morphology) may be differentiated. A geomorphological classification allows for a structured description of spatial variation in stream habitat. Its usefulness for ecological studies is based on the idea that these are a major factor in the determination of the distribution of biota.

Rowntree and McGregor (1996) compiled a segment (zone) and reach analysis of the Berg River as part of the 1996 IFR study, based on the gradient changes, distribution of runoff and sediment yield in the catchment, which divided the main channel of the Berg River into four segments (mountain, foothill, lowland and coastal). The MAR of the Franschhoek and Berg River catchments above their confluence is in the order of 600 million m$^3$ per year, and the annual sediment yields are low due to the resistant nature of the Table Mountain Sandstones and thin soils. Downstream of the confluence the incremental MAR decreases rapidly and is only in the order of 100 million m$^3$ per year between Paarl and Wellington. The sediment yields increase in this zone as the river flows through a wide alluvial plain of sand sized material, and the tributaries drain the Malmesbury series. Further downstream the incremental MAR decreases to around 30 million m$^3$ per year.

A more refined geomorphological classification framework was developed in 2000, distinguishing a wider range of geomorphological zones. These, integrated with the 1996 reach analysis, are described in Table 2.6.
### Table 2.6. Summary description of the geomorphological zones and reaches of the Berg River along with major riparian vegetation and in instream invertebrate community characteristics.

<table>
<thead>
<tr>
<th>Geomorphological / longitudinal zone and geology</th>
<th>Geomorphological Reach</th>
<th>Major river confluence or landmark</th>
<th>Reach length (km)</th>
<th>Cumulative length from source (km)</th>
<th>Reach Gradient</th>
<th>Features</th>
<th>Vegetation</th>
<th>Invertebrate indicator groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mountain headwater / mountain stream</td>
<td>1-3</td>
<td></td>
<td>2.3</td>
<td>2.3</td>
<td>0.33</td>
<td>Very steep headwall streams; Confined valley, colluvial foot slopes, incised channel, steep gradient mountain stream;</td>
<td>Wetland and sponges, fynbos Natural riparian species include Erica caffra, Brabejum stellatifolium and Metrosideros angustifolius; instream vegetation consists of patches of aquatic moss and Isolepis digitata</td>
<td>Blephariceridae; Notonemouridae; Telagonodidae; Barbarochthonidae; Leptoceridae; Helodidae; Elmidae</td>
</tr>
<tr>
<td>Table Mountain Group</td>
<td>4-7</td>
<td>Extends to upstream of IBT tunnel</td>
<td>10.5</td>
<td>12.8</td>
<td>0.0714</td>
<td>Above the dam site: steep valley side slopes, open valley floor, braided channel with shallow pools, rapids and plane bed morphology; medium to sparse in-channel vegetation Below the dam site: fan-type feature with divergent drainage; main channel pool-riffle morphology</td>
<td>Prionium serratum (palmet) should line most of the banks together with Brabejum stellatifolium, Maytenus oleoides, Metrosideros angustifolius, Kiggelaria africana and Podocarpus elongatus. Most of this zone has been substantially altered by alien invasion, chiefly A longifolia and A. mearnsii. Palmet banks are rare along the river nowadays.</td>
<td>Athericidae; Notonemouridae; Heptageniidae; Leptophlebiidae; Telagonodidae; Barbarochthonidae; Leptoceridae; Philopotamidae; Helodidae; Elmidae; Corydalidae</td>
</tr>
<tr>
<td>Upper foothill Table Mountain Group and Cape Granite suite</td>
<td>8</td>
<td>to Wemmers River confluence;</td>
<td>7.9</td>
<td>20.7</td>
<td>0.0076</td>
<td>Open topography with gentle, cultivated slopes; sinuous channel, sharp reduction in gradient, increased channel width; cobble bed with lateral cobble bars; increased sand; pool-riffle morphology; much channel disturbance</td>
<td>Under natural conditions, sandy banks would be overgrown with Paspalum vaginatum, which extends into the water. Isolepis digitata is almost absent from the rocks in this section of the river. In braided sections numerous small islands would often consist almost entirely of large patches of Prionum serratum. Most of the river has been substantially altered by channel alteration and alien invasion - dominant riparian species = A. mearnsii and Eucalyptus sp.; floating aquatic weed, Myriophyllum aquaticum.</td>
<td>Caenidae; Heptageniidae; Leptophlebiidae; Ecnomidae; Leptoceridae; Elmidae; Aeschnidae</td>
</tr>
<tr>
<td>Lower foothill Table Mountain Group to east, Cape Granite suite and Malmesbury Group to west, valley floor alluvium</td>
<td>9</td>
<td>to N1 road crossing, just upstream of Paarl includes BRM3</td>
<td>19.1</td>
<td>39.8</td>
<td>0.0036</td>
<td>Open topography with gentle, cultivated slopes; sinuous channel, sharp reduction in gradient, increased channel width; cobble bed with lateral cobble bars; increased sand; pool-riffle morphology; much channel disturbance</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>to Krom river confluence</td>
<td>22.5</td>
<td>62.3</td>
<td>0.0009</td>
<td>Open topography; increased channel sinuosity, reduced gradient; mixed bed (cobble and sand), variable channel width, infrequent islands; long pools with cobbly riffle and lateral bars; possible aggradation in pools; highly disturbed channel</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 2.6 cont. Summary description of the geomorphological zones and reaches of the Berg River along with major riparian vegetation and in instream invertebrate community characteristics.

<table>
<thead>
<tr>
<th>Geomorphological / longitudinal zone and geology</th>
<th>Geomorphological Reach</th>
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<th>Cumulative length from source (km)</th>
<th>Reach Gradient</th>
<th>Features</th>
<th>Vegetation</th>
<th>Invertebrate indicator groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower foothill cont.</td>
<td>11</td>
<td>to Kompanjes River confluence</td>
<td>18.7</td>
<td>81.0</td>
<td>0.0011</td>
<td>Open valley topography; fairly significant direct contributing areas for stormwater runoff and sediment; irregular meanders, wider, divided channel; sand bed; pool rapid morphology</td>
<td>Riparian vegetation includes Buddleia saligna, Cynodon dactylon, <em>Prionium serratum</em>, <em>Pycreus polystachyos</em>, <em>Rhus angustifolia</em> and <em>Salix mucronata</em>, with <em>Olea europaea</em> ssp. africana naturally dominant. <em>Phragmites australis</em> appears as sporadic clumps and becomes consistently present in lower portion as reed fringe to the main channel and to channel braids. Alien invasion still substantial - <em>Eucalyptus</em> sp. Is conspicuous and regularly dominant, along with <em>Acacia mearnsii</em>.</td>
<td>Tricorythidae; Ecnomidae; Hydropsychidae; Chironomidae; Simulidae; Oligochaeta; Coenagrionidae; Libellulidae; Ancyliidae</td>
</tr>
<tr>
<td>Lowland River Malmesbury Group</td>
<td>12</td>
<td>to Klein Berg River confluence; includes BRM4</td>
<td>33.8</td>
<td>114.8</td>
<td>0.00042</td>
<td>Irregular meanders, single thread channel, highly variable width; pool morphology with infrequent lateral bars and rapids</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>to Twenty-fours River confluence</td>
<td>5.2</td>
<td>120.0</td>
<td></td>
<td>Short reach with tortuous meanders, sand bars and shallow pools</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>to Matjes River confluence;</td>
<td>25.4</td>
<td>145.4</td>
<td>0.00055</td>
<td>Significant contributing area of runoff and sediment from cultivated lands; reduced gradient; irregular meanders with lateral bars, often associated with tributary streams</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>To Morreesburg-spruit confluence</td>
<td>11.0</td>
<td>156.4</td>
<td></td>
<td>Moderately confined valley; irregular wandering channel; narrow lateral bars with occasional islands; variable channel width, narrower channel</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>to head of the estuary;</td>
<td>48.0</td>
<td>204.4</td>
<td>0.00033</td>
<td>Less confined valley; irregular meanders; narrow lateral bars; narrow channel continued</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Floodplain river / estuary Wind blown sands and alluvium</td>
<td>Not included in geomorphological reach analysis;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Flat to gently undulating topography</td>
<td>Clifforisia strobilifera conspicuous over this section; many Eucalyptus seedlings; <em>Eichornia crassipes</em> visible along this section the only exotic able to survive the higher salinities = <em>Acacia cyclops</em></td>
</tr>
</tbody>
</table>
Harrison and Elsworth (1958) described five longitudinal zones based on key geomorphological features and changes in biotopes or habitats and vegetation, and these generally agree with the geomorphological zonation of the Berg River, as indicated in Table 2.6. The main physical features of this zonation are a shift from a steeply graded, fast flowing upper river zone with a mostly cobble and boulder bed, through a less steep, but still morphologically diverse foothill zone, towards an almost canal-like, soft-bottomed lower river zone, with deeper and slower flows. According to most researchers, the macro-invertebrate fauna of the Berg River appear to follow the same zonation pattern as defined in physical terms, by Harrison and Elsworth (1958), which also correlates broadly with longitudinal patterns in riparian vegetation (Table 2.6).

Water chemistry in the Berg River catchment also shows longitudinal patterns, and these are presented for different time periods, for major variables, in Figure 2.6a-f (site locations along the length of the river are provided in Figure 2.2). Harrison and Elsworth (1958) provided the earliest window into water quality in the Berg River. Even so, much of the Berg River in the early 1950s was already impacted with respect to water quality. However, based on the catchment geology and the earliest data that are available, the river can be described as characterised in its upper reaches by naturally acid, low-nutrient, low TDS and conductivity waters (Figure 2.6a-f, 1950 – 1959 data period). These characteristics altered with distance downstream, being highly dependent on both the underlying geology and flow conditions. Even under natural conditions, the river would have shown a strong trend of increasing conductivity, increasing nutrients and increasing pH with distance downstream (Figure 2.6).

The natural water chemistry of the tributaries is strongly correlated with their underlying geology. On these grounds, tributaries of the Berg River can usefully be divided into two main classes – those rising in the TMS-dominated mountain ranges, referred to as “TMS rivers”, and those rising on the more level, low-lying and Malmesbury shale-dominated ground, referred to as “shale rivers” (Fourie and Steer 1971). The rivers shown schematically in Figure 2.7 have been coded in terms of these broad categories.

The shale rivers (e.g. the Vis, Doring, Sandspruit, Morreesburg / Morreesburgspruit and Matjies Rivers) have naturally relatively high salinities. By contrast, TMS rivers all have low concentrations of TDS (e.g. the Banhoek, Franschhoek, Klein Berg, Leeu, Kompagnies, Wolwekloof and Twenty Four Rivers). They also tend to be naturally brown in colour, as a result of dissolved humic acids (Bath 1993a).

Comments on changes in major water chemistry variables between 1950 and 2000

Electrical conductivity (EC) increased substantially at all sites, and particularly in the lower reaches of the Berg (BRD to KFN) since 1950 (Figure 2.6 a-f). These increases were primarily the result of increases in saline return flows from irrigation (irrigated areas along the Berg have increased since 1950), coupled with abstraction of water from the main channel and its less saline tributaries. The most pronounced increase in conductivity occurred between the 1950s and the 1960/70s. During the 1980-2000 monitoring period, and in particular, since 1990, changes in conductivity were less pronounced.

Over the period for which data are available, Phosphorus accumulated in the system as a result of both point and non-point impacts – primarily sewage effluent and agricultural return flows. Much of this phosphorus is bound in the sediments of the Berg River, and mobilised during storm events.

Phosphorus data for the Berg River in the 1950s were however limited to undated ranges for each site, with only “extreme” samples being dated. Available data show that a marked increase in phosphorus has taken place downstream of DJT since then.

Coupled with increases in phosphorus are increases in mean concentrations of other nutrients – e.g. nitrogen compounds (NO$_3$-N and NH$_4$-N). Limited historical data did not allow trends in suspended solids to be established.
The data collected over the BRBMP period show that both phosphorous and nitrogen compounds were markedly higher than in the 1980 – 2000 period, most dramatically so downstream of G1H020, with G1H036 and G1H013 both showing 200 to 300 % increases in both summer and winter phosphorus concentrations, and G1H023 (near Kersefontein) showing an increase of between 100 and 150%. Nitrogen nutrients have increased in the river at G1H036 and G1H023 since the 1980-2000 periods by at least an order of magnitude.

These increases over time probably reflect a spatially variable combination of increases in runoff from poorly serviced urban settlements, an increase in the volumes of treated sewage effluent released into the river from various WWTWs, an increase in agricultural runoff, as well as increasing levels of unserviced or poorly serviced urban settlements since the 1980s and 1990s.
Figure 2.6 (a-c)  Summary data for selected variables at major monitoring sites along the Berg River. Summer and winter data, for three time periods. Missing values arrowed on each graph. Site locations are indicated in green in Figure 2.2.
Figure 2.6 (d-f) Summary data for selected variables at major monitoring sites along the Berg River. Summer and winter data, for three time periods. Missing values arrowed on each graph. Site locations are indicated in green in Figure 2.2.
Key:
- Low EC category tributary  N  P  eutrophic with respect to phosphorus (P) or nitrogen (N)
- Medium EC category tributary  P  N  hypertrophic with respect to phosphorus (P) or nitrogen (N)
- High EC category tributary

Figure 2.7  Longitudinal bed profile of the Berg River to Piketberg, showing chemical characteristics of major tributaries.
2.5.2 Channel characteristics and the influence of flow

The magnitude of the discharge in a river may be related to a range of hydraulic variables, including depth, average flow rates, wetted perimeter and the magnitude of hydraulic forces acting on the river bed, all of which increase with increases in flow (e.g. Figure 2.8 shows this general relationship). This relationship was demonstrated for the Berg River during the BRBMP.

![Figure 2.8](Image)

Biotope mapping at different base flow discharges shows seasonal differences in the availability of different biotope types i.e. as a function of discharge at the upper Berg River sites, but not in the lowland river. At all sites, increase in average depth and velocity within the array of biotopes is a function of increasing discharge, notwithstanding the fact that at some threshold, the biotope may transform, for example riffles become runs as depth increases to a height where bed particles are submerged. However, because elevated flow also increases the wetted area of the river bed, this may result in the creation of larger areas of slack water and backwater – shallow and / or slow-flowing biotopes which provide increased hydraulic shelter in the face of the general increase in velocities and hydraulic stress acting within the channel at higher discharge. The extent to which newly created hydraulic habitat requires conditioning (e.g. through the development of a micro algal bio film) before it is useful habitat for more than hydraulic shelter is something that merits consideration.

The relative importance of different flows for channel maintenance can best be evaluated by determining the amount of sediment transported by each. The discharge that is responsible for the transportation of the greatest amount of sediment over time is termed the effective discharge. The following pertain to the BRM sites, as determined during the BRBMP, and reflect instantaneous discharges (not average daily discharge):

- the effective discharge for BRM2 is shared between two flow classes - between 23.3 and 72.4 m$^3$/s – which together account for 38% of sediment transport. Some 43.6% of the sediment is transported by discharges higher than 23 m$^3$/s
- the effective discharge for BRM3 is 41.8 m$^3$/s under present-day conditions which accounts for 28% of transport, with 57% of sediment transport occurring above this discharge
- the effective discharge for BRM4 is 62.0 m$^3$/s which accounts for % of transport with some 48% of sediment transport occurring above this discharge
- the effective discharge for BRM5 is 204.0 m$^3$/s, which accounts for 42% of transport, with 73% of sediment transported above this discharge
• the effective discharge for BRM6 is 308.6 m$^3$/s which accounts for 37% of transport, with 55% of sediment transported above this discharge.

Little change in bed material size and channel cross section would be expected for a stream in quasi-equilibrium, with minor seasonal shifts in the sand deposition and scour associated with summer low flows and winter floods respectively. Small “freshest” and floods progressively scour fine particles from the interstitial spaces between bed particles, as was evident, for example, at BRM1, where the embeddedness decreased significantly from around 60-70\% in summer 2003 to 10-40\% by late winter 2003, despite it being a “dry” year, where Class 1 and 2 floods made up more than half of the flood volume for that year (see Table 2.3). The flood – invertebrate study conducted during the BRBMP showed that DRIFT Class 3 and 4 floods (larger intra-annual events) in the upper reaches of the Berg River are associated with up to 40\% of actual bed movement, including gravels, cobbles and boulders of all size classes, although this movement was generally less than 1 m in distance downstream. The significance of this for channel maintenance, however, is in the new exposure of interstitial fines that such movement produces, and thus the constant reworking of bed materials. Similarly, in the lower river reaches, minor bed level changes were associated with reworking of sandy deposits during the floods experienced over the BRBMP. This quasi-equilibrium, however, is characterised by inter-annual variability in the amplitude of deposition and scour changes, related to the variability of the actual flood flows in any year. At BRM6 for example, the pool immediately downstream of the rapid became up to 1 m shallower, through sand deposits between January and September 2003, reflecting the absence of larger, scouring floods.

Fundamentally changing sediment supply or the hydrological regime, however, will result in a new quasi-equilibrium being established. The hydrodynamic model developed from these hydraulic relationships during the BRBMP made predictions of the magnitude of these changes, which are addressed in section 2.6.

Historical changes to the channel between BRM2 and BRM4 (Franschhoek to Voelvlei) have had a substantial influence on channel shape and the array and extent of different biotopes, and here these changes override the effects of flow in determining channel form. The biggest change to channel pattern in the Berg River between the 1930’s and the present day is that the braided system in the upper reaches near Franschhoek and the Paarl area has largely disappeared. Here, many of the channels of the braided system have been cut off by weirs and levees to prevent flooding of the areas away from the main channel, which are now being used for agricultural purposes, confining the river to a single channel during low flow conditions. This means that the river flows across the whole floodplain less frequently, if at all. The consequence of such changes is that sediment deposited on the floodplain during floods remains there for longer and leads to the vegetation establishing a stronger hold and encroachment on the main channel. This would lead to higher floodplain resistances, and has been exacerbated by afforestation in the upper catchment.

Downstream of the Wemmershoek River, extending to beyond Wellington, the river has become confined to a narrow single main channel due to flood levees constructed by farmers. The narrowing of the river by development of the floodplain such as afforestation and levees could result in higher flow velocities as the flow is confined to a smaller area, and thus scouring could occur in some areas.

Elsewhere, it seems that the river goes through minor natural periodic changes such as migrating sandbars.

The alien vegetation removal programme initiated near the start of the BRBMP has resulted in removal of vegetation from channel banks and floodplain areas, thereby decreasing bank stability.
Significant bed changes in bed level were apparent at BRM2 and BRM4 between years and between the summer and winter surveys, representing increased erosion and sediment supply after the removal of woody alien invasive trees in the riparian belt. The magnitude of this change is a direct consequence of winter flood magnitudes.

For example, the larger floods in 2005 than in the other years of the BRBMP were associated with dramatic bank erosion at BRM2, lateral expansion of the channel, coupled with deposition of coarse bed load, resulting in a flattening of the bed form. At BRM4 progressive erosion over the BRBMP caused a 1 m drop in bed level. This type of change is likely to be a feature of these portions of the river for some time to come, until a new equilibrium is reached. The effects of simultaneous change in the flow regime will be difficult to differentiate.

2.5.3 Water quality in the Berg River and the influence of flow

Longitudinal gradients in electrical conductivity, pH and nutrient concentrations have been discussed in section 2.5.1, along with a summary of how these variables have increased in the river over time as a result of anthropogenic factors. The primary natural influence on these patterns in water chemistry is catchment geology, although anthropogenic influences have had a major influence on, particularly the concentrations and loads of nutrient and dissolved substances and on pH. (Electrical conductivity (EC) data are used as a surrogate measure for total dissolved solids.)

The tributaries of the Berg River exert considerable influence on water chemistry of the main stem, as a function of both geology and flow regime. Two measures are important in assessing the impact of the different chemical constituents – concentrations (e.g. in mg per litre of water) and the instantaneous or total load (in grams per second delivered at a point, or tonnes per annum). In terms of assessing the relative impact of different tributaries on the Berg River itself, the former are not particularly useful, unless viewed in the context of discharge, and thus loading. The examination of loads delivered to the main stem by any particular source (tributary or, for example, effluent inflow) allows for the most significant contributors to water quality deterioration in the Berg River to be isolated. Also, the loading along the system should be used as the basis for interpreting future water quality impacts, where changes in flow patterns as a result of the dam may alter the relative contribution of chemical loads from the tributaries.

The influence of the different tributaries on water quality in the Berg River mainstream is thus a function of their underlying geology, but largely also depends on their respective flow regimes. For example, the seasonal, Malmesbury Shale-draining tributaries downstream of Paarl are only likely to affect mainstream water quality at the beginning of the rainy season, when they flush in surface salts accumulated in pools as a result of leaching and groundwater evaporation during summer. The fact that their waters may have higher concentrations of salts in summer may be irrelevant to the Berg River main stem, if the flow in the river is too low to contribute significant loads to the main stem.

Figures 2.9 and 2.10 illustrate the relative seasonal (summer and winter) loads of TDS brought into the Berg River by tributaries, compared with their annual runoff. These figures provide some perspective on the level of actual TDS loading associated with different tributaries, with relatively saline systems contributing only a small proportion of total salts in the mainstream. This is either as a result of the low flow volumes with which they are associated, or because of the timing of their input into the Berg, when the increased volume of water in the Berg River mainstream diluted their input. Thus TDS values alone cannot be used to infer the degree of
influence of a tributary on the main channel – calculated loads are of more relevance in this regard.

Data collected during the BRBMP on gauged tributaries of the Berg River indicate the following:

- EC values were lowest in the rivers draining off the TMS dominated eastern and northern parts of the catchment (the Franschhoek, Banhoek, Kompagnies, Klein Berg, Leeu and 24 Rivers, as well as from Theewaterskloof), with summer maxima, during periods of low discharge.

Where loading could be estimated, using limited daily flow data, these showed however that although EC values and TDS concentrations were lowest in winter, actual loading was usually highest, as a result of higher discharge.

- EC values were higher in the Doring, Vis and Matjies Rivers, with mean seasonal EC all above 100mS/m. All seasonal means were however below 400 mS/m, with winter maxima of up to 606 mS/m. These rivers all appeared to dry up during summer. Estimates of loading of dissolved salts showed variable but generally high loading in the Matjies during winter, exceeded only by the unexpectedly high loading calculated for the Twenty Four River. The latter was however based on a single datum only. Bath (1993a) showed that the highest loading into the Berg River during his monitoring period was from the Matjies River, again with most of the loading occurring during winter.
Figure 2.9 Total dissolved solid load compared to runoff, from tributaries flowing into the Berg River: October 1988 to September 1989. Diagram after Bath (1993). Numbers refer to names of tributaries in the key.

Figure 2.10 Seasonal breakdown of total dissolved solid (TDS) loads from tributaries into the main channel of the Berg River: October 1988 to September 1989. Diagram after Bath (1993). Numbers refer to tributaries, listed in Figure 2.9.
The highest measured EC values occurred in the Sandspruit and Morreesburg Spruit, with mean seasonal EC values all above 900 mS/m and no values below 400 mS/m. EC values and TDS concentrations were lowest in these rivers during winter, due to increased discharge. The lack of flow data meant that loading could not be estimated. Bath (1993a), however, showed that, for the period 1980- to 1990, the Sandspruit had the second highest TDS loading in the system, despite low runoff, as a result of the high TDS concentration. Most of this occurred during winter.

It should be noted that no water chemistry data exist for the tributaries entering the lower reaches of the Berg including the Sout, Boesmans and Plattekloof Rivers. These systems may however contribute significant TDS loads into the Berg River, mainly during winter.

Phosphorus enrichment appeared to be largely associated with discharges from WWTWs and to a lesser extent agricultural activity. The Franschhoek, Dwars, Matjies and Morreesburg Rivers all receive discharges of treated sewage from at least one WWTW and are either hypertrophic (i.e. > 0.130 mgP/l) or eutrophic (i.e. >0.047-0.130 mg P/l) in all seasons for which there is flow. The only systems with phosphorus concentrations in the mesotrophic range (> 0.015-0.047 mg P/l) were Klein Berg and Leeu Rivers.

Enrichment in the form of nitrogen nutrients was less pronounced than phosphorus enrichment.
- no tributaries had concentrations of NO$_3$+NO$_2$-N within the hypertrophic range, as suggested by DWAF(1996a) (i.e. >10 mg N/l)
- the Franschhoek River fell within the eutrophic range with respect to nitrogen (2.5-10 mg N/l) during summer, as did the Doring and Matjies Rivers during autumn and winter, respectively
- The Franschhoek (autumn, winter and spring) and Matjies (spring and winter) Rivers were within DWAF (1996a)’s range for mesotrophic conditions with respect to nitrogen nutrients (i.e. 0.5-2.5 mgN/l)
- The Dwars (upper reaches only), Doring (spring only) and Kompagnies, Vis, Klein Berg and Matjies (spring and winter) all fell within the range of dissolved nitrogen concentrations described by DWAF (1996) as indicative of oligotrophic conditions.

The influence of river flow on water chemistry is evident in seasonal changes in chemistry along the main stem, as a function of seasonality in rainfall and river discharge, as well as the loading from inflowing tributaries. Major changes in water chemistry may be explained by examination of catchment geology, anthropogenic impacts, and river and tributary flow conditions, including the loads contributed from various tributaries. The most salient aspects of the relationship between key water quality variables (dissolved salts and nutrients) and flow may be summarised as follows:

- **EC / TDS concentrations** in the upper river (G1H004) generally show the summer maxima and winter minima typical of systems with high winter dilution rates. Estimates of loading, however, show, two periods of increased TDS load – summer (when concentrations are high but flow is low) and winter, when concentrations are low but discharge is high. The elevated summer load is due to inputs from the upstream trout farm, as well as from summer irrigation releases from Theewaterskloof Dam, via the Berg River Siphon which discharges upstream of the gauge.
Reversal of this pattern is evident downstream, particularly by G1H036, where EC concentrations are substantially elevated, but with lowest values in summer and maxima in winter / spring. The Franschhoek and Dwars Rivers are the two main tributaries that discharge into the Berg River between G1H004 and G1H020.

These have a relatively high winter loading of TDS, as a result of high discharge, and add to the loading of the river during winter and spring. Between G1H020 and G1H036, two WWTWs discharge effluent directly into the Berg River (Paarl WWTW and Wellington WWTW), while the river also receives urban runoff and agricultural return flows, which are highest in winter, as a result of increased surface runoff.

Between G1H036 and G1H013, the Berg River passes through extensive areas of agricultural land – mainly winter wheat and pasture, which do not contribute summer return flow to the river. The high EC tributaries that enter the river along this reach are also generally seasonal, and thus do not contribute any TDS load to summer flows. Also, during summer G1H013 essentially comprises water from Voelvlei Dam, since most of the river flow upstream of the Voelvlei outlet is abstracted. Thus summer flow is dominated by inputs from fresher tributaries and TDS loading into the system, including agricultural return flows, is also low. During winter, however, TDS increases substantially in the river. Only a small proportion of winter TDS is derived from the river upstream, as represented by G1H036, despite higher flows in the river. The seasonal tributaries of the Berg probably contributed the highest proportion of TDS loading at this site, which peaks in winter and spring.

Downstream of G1H013, the seasonal Matjies River and Morreesburgspruit join the Berg River. These two systems contribute high to very high TDS loads in winter, affecting TDS and EC as measured in Misverstand Dam. Thus at Misverstand TDS concentrations are associated with a double peak, with a high in summer and a larger peak occurring in winter. The summer peak has been attributed almost entirely to irrigation return flows, while the pulse of high TDS water in winter is probably mobilised by infiltration of excess rainfall in the shale dominated soils of the middle to lower Berg River, and increased flow in the river.

Phosphate concentrations also show seasonality as a result of differences in rainfall and runoff, but with summer minima and winter maxima. The most pronounced pattern in phosphate concentration is the dramatic elevation of this nutrient at G1H036, as a result of anthropogenic activities (mainly WWTF effluent), where phosphate concentrations persistently fall within the hypertrophic range for phosphorus, whilst the rest of the river is mesotrophic for this nutrient. Phosphate concentrations at G1H013 are substantially reduced in summer, but mainly because of the high rate of summer abstraction from the Berg River between G1H036 and the Voelvlei outlet, with the result that virtually all of the river flows downstream of the Voelvlei outlet actually comprise water from the Twenty Four River, the Leeu and the Klein Berg Rivers, rather than the upstream reaches of the Berg River itself. During autumn, winter and spring, a larger proportion of nutrient enriched water from G1H036 passes into the lower reaches of the river, contributing to the increase in phosphate concentrations at G1H013 during these seasons.

Winter increases in phosphate concentration may be explained by the relationship between phosphate concentration and flow, which is characterised by an offset between storm peak and phosphorus peak. As high flows build up to a peak, so phosphorus concentrations decrease, as a result of dilution. As the flow peak declines, so phosphate concentrations increase, usually to a rapid peak. This is possibly connected to entrainment of phosphorus rich
sediment during high flows, and the lag in their settling out of the system at low flows.

- Estimates of phosphate loading show substantially elevated winter and spring loads throughout the system, as a result of the increases in concentration (through mobilisation of sediment and nutrient rich return flows), coupled with elevated discharge.

- Also, while concentrations of phosphate were markedly highest at G1H036, phosphate loading at the downstream G1H013 was nearly as high as at G1H036 – the result of the greater discharge at the downstream site.

This means however that G1H013 must be influenced by additional sources of phosphate, other than G1H036, to account for the higher loading.

Potential sources include the Vis and Sandspruit Rivers, both of which were assessed as eutrophic with respect to phosphorus, as well as runoff from agricultural areas.

- Nitrogen enrichment was not at the levels of phosphorus enrichment anywhere along the Berg River, with nitrogen nutrient concentrations at all sites being in the mesotrophic range (0.5-2.5 mg N/l) or lower, as described by DWAF (1996a), despite being massively elevated at G1H036, as a result of non-flow related impacts, as was the case with the other water quality variables.

- The data shown in Figure 2.11, besides the longitudinal change, indicate marked seasonal differences in nitrogen nutrients in the Berg River, with consistent summer minima and autumn / winter maxima, which decrease in spring. Concentrations of nitrogen compounds were the lowest at G1H004, and seasonal winter / spring maxima not strongly evident, despite the fact that even this upstream site lies downstream of both the Dewdale trout farm and the Berg River siphon. Concentrations increased downstream of G1H020, particularly in and below Paarl – dramatically so in the case of autumn, winter and spring data. These are non-flow related impacts of development, particularly WWTF releases. Downstream of G1H036, recovery from nutrient enrichment with distance downstream occurs, but, as in the case of the phosphate data, mainly because summer flows between G1H036 and the Voelvlei outlet are almost entirely lost to abstraction, with the result that summer flows at G1H013 comprised almost entirely flows from Voelvlei Dam and the tributaries that confluence in this section of the river.

- Autumn and winter maxima in terms of nitrogen compound concentrations are probably the result of the mobilisation of synthetic nutrients from agricultural areas during autumn, winter and the spring growing periods.

- Peak loading occurs during winter and to a lesser extent in autumn, linked to increased flow in the river channel. At G1H004 the highest load is during spring, presumably because this coincides with some elevated flow in the river, trout farm activities and the spring onset of IBT releases. Interestingly, during winter, loading at G1H013 exceeds that at G1H036, despite the higher nutrient concentrations at the latter site. This is a reflection of the higher discharge at G1H013. As in the case of phosphate loading, loading estimates at G1H013 indicated an additional source of nitrogen in winter downstream of G1H036. Likely sources include diffuse runoff from the agricultural areas in the vicinity of G1H013, many of which produce winter wheat. These would be most likely to leach synthetic nutrients into the river during autumn, winter and spring growing periods.
In conclusion, water quality in the Berg River is related to both the concentrations of effluents and minerals entering the river through its tributaries and point or diffuse return flows, but, importantly the magnitude of these flows, which determines the overall loading on the system. The Berg River Dam will reduce the magnitude of flow contributed from the upper catchment, and thus increase the relative contribution of loads from tributaries and point sources such as WWTFs and the IBT.

As a consequence, and even with no other change in the present loads carried by these inflowing sources, this will result in an alteration in the load in the main stem river. This is dealt with in more detail in Section 2.6.
2.5.4 Riparian vegetation in the Berg River and the influence of flow

There are three main axes along which changes in riparian vegetation may be described: longitudinal - from the river source to its mouth; vertical - between the river bed and bank, and in relation to fluvial aquifers; and lateral - across the floodplain. Three parameters, geology, geomorphology and flow (especially flood) regime, act in concert as the major drivers of riparian vegetation plant community assemblages, structure and dynamics.

As rivers adjust their morphology (width, depth, slope and platform) to carry increasing discharge and sediment supplied from the drainage basin, so too do the river bed and the banks become altered, with their own riparian characteristics. Upper reaches usually consist of narrow streams in narrow valleys, and so the riparian zones tend to be poorly developed with indistinct or incomplete lateral zonation of plant communities up the banks. The width of the riparian zone tends to increase with distance downstream as valleys widen, resulting in less lateral constraint on channel form. Flood terraces and floodplains become a more obvious feature of the riverine landscape in these reaches, with a consequent increase in the extent and complexity of the riparian vegetation. Overlaid onto this longitudinal zonation in channel form and riparian characteristics are those of geology which in the Berg River adds to the complexity of plant communities along the length of the river e.g. with the shift from TMS to shales at Piketberg. Longitudinal patterns in riparian vegetation are summarised in Table 2.6.

Based on studies of riparian vegetation and different flow classes, Boucher (2002) identified a generalised pattern of plant community changes perpendicular to the river channel from the water’s edge. He identified a set of plant community “zones” reflecting primarily differences in the period and regularity of inundation. The relationship between these vegetation zones and different flow and flood categories are illustrated in Figure 2.12. For example, data from a number of sites showed that the maximum height reached by the 1:2 year inter-annual flood is closely linked with the lower edge of the woody tree “zone” within the riparian belt.

The BRBMP monitoring programme found that many of the zones described in this generalised relationship were not floristically different at the monitoring (BRM) sites, but broad categories (Wet Bank, Lower Dynamic, Dry Bank) were generally differentiated by multivariate statistical analysis.

The zones also did not always correspond to the flood levels purported in the relationships described by Boucher (Figure 2.12).

These anomalies may at least in part be attributed to the considerable existing (and in some reaches, ongoing) anthropogenic disturbance of the riparian vegetation described by the study. For example, bank collapse at BRM2 and erosion at BRM4 upset vegetation zonation patterns. Loss of species due to fire, or to the clearing of alien (and sometimes, inadvertently, indigenous) vegetation altered the floristic description of zones from year to year. Shifts in species composition – e.g. increased species, as vegetation recovers following alien plant removal – were also observed. This highly dynamic state of the vegetation might explain the lack of consistent relationships over the monitoring period between the water levels associated with different classes of floods and the vegetation zonation at the site.
Figure 2.12 Schematic showing generalised plant community zones perpendicular to the river channel and their relationship to various components of the flow regime (graphic supplied by JM King). WSLF = Wet Seasonal Low Flow; DSLF = Dry Season Low Flow; four classes (1-4) described DRIFT intra-annual flood categories, whilst 1:2 and 1:20 describe inter-annual return-period floods.

Some responses of the riparian vegetation to the flows measured in the river during the BRBMP were:

- a tendency toward increased cover of herbaceous vegetation in the Wet Bank zone, indicating an absence of flushing flows
- colonisation of open areas fringing the free water by Wet Bank vegetation, in the absence of floods, which initiates the process of channel narrowing
- a downward shift in Dry Bank vegetation into the Wet Bank zones
- die-back or deteriorating condition of some upper Wet Bank and Tree - Shrub species (Salix mucronata and Buddleja saligna respectively, attributed to drought years and particularly constant lower flows
- narrowing of the Wet Bank zone as a result of constant flow of turbid water (irrigation releases). High turbidity levels in the water reduce light penetration and prevent semi-aquatic plants growing in deeper water as is normal in the naturally clear streams of the Western Cape. The relative constancy of the flow releases also caused a general narrowing of the Wet Bank zone because of lack of wetting to higher bank levels followed by exposure at lower levels.

2.5.5 Periphyton in the Berg River and the influence of flow

In open-canopied rivers such as the Berg River, autotrophic benthic algae, (the main component of periphyton), provide much of the energy for the maintenance of the rest of the ecosystem. Periphyton therefore occupies a pivotal position in aquatic ecosystems at the interface of the chemical-physical and biotic components of the food web. Periphyton is particularly responsive to flow and nutrient alterations.
A conceptual model of the factors that determine periphyton biomass in New Zealand streams (Biggs et al. 1998) predicts that periphyton biomass will be highest in reaches that are undisturbed by floods, have low maximum flows, are nutrient rich, depauperate in grazers and have unlimited light.

In the Berg River, periphyton communities’ at all four monitoring sites reflect seasonal cycles of biomass accrual and loss, with maximum biomass recorded during the summer and minimum biomass recorded during the winter. The study found a significant correlation between two different measures of hydrological disturbance and seasonal cycles of periphyton biomass: when the frequency of small floods (i.e. the DRIFT class 1 floods) is higher than average and the variability in flow over the three month period prior to sampling is the greatest, periphyton biomass was found to be the lowest. Also, a weak but significant correlation between periphyton biomass and temperature suggests that temperature may contribute to seasonal changes in periphyton community structure. In other words, a cessation of flood disturbance at the end of winter, coupled with an increase in water temperature and longer day length coincides with an increase in biomass during the spring, reaching a peak biomass in the summer. A weak but significant positive correlation between periphyton biomass and grazer biomass during this study suggests that both periphyton and grazers may be controlled by the same factor, probably flood disturbance.

Nutrients appear not to be correlated with seasonal cycles of periphyton biomass. Nutrient concentrations appear to be the major driver of periphyton community structuring down the length of a river as reflected in the spatial patterns described during the study. The indications for the Berg River, however, are that seasonal cycles in periphyton biomass accrual and loss are independent of nutrient availability.

Seasonal changes in the periphytic community structure in the upper river, upstream of the IBT followed the typical seasonal succession in taxonomic structure expected under un-enriched conditions, from diatoms dominant during the winter when flood disturbance is frequent and temperatures are low, through to a dominance by green algae and a significant contribution by blue-green algae during the summer when temperatures are higher, day length is at a maximum and flow is stable. This pattern of seasonal succession was not as clear at the other three monitoring sites, which is attributed to anthropogenic changes, from fluctuations in nutrient availability, degree of shading (due to turbidity) and shear stress associated with the IBT, to land use activities that result in unpredictable changes in water quality variables (particularly nutrient availability and TSS) which are likely to disrupt the expected seasonal succession in periphyton taxonomic structure.

During the BRBMP, periphyton biomass showed an inter-annual winter and /or spring maximum in 2004. It is surmised that the low frequency of floods in 2004 may have been responsible for increased periphyton relative the same period in the other years. This suggests that the frequency of small floods, rather than the occurrence of large floods may be fundamental to the temporal (inter-annual) variability in periphyton biomass in the Berg River. However, the differences in periphyton patterns between BRM1 and BRM2 suggest that, under conditions of even slight enrichment – phosphorus concentrations in particular were higher at BRM2 relative to BRM1 – inter-annual variability in the extent of periphyton reduction by flood disturbance may be the product of both nutrient availability at any given time (which drives recovery) and the frequency of small flood events (which drives biomass loss).

2.5.6 Macro Invertebrates in the Berg River and the influence of flow

Longitudinal patterns in macro invertebrate assemblages in the Berg River have been demonstrated in a range of surveys, as early as the 1950s. These patterns show a gradual change in assemblage composition from point to point along the river, but the largest change is a clear split between the cobble foothill sites and the
lowland river sites. Longitudinal patterns in invertebrate assemblages are summarised in Table 2.6.

These patterns are primarily the result of the geomorphology of the different reaches, which reflects the sediment and hydrological regime, as well as water quality changes along the length of the river.

The Macro invertebrate Response Assessment Index, MIRAI, is a recently developed index that quantifies the riverine invertebrate response to changes in flow, water quality, habitat condition, seasonality and connectivity against a reference condition for that river. The results of this assessment, based on three years of monitoring, and compared to a reference condition that could be quite accurately determined for the Berg River because of good historical data on invertebrates in the Berg River, indicate which ecosystem attribute is most responsible for a change from the natural condition with respect to invertebrate assemblages.

At BRM1, the greatest deviation from the reference condition was recorded for the water quality metric group, although differences between the three metric groups were not substantial and the site itself, representing the foothill zone upstream of the IBT is in good condition with respect to invertebrate fauna. At BRM2, the flow metric group scored the lowest – this site is heavily impacted by the effects of the IBT upstream. The IBT results in significantly higher base flows in summer, which evidently have an impact on the invertebrate assemblages in this river reach. The three lower sites scored the lowest in the water quality metric group, reflecting the general deterioration in water quality down the length of the Berg River.

The dry season releases of water from the IBT cause a shift in the impacted communities away from the typical summer, low-flow community towards a transitional community that more closely resembles the autumn and spring fauna. Typical low-flow taxa are lost or reduced in number, and the winter fauna, that would be better adapted to the high flows typical of the IBT releases, are not available at this time of year for colonisation of the impacted sites. An example of the quite substantial habitat alteration as a result of flow at this site is the occurrence of the large, predatory Centroptiloides bifasciata (Baetidae) during the IBT release periods. This species prefers fast-flowing water, but did not occur at BRM1, and indeed was not recorded from the Berg River prior to the onset of IBT releases. Snaddon and Davies (2000) found that the summer invertebrate community below the IBT resembled one typical of lake outlets. The IBT releases vast quantities of zooplankton, and organic matter which is readily available to those invertebrate taxa that can take advantage of this food source. In addition, the predictability of increased flow ensures a high availability of food throughout the months of water release.

Invertebrate assemblages differed across different biotopes at the BRBMP sampling sites (biotopes comprise a combination of the dominant substratum type and flow type). These differences are represented by changes in species composition in some cases, but more often by differences in density of taxa over the range of biotopes. Biotope preferences for a number of species may be inferred from these results, for example, Caenis sp. (Caenidae), Afroptilium sp (Baetidae), Adenophlebia sp. Aprionyx spp. (Leptophlebiidae) are largely restricted to backwaters and poorly represented in fast runs / riffles; Demoreptus capensis (Baetidae) and Desmonemoura pulchellum (Notonemouridae, Plecoptera), Cheumatopsyche maculata (Trichoptera) and Simuliidae dominate in fast runs / riffles.

No species are exclusive to only biotope, however, because each species’ flow and substratum preferences reflect a range of tolerances. Examples of taxonomic (species or genus level) preferences for particular flow or flow-induced conditions (non-flood period) come from a parallel study on the Berg and Molenaars fauna and are presented in Table 2.7. The strongest relationships were found with velocity or hydraulic variables that are related to velocity (e.g. Froude No.) and with the
concentration of organic matter, which itself reflects areas of deposition, thus related to flow velocities.

Table 2.7 Pearson’s correlation coefficients of 4th root transformed invertebrate densities and abiotic variables, for taxa in the Molenaars River (M) in June 2003 and the Berg River (B) in May 2004. Only significant relationships are presented. Results are given as the Pearson’s r-value. p-value is indicated as follows: * p <0.05; **p< 0.01; † p<0.001; ‡ p< 0.000. Organic matter data were log-transformed to achieve normality.

<table>
<thead>
<tr>
<th>Responses to depth</th>
<th>Responses to velocity or hydraulic indices derived from velocity</th>
<th>Responses to organic matter</th>
<th>Responses to inorganic matter</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>B</td>
<td>M</td>
<td>B</td>
</tr>
<tr>
<td>Tanytarcini</td>
<td>Chironomini -0.34 *</td>
<td>Tanytoidine 0.81†</td>
<td>Tanytoidine 0.85 ‡</td>
</tr>
<tr>
<td></td>
<td>Orthocladiinae 0.47†</td>
<td>Tanytoidine 0.47</td>
<td>Tanytoidine 0.36‡</td>
</tr>
<tr>
<td>A. harrisoni -0.43**</td>
<td>Tanytoidine -0.32 *</td>
<td>Chironomini 0.79§</td>
<td>Tanytarcini 0.34 *</td>
</tr>
<tr>
<td></td>
<td>Tanytoidine -0.30*</td>
<td>Chironomini 0.40 ‡</td>
<td>Elmidia 0.39§</td>
</tr>
<tr>
<td>Aeschnidae 0.78**</td>
<td>Choroterpes sp. -0.54*</td>
<td>Choroterpes sp. 0.85†</td>
<td>Choroterpes sp. 0.72**</td>
</tr>
<tr>
<td></td>
<td>Adenophlebia sp. -0.38*</td>
<td>Adenophlebia a sp. 0.39 *</td>
<td>Helodidae 0.41*</td>
</tr>
<tr>
<td>Hydroptilidae 0.56*</td>
<td>A. (bergensis) sp. -0.47*</td>
<td>Aprionyx sp. 0.90 *</td>
<td>Aprionyx sp. 0.55†</td>
</tr>
<tr>
<td></td>
<td>Orthocladiinae 0.04*</td>
<td>A. (bergensis) sp. 0.93†</td>
<td>Athericidae 0.58 *</td>
</tr>
<tr>
<td>Hydraenidae -0.61*</td>
<td>Afroptilum sp. -0.56†</td>
<td>A. harrision -0.67 *</td>
<td>D. capensis -0.49 *</td>
</tr>
<tr>
<td></td>
<td>Pseudocloeon sp. -0.37*</td>
<td>A. agilis -0.69**</td>
<td>Athericidae 0.40 *</td>
</tr>
<tr>
<td></td>
<td>D. capensis 0.65†</td>
<td></td>
<td>Baeitis spp. -0.51*</td>
</tr>
<tr>
<td></td>
<td>Baetis spp. 0.31 *</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Elporia spp. 0.51†</td>
<td></td>
<td></td>
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</tbody>
</table>

Some seasonal variation in biotope preferences appear to be driven by flow. For example, the plecopteran stonefly nymph, *Desmonemoura pulchellum*, was more widespread across biotopes in the winter and autumn months, compared with the summer, when the nymphs tended to prefer runs and riffles, the faster-flowing biotopes. This suggests that increased flow in winter acts to alter the condition of a range of biotopes, altering their suitability for different species.

Seasonal differences between invertebrate assemblage compositions at the five sites were more marked at the lowland sites than at the foothill sites. At the lower sites, there was a paucity of invertebrates in samples taken in the high flow months, rather than a replacement by other taxa as at the upper sites. This supports the observation of Harrison and Elsworth (1958) who remarked that the while invertebrates inhabiting the runs and riffles at the upper river sites tended not to be affected by the higher discharges in winter, the soft-bottom communities further down the river were basically washed away by winter floods. The decline in numbers of taxa found at the lowland river sites, and the overall paucity of invertebrates could also be due to the fact that some of the biotopes that were sampled in summer were too deep to be sampled in winter, whereas at BRM1 and BRM2 the same biotopes could generally be sampled in all seasons.
At both BRM1 and BRM2, however, the riffles and runs also showed distinct seasonality, with total scores and the number of taxa generally peaking in these biotopes in summer.

An interesting observation can be made regarding the vegetation out of current biotope – this biotope assumed greater importance for the biota in winter at the cobble foothill sites, but was more important in the summer and spring months at the lowland river sites. This biotope performs different roles in different parts of the river.

In the upper river, it is more important as a refuge during high flows in winter while, in the lower river, it is inhabited by invertebrates that prefer this biotope to any other, perhaps for its shelter from predators, or as an attachment site. Invertebrates also visit this biotope for egg-laying and feeding.

An investigation into the responses of invertebrates to floods the Berg River was conducted in a parallel study to the BRBMP during 2004 (Ractliffe et al. 2006). During this flood study there were two large intra-annual floods that moved between 25 and 43 % of the river bed and three minor spates (DRIFT Class 1 and 2) that moved less than 3 % of bed particles. The larger floods represented a low and a high DRIFT Class 4 flood, and moved all size categories of river bed materials, but to different degrees. The floods were associated with some 58 % decrease in total invertebrate density, cumulative for the two-month period. The study found that:

- Movement of substratum particles is not a threshold for disturbance-responses, since almost all invertebrate taxa were reduced on unmoved as well as moved substrata. However, there is a wide difference in the relative refugium afforded to different taxa, as a result of some substrata remaining stable over a flood.

- The study demonstrated substantial differences in the disturbance-response between different and potentially competing species. For example, whilst nearly all individual invertebrate taxa declined significantly with the large floods, three mayfly taxa increased in densities on stones - *Lithogloea harrisoni* and *Nadinitella crassi* (Telagonodidae) and *Pseudocloeon* spp. (Baetidae). In addition to this, small (Class 1 – 3) floods recorded in the Molenaars River in 2003 did not either affect *Simulium* spp., *Demoreptus capensis*, Notonemouriidae, Orthocladiinae (Chironomidae) and Helodidae but the larger floods in the Berg River appeared to exceed a disturbance threshold for these taxa, reducing their populations.

- The preliminary species-specific results may aid in setting flow requirements in rivers, during Environmental Water Requirements studies, particularly where there is evidence of species interactions, or where pest species (Chironomidae, Simulidae) may proliferate under low disturbance regimes.

**2.5.7 Fish in the Berg River and the influence of flow**

Under natural circumstances, there are many factors that determine the composition and structure of fish assemblages in streams and rivers. These include physical factors such as location along the length of the river, availability of suitable habitat, water quality, or biological factors such as food availability, competition and predation. In the case of the Berg River, anthropogenic disturbance has added a number of additional dimensions which, to a large extent have supplanted the natural forces structuring fish populations in the river. This is evidenced by the dramatic changes that have taken place in indigenous fish populations in the Berg River between historic times (pre-1900) and the present. The four primary freshwater fish species in the Berg River are the Berg River Red Fin *Pseudobarbus burgi*, the Cape Whitefish *Barbus andrewi*, the Cape Kurper *Sandelia capensis* and the Cape...
Galaxias *Galaxias zebratus*. All of these were once described as being abundant in the Berg River, are now represented by small isolated populations, if at all.

Key anthropogenic factors responsible for the observed changes in the abundance and distribution of indigenous fish in the Berg River include introduction of alien fish species, reduction in in-stream flows, changes in water quality (nutrient enrichment, salinisation, toxic effluents), invasion by alien riparian vegetation, and construction of physical barriers to movement (dams and weirs).

Invasion by piscivorous alien fish has frequently been singled out as the primary reason for the reduction in indigenous fish populations in Western Cape river systems.

No less than ten alien piscivorous fish species have been introduced to the Berg River, including three species of Bass (*Micropterus dolimieu, M. salmoides* and *M. punctulatus*), three species of Trout (*Salmo trutta, Onchorhynchus mykiss, Salvelinus fontinalis*), Sharptooth Catfish *Clarias gariepinus*, Mosquito Fish *Gambusia affinis*, Bluegill Sunfish *Lepomis macrochirus* and Salmon *Salmo salar*. All but two of these (*S. fontinalis* and *S. salar*) survive to this day, and are represented by thriving populations. Of these species, smallmouth bass *Micropterus dolimieu* is most likely the main culprit responsible for the plight of indigenous fish in the Berg River. *M. dolimieu* exhibits similar habitats preferences to all of the indigenous species, preferring the clear, swift flowing waters of mountain streams, and is known be a voracious predator of these species. Indigenous fish do not appear to be able to coexist in the same habitat as *M. dolimieu* for any length of time; all extant populations of indigenous fish on the Berg being separated from *M. dolimieu* by natural or artificial physical barriers such as waterfalls, weirs or dams.
2.6 HABITAT INTEGRITY AND PRESENT ECOLOGICAL STATE OF THE BERG RIVER

The assessment of Habitat Integrity is a measure of the integrated composition of physico-chemical and habitat characteristics relative to the characteristics of natural habitats within the same river reach (DWAF, 1999). Thus, the assessment of the habitat integrity of a river can be seen as a precursor of the assessment of biotic integrity and together, these two components constitute the ecological integrity of the system (Kleynhans, 1996). As part of the IFR refinement process in 1996, video footage from a helicopter was taken of the full length of the river, to determine its instream and riparian Habitat Integrity (Kleynhans, 1996). The river was subdivided into 49 x 5km segments, beginning from a point near (but not at) the headwaters. Video footage was used to separately analyse instream and riparian habitat integrity, and the results presented per 5-km stretch of river. These 5 km segments are indicated in Figure 2.17.

The BRBMP terms of reference requires that the Habitat Integrity status of the Berg River be updated for the final report. A more refined way in which to assess Habitat Integrity is to integrate the Present Ecological State of each of the ecosystem components. For this update, the reaches described in Table 2.6 were evaluated in terms of both their Habitat Integrity as well as the Present Ecological State.

The Department of Water Affairs and Forestry (DWAF 1999) prescribes a method for the categorisation of the Present Ecological Status (PES) of a river, which defines its ecological integrity, condition or degree of “naturalness”. PES is now also referred to as Ecostatus. The PES of a river or river reach is based on a summary of separate “Ecostatus” assessments of the extent of change that has occurred to different components of the river – geomorphological attributes like channel shape and form, water quality, hydrological modification, riparian and instream vegetation, fish, and invertebrates. The PES is presented as one of seven Classes, summarised in Table 4. Based on this methodology, the Berg River immediately downstream of the proposed Berg River Dam, now under construction, was classified as a Class C river, reflecting moderate level of modification. Downstream of the confluence of the Franschhoek and Berg Rivers, however, the river falls into a Class D / E Ecological Status – reflecting large to serious changes in the natural state of the river. The most severe changes are reflected in the total loss of indigenous fish, substantial modification of the channel and banks through farming practices, and near-total replacement of riparian vegetation with alien invasive plants. Agricultural and urban development, particularly sewage treatment plants have resulted in a large modification in water quality and loss of aquatic invertebrate species.

<table>
<thead>
<tr>
<th>Ecological Status Class</th>
<th>Description of General Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Unmodified, natural.</td>
</tr>
<tr>
<td>B</td>
<td>Largely natural with few modifications. A small change in natural habitats and biota can take place but the ecosystem functions should essentially be unchanged.</td>
</tr>
<tr>
<td>C</td>
<td>Moderately modified. A moderate change in natural habitat and biota can take place but the basic ecosystem functions should still predominantly be unchanged.</td>
</tr>
<tr>
<td>D</td>
<td>Largely modified. A large change in natural habitat, biota and basic ecosystem functions can occur.</td>
</tr>
<tr>
<td>E</td>
<td>Seriously modified. The losses of natural habitats and basic ecosystem functions are extensive</td>
</tr>
<tr>
<td>F</td>
<td>Critically modified. Modifications have reached a critical level and the system has been modified completely with an almost complete loss of natural habitat.</td>
</tr>
<tr>
<td>Geomorphological / longitudinal zone and geology</td>
<td>Geomorphological Reach (length in km)</td>
</tr>
<tr>
<td>-----------------------------------------------</td>
<td>--------------------------------------</td>
</tr>
<tr>
<td>Mountain headwater / mountain stream</td>
<td>1-3 (2.3)</td>
</tr>
<tr>
<td>Table Mountain Group</td>
<td>4-7 (10.5)</td>
</tr>
<tr>
<td>Upper foothill Table Mountain Group and Cape Granite suite</td>
<td>8 (7.9)</td>
</tr>
<tr>
<td>Lower foothill Table Mountain Group to east, Cape Granite suite and Malmesbury Group to west, valley floor alluvium</td>
<td>9 (19.1)</td>
</tr>
<tr>
<td>Section</td>
<td>Location</td>
</tr>
<tr>
<td>---------</td>
<td>----------</td>
</tr>
<tr>
<td>D</td>
<td>Canalisation of river through Paarl and agricultural encroachment elsewhere</td>
</tr>
<tr>
<td>E</td>
<td>Canalisation and modification of lower lateral veg. Bank disturbance and alien infestations extensive.</td>
</tr>
<tr>
<td>F</td>
<td>As above</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Section</th>
<th>Location</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>Lower veg zones more natural but still suffering from upstream releases. Bank disturbance and alien infestations extensive.</td>
<td>Still influenced by upstream inputs from WWTWs; agricultural runoff-exacerbated by loss of buffers</td>
</tr>
<tr>
<td>F</td>
<td>As above</td>
<td></td>
</tr>
</tbody>
</table>

### Lowland River Malmesbury Group

<table>
<thead>
<tr>
<th>Section</th>
<th>Location</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>Invasion of the riparian area by large aliens such as blue-gums has less to erosion of the macrochannel</td>
<td>Effect of upstream releases less through abstraction thus some variability returns. Farming results in reduced riparian belt, although some upper zone bank veg still present as banks not disturbed up to channel because floods still happen fairly often here.</td>
</tr>
<tr>
<td>C</td>
<td>Effect of upstream releases less through abstraction thus some variability returns. Some upper zone bank veg still present as banks not disturbed up to channel because floods still happen here.</td>
<td>Downstream of Voelvlei inlet, water quality improves because of dilution; most of upstream flows abstracted so river water quality is effectively that of Klein Berg and 24 Rivers. Runoff from agricultural areas Increased seasonal EC contribution because of Matjies River Higher winter P concentrations because of mobilisation of P in sediments during floods</td>
</tr>
<tr>
<td>F</td>
<td>As above</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Section</th>
<th>Location</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>Lateral agricultural disturbance increased on one bank &amp; less on opposite with overall upstream negative influences such as nutrient increase plus flow variability decreasing thus accumulating overall negative trend with increase in woody aliens.</td>
<td>Runoff from agricultural areas Increased seasonal EC contribution because of Matjies River Higher winter P concentrations because of mobilisation of P in sediments during floods</td>
</tr>
<tr>
<td>C</td>
<td>Invertebrates are most diverse in the vegetation biotopes, but are overall less selective in terms of habitat preference. This leads to less distinctive communities in different biotopes. Diversity and numbers drop significantly in winter, rather than a replacement of summer species with winter species.</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>As above</td>
<td></td>
</tr>
<tr>
<td>15 (11.0)</td>
<td>to Morreesburg-spruit confluence</td>
<td>D minus negative trend as water volume and quality deteriorates with climate drier than upstream so instream effects exacerbated.</td>
</tr>
<tr>
<td>16 (48.0)</td>
<td>Extends from Misverstand Dam just dist Morreesburgspruit; to head of the estuary; includes BRM6</td>
<td>E Good in spots but more bad with overall veg showing increased negative trend with increased abstraction and drier climate prevails thus little amelioration of reduced flow. A reduction of lower zones extent through erosion occurs.</td>
</tr>
</tbody>
</table>
2.7 IMPLICATIONS OF THE BERG RIVER DAM FOR ECOSYSTEM FUNCTIONING

The Berg River Dam will have a much larger effect on the water volumes released than most other dams in South Africa. This is mainly due to the pump station that will abstract water from the reservoir when the water level in the reservoir reaches a certain height. The short spillway length (40m) will cause major flood attenuation and the abstraction works downstream of the Franschhoek and Dwars Rivers’ confluence with the Berg River will decrease the flow even more by abstracting the water of these two tributaries to supplement water storage of the Berg River Dam. This reduced water volume due to the dam can clearly be seen from the hydrodynamic mass balance that was constructed from the simulated data. The effect of the Berg River Dam will be most pronounced down to Paarl, it will also have a significant effect on the sediment and water volumes between Paarl and Hermon. As the water contribution from the tributaries increase further downstream the effect will decrease to a minimum at Misverstand Dam.

The modelling shows that, for all the sites along the Berg River, the dam will have a noticeable impact on the magnitude of inter-annual floods. This is due to flood attenuation and removal of many floods as a result of the dam operation. At sites BRM2 and BRM3 the decrease in return period floods of between 2 and 20 years is extreme. The post-dam 1:2-year flood peak at BRM2 is only 3% of the present flood peak, while the 1:20-year flood peak is only 41% of the flood peak at present. The differences further downstream, towards BRM5 and BRM6, are not as pronounced, although the post-dam 1:2-year flood peak at BRM 6 is still only 83% of the flood peak at present. The reducing impact of the dam with distance downstream is because the floods from the upper reaches make a lower contribution to the larger floods at BRM5 and BRM6 as demonstrated by the hydrological analysis, so that when these upper-river generated floods are reduced the tributaries still contribute the most to the larger floods.

All classes of floods (both inter- and intra-annual events) will be attenuated and both winter and summer base flows will be reduced, with a loss in flow variability. Table 2.8 provides an indication of the actual number and sizes of floods that would be released in the 10-year modelling period, based on the IFR recommendations and using a first-estimate operating rule for release of the floods. The operating rule forgoes the release of larger (but intra-annual) floods in a “dry” year if the specified IFR flood of a given magnitude is not observed by some cut-off date.

However, the analysis of the year-to-year variability in flood flows in this study shows that a given total flood volume may be split quite differently between various intra-annual flood classes from one year to the next, and in “dry” years there may be a considerably greater proportion of flows occurring as class 1 and 2 floods. This is another form of intra-annual variability that maintains the stochastic nature of flow in these rivers, which would be lost without more flexibility in operating rules.

Table 2.10 Timing and magnitude of simulated artificial flood releases based on historical records, from the hydrodynamic modelling in the BRBMP.

<table>
<thead>
<tr>
<th>Dates of 1st flood release</th>
<th>Incoming Peak (m³/s)</th>
<th>Released Peak Flow (m³/s)</th>
<th>Dates of 2nd flood release</th>
<th>Actual Peak (m³/s)</th>
<th>Released Peak Flow (m³/s)</th>
<th>Dates of 3rd flood release</th>
<th>Actual Peak (m³/s)</th>
<th>Released Peak Flow (m³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20/04/1995</td>
<td>2.4</td>
<td>15</td>
<td>No floods released</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18/04/1996</td>
<td>28.8</td>
<td>15</td>
<td>07/06/1996</td>
<td>191.2</td>
<td>100</td>
<td>24/09/1996</td>
<td>136.8</td>
<td>136</td>
</tr>
<tr>
<td>27/04/1997</td>
<td>0.8</td>
<td>15</td>
<td>08/06/1997</td>
<td>79.6</td>
<td>79</td>
<td>No flood released</td>
<td></td>
<td></td>
</tr>
<tr>
<td>05/04/1998</td>
<td>25.8</td>
<td>15</td>
<td>06/06/1998</td>
<td>82.9</td>
<td>82</td>
<td>15/07/1998</td>
<td>290.5</td>
<td>220</td>
</tr>
<tr>
<td>20/04/1999</td>
<td>6.1</td>
<td>15</td>
<td>18/06/1999</td>
<td>108.1</td>
<td>100</td>
<td>No flood released</td>
<td></td>
<td></td>
</tr>
<tr>
<td>23/04/2000</td>
<td>2.9</td>
<td>15</td>
<td>18/07/2000</td>
<td>109.9</td>
<td>100</td>
<td>02/09/2000</td>
<td>125.9</td>
<td>125</td>
</tr>
<tr>
<td>13/04/2001</td>
<td>10.4</td>
<td>15</td>
<td>03/07/2001</td>
<td>81.3</td>
<td>81</td>
<td>No flood released</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16/04/2002</td>
<td>4.9</td>
<td>15</td>
<td>09/07/2002</td>
<td>87.6</td>
<td>87</td>
<td>28/07/2002</td>
<td>225.2</td>
<td>220</td>
</tr>
<tr>
<td>22/04/2003</td>
<td>1.8</td>
<td>15</td>
<td>No flood released</td>
<td></td>
<td></td>
<td>18/08/2003</td>
<td>184.5</td>
<td>184</td>
</tr>
</tbody>
</table>
The predicted changes in abiotic and biotic conditions specific to different river reaches are summarised below.

2.7.1 Upper Foothill reach

The worst effects of the Berg River Dam will occur between the dam wall and the Franschhoek tributary (i.e. BRM2), where the river relies solely on releases from the dam. More specifically, only about 30 Mm$^3$/per annum (21% of the present MAR) at BRM2 will be released into the river with the dam in place. With the IFR flood releases modelled by the hydrodynamic model, this will increase to 35 Mm$^3$/per annum, or 25% of the MAR. This is much lower than the 42.5 Mm$^3$/a (32.5% MAR) specified as the Reserve for the Berg River.

These flow reductions mean that the main channel width at BRM2 will decrease by about 25%, which is 10 m on the current 40 m width, directly due to the decreased flood peak magnitudes and number of floods which will pass through the dam. Narrowing is due to higher hydraulic roughness caused by the encroachment of vegetation on the river banks. The river banks are easily erodible and the smaller main channel shape and flatter bed slope could lead to changes in the river plan form. This reach of the river is braided, but with the change in dominant flood peak after completion of the dam the river could become meandering with a higher sinuosity in character.

Main channel depth will also decrease (estimated to be as much as 42%) and the longitudinal slope of the bed will decrease due to the Berg River Dam construction upstream. A reduction in the size and number of large, inter-annual floods anticipated downstream of the Berg River Dam will result in an increase in bed armouring. Also, this reach will have a limited source of sediment from the catchment once the dam is in place. Sand deposition is however possible due to the possible change in river sinuosity and river bank erosion upstream of BRM2. Cobble and boulders at the bed will reach a new equilibrium over time, with limited movement.

A reduction in summer base flows as a result of the cessation of irrigation releases from the IBT will cause both depths and velocities of biotopes to decrease considerably by about 62 - 66%, and 10 - 66% respectively. While velocities will probably not be significantly changed in winter under post-dam conditions and discharge will decrease, average water depths are expected to increase by about 10%. This is largely due to the narrower width of the post-dam active channel. Further, the reduction in sediment transport will result in lower TSS concentrations, and thus increase in light penetration.

The decrease in summer base flows will probably lead to a reduction in the extent of medium and deeper runs, and an increase in the extent slow, shallow runs and trickle runs, due to the increased emergence of larger cobbles and boulders above the water level. Shallow ripples may persist during the summer months, in parts of the channel where a change in gradient allows such broken flow. However, they are likely to be less turbulent, as a result of slower flows, and so less rich in oxygen.

In winter, it is expected that the channel at BRM2 will be dominated by deep run. Riffles may persist, but are more likely to be replaced by runs or rapids as the channel narrows. Slack waters and backwaters will be substantially reduced as a result of the narrower channel and the likelihood of the channel becoming a more channelised, meandering system.

Thus, overall, the quality of the riffle and run habitat is likely to deteriorate, due to loss of oxygen from reduced turbulence and increased sedimentation due to loss of flushing flows. Also, a lack of variation in discharge throughout the summer months will lead to a lack of diversity in the quality and quantity of biotopes.

In terms of water chemistry, it is likely that water temperatures will be lower, with a reduction in the seasonal temperature range. Nutrient enrichment in this reach of the river is expected to decrease, largely as a result of closure of the trout farm and cessation of IBT releases. Increased sedimentation as a result of reduced sediment transport could
result in the long-term build-up of phosphorus in the reach, since phosphorus is stored in sandy sediments, and mobilised by floods, to be exported downstream. In the event that the Berg River Dam becomes nutrient-enriched, BRM2 will be most impacted by increases in nutrients.

These are ideal conditions for the accumulation of periphyton biomass at BRM2, all other factors remaining unchanged. However, biomass growth may to some extent be counterbalanced by a predicted decrease in water temperature and an improvement in water quality with the cessation of IBT releases. Considering that current nutrient concentrations, together with warm water conditions promote the growth of periphyton during the summer months when flood disturbances are low, the peak summer biomass may thus in fact decline as temperatures and nutrients are reduced. By contrast, an increase in bed stability and a loss of flow variability which currently control periphyton accumulation during the winter months is likely to result in an increase in periphyton biomass during the winter. Thus, the current seasonal variability in periphyton biomass is predicted to be reduced. Whereas the periphyton community is currently characterised by single-celled green algae and diatoms, it is likely that stable conditions will promote a shift to a more complex community, dominated by erect, stalked and/or filamentous taxa. Should phosphorus concentrations increase (as is predicted), then it is possible that the community may shift towards one that is dominated by nitrogen fixing blue-green taxa.

There will probably be less inundation of the macro-channel as a result of flood events – this will be reduced to periods of artificial flow releases. Even then, the inundation of the macro-channel is likely to be less extensive, due to the decreased width of the low flow channel. This will lead to the loss of backwaters and the possible stranding of marginal vegetation, which has been seen to be an important biotope for the foothill river invertebrates. This might be balanced by increased growth of marginal vegetation due to the decreased size and frequency of floods.

Should the channel evolve into a less dynamic, narrower channel with some armouring, this might lead to a loss of hydraulic refugia ("localised areas where hydraulic forces acting on the substratum remain low during a flood event" (Ractliffe et al., 2006)) that are important for the persistence of invertebrates during and after high flow events. Channel maintenance flows (intra-annual floods) are important for maintaining channel heterogeneity, especially in these cobble foothill reaches of the Berg River.

No indigenous fish populations are thought to exist downstream of the dam – at least no viable populations.

As to the impacts of the dam on alien species in the river, one can expect a major reduction in fish abundance in the section of river between the dam and the Franschhoek tributary and possibly some change in species composition. Numbers of small mouth bass in this section of river are likely to decline dramatically due to absence of suitable habitat for much of the year, accompanied by a possible increase in the abundance of mosquito fish which are smaller and probably better suited to the available habitat.

A detailed list of the likely impacts of these changes on different invertebrates’ taxa and guilds is provided in Appendix 1.

### 2.7.2 Lowland river

The following changes are expected at the lower sites – BRM4, BRM5 and BRM6 – as a result of the construction of the Dam, and assuming that strict controls over irrigation abstraction are exercised:

At a monitoring site near Paarl (BRM3, not included in biological monitoring), 70% of the MAR will be available, indicating that the tributaries entering the river between BRM2 and BRM3 lead to considerable recovery in the main stem in terms of annual runoff. This increases to 78% of the present MAR available at BRM4, about 70 km from the Berg River Dam, which demonstrates the significantly less runoff to the system contributed by tributaries entering the river between BRM3 and BRM4. Some 83% and 87% of the
present MAR will be available at BRM5 and BRM6 respectively, with the Berg River Dam operational, and with artificial releases.

At BRM4, it is estimated that the main channel width will decrease by 15%, from the current bank full width of 25 m, to 21 m in future. The main channel depth will become shallower by about 12%, and the longitudinal slope of the river will decrease, by increasing the sinuosity of the river. The new equilibrium is typically reached 7 to 10 years after completion of a dam.

In summer, these changes in flow will result in pools becoming dominant, but a diversity of biotopes would be present. The predicted narrowing of the channel, however, may result in a reduction in the extent of marginal biotopes such as slack waters and backwaters. Biotopes would generally be deeper than those recorded presently, but velocities would remain similar to present day conditions. However, should the present level of illegal abstraction continue, then typical summer discharges at this site may be reduced to zero. Under this scenario, the site would be characterised by isolated backwaters with stagnant pools, but all other biotopes would disappear.

In winter, there will be little change in depths and velocities in the different biotopes, and in the configurations of biotopes at the site: although discharge will be reduced, the narrowing of the channel is likely to compensate for this, and depths are likely to be maintained as they are.

From a water quality perspective, because the dam will reduce the magnitude of flow contributed from the upper catchment, it will thus increase the relative contribution of loads from tributaries and point sources such as WWTFs and the IBT, which will be released near to the Wemmers River.

Nearer to Paarl, increased nutrient enrichment, in terms of both phosphorus and nitrogen, is expected as the Franschhoek tributary is presently associated with higher nutrient levels than the Berg River at G1H004, and its relative contribution to discharge in the Berg River will increase in future, thus increasing its relative contribution to nutrient loads. The Paarl WWTW is estimated to result in a 5500% summer increase in phosphorus loading in the Berg River downstream of the effluent discharge point, and a 670% winter increase. By the same token, the lower discharge in the river and reduced flooding will result in a lower export of phosphorous and other loads from these reaches into the downstream reaches and its retention in the upper river reaches.

The projected increase in pool habitat in the lower parts of the river to BRM4 will favour species such as bluegill sun fish *Lepomis macrochirus* and large mouth bass *Micropterus salmoides*, at the expense of those that prefer faster flowing waters (e.g. *M. dolimieu* and *O. mykiss*). *C. gariepinus* seems to be spreading rapidly through the Berg system since it was first noted in 2000. As it increases in abundance it is likely to take a heavy toll on populations of other alien species, an effect which may well eclipse any effects of the dam.

BRM4 is basically the last point on the river where relatively large changes in terms of the fluvial morphology are expected due to the Berg River dam construction.

At the lower sites, BRM5 and BRM6, velocities during base flow conditions are unlikely to change significantly although it is likely that less slack water habitat will be available and depth will decrease marginally. Also, sediment transport will be reduced at BRM5 as floods are reduced or attenuated with distance downstream.

The increase in relative contribution to flows by the tributaries (as a consequence of less water from the upper river) will be small – for example the Klein Berg (increase in contribution from 14 to 17% of total flow at the confluence), and the Sandspruit (contribution will increase from 0.4 to 0.5% of total flow). However, the high TDS concentrations in rivers such as the Sandspruit cannot be discounted on the grounds of their low proportional contribution - the Sandspruit is contributes high volumes of TDS to
the Berg River and even a slight increase in the relative contribution of the tributary by volume to the main river system would result in an exaggerated increase in TDS loading in the system.

The highest periphyton biomass was recorded on soft sediments in the slower flowing slack waters at BRM5 and BRM6 during the summer. With a narrowing of the channel and a potential decrease in the availability in slack water biotopes, it is possible that summer periphyton biomass may decline. Nevertheless, a reduction in flow variability and the size and frequency of floods at BRM5 might result in an increase in periphyton biomass, particularly epiphytic algae attached to marginal vegetation. Should salinity increase significantly at these lower sites, it is likely that the community will shift to one that is dominated by fewer, hardier taxa that are tolerant of higher salinities.

Most of the invertebrate taxa found at these sites were able to inhabit a range of biotopes, so a decrease in invertebrate diversity is unlikely. A loss of the flows necessary for the shifting of sandbanks noted during the monitoring period could lead to a decrease in channel heterogeneity, the loss of some habitat patches and so a possible decrease in invertebrate density.

In the lower portion of the river the Matjies River will increase in proportional contribution from 15 to 17.6% of flow in the main river. Since this river contributes highest loading rate into the Berg River of all tributaries, a slight increase in TDS may be anticipated in Misverstand Dam as a result. Modelling on the basis of the revised FLOSAL model suggests that the increase in TDS concentration will typically be in the order of 50 to 60 mg/l.

Calibration of the ACRUSalinity model for the Berg River should allow more accurate quantification of the impact of these slight increases in proportional contribution of the most saline tributaries on TDS concentrations in Misverstand and thus on the lower Berg River. Total loads delivered to the estuary should also be reduced as a result of the lower flows, although these will not be as pronounced as in the upstream reaches, where the influence of flow reduction from the dam will be more apparent. Lower flows there may also however increase residence time within the estuary, making these compounds more biologically available.

2.8 IMPLICATIONS FOR RESEARCH AND MONITORING

This chapter has identified the likely implications of the Berg River Dam for the ecosystem components included in the study, based on the predictions of the hydrodynamic modelling.

It was beyond the brief of this project, however, to compile a quantitative model of ecosystem functioning regarding the other study components. Recommendations for monitoring of a large variety of parameters in the river are summarised in Chapter 4 of this report. However, it is important that the design and implementation of the monitoring programme set up clear hypotheses about the magnitude of change expected, as a basis for testing and refinement of our understanding of ecosystem functioning in the Berg River. This understanding is ultimately the only basis for sound resource management.

2.9 REFERENCES


Western Cape System Analysis. Berg River Invertebrate Study. Department of Water Affairs and Forestry Report No PG000/00/1392.

Department of Water Affairs and Forestry. 1996(a).


CHAPTER 3 – ESTUARY CONCEPTUAL MODEL

J.K. Turpie & B.M. Clark

Based on workshop inputs by:

Lara Atkinson, Gerrit Basson, Guy Bate, Julia Beck, Charlie Boucher, Barry Clark, Gerald Howard, Lee Jones, Roger Parsons, Geordie Ratcliffe, Eckart Schuman, Susan Taljaard, Jane Turpie, Henk van Kleef and Tris Wooldridge
3.1 INTRODUCTION

3.1.1 Background

The Berg River estuary is one of only four perennial estuarine systems on the west coast of South Africa, and one of the largest of the country’s approximately 258 functional estuaries. It is a river-dominated estuary, and is one of only three estuaries in which muddy sediments are deposited seaward of the mouth (Cooper 2001). It is also fairly unusual in having a very large supratidal floodplain in association with the upper reaches of the estuary. Because of its physical type rarity, large size and high diversity and abundance of biota, the estuary is rated among the top three estuaries in South Africa in terms of its conservation importance (Turpie et al. 2002, Turpie et al. 2004).

Freshwater flows into the estuary are considered to have a major influence on the functioning and biota of the estuary and its associated floodplain, and hence vital to the future conservation of this system. However, the quantity and quality of freshwater flows is likely to be affected by the construction of the Berg River Dam. This study was commissioned as part of a baseline study which will inform the definition of the freshwater reserve for the estuary (minimum quantity and quality of freshwater flows to be provided after construction of the Berg River Dam) and against which impacts on the estuary will be monitored following dam construction.

The freshwater reserve allocated to the Berg River estuary will depend on the estuary’s classification, which is carried out using Resource Directed Measures (RDM) methodology. Based on ecological, social and economic considerations, the estuary will be assigned a class (A to D) which will effectively describe the desired future state of health of the system, which in turn determines the amount and quality of water that will reach the system (and the associated temporal dynamics). The classification is accompanied by a detailed description of the desired state of various components (called “resource quality objectives”). Continued monitoring will determine whether the resource quality objectives have been met.

Understanding the trade-offs involved in water allocation to an estuary requires a good understanding of how patterns of flow and water quality affect the functioning and characteristics of that estuary. The ecological implications of changes in flow are usually estimated by physical and biological scientists as part of the RDM (reserve determination) process. This entails a study of the estuary, modelling of physical conditions to arrive at an estimated natural condition, estimation of the current state of health of the system relative to natural conditions, and description of the probable state of health of the system under several potential water allocation scenarios. Specialists estimate the state of their components under natural conditions and alternative scenarios based largely on their “gut-feel”. Although the process is largely unconscious, this involves integrating multiple relationships between multiple variables to estimate changes such as change in the biomass of a particular group of organisms. The assumptions involved have never actually been described by the specialists. This means that much of the precise rationale is lost and assumptions cannot be challenged or tested.

A common understanding of the way in which different components of the Berg River estuary interact with one another will greatly enhance our ability to predict how different components of the ecosystem respond to changes in the quantity or quality of freshwater inputs. This involves teasing apart flow-related influences from other factors that influence an estuary’s biodiversity. This, in turn, will improve the confidence levels in decision processes which result in the classification of this and other estuaries. It will also help to design an efficient monitoring protocol for the Berg River estuary that will concentrate on key variables and that can isolate flow-related effects from other effects.
3.1.2 Aims of the study

The aim of this study was to build up a conceptual model of the estuary and floodplain in order to provide a simplified picture of the linkages and interactions between different physical and biotic components of the system, with particular emphasis on the flow- and water quality-related linkages.

3.1.3 Approach

This study was based on the work that has taken place on the Berg River estuary as part of the three-year baseline study. Specialists undertaking the work were invited to present their preliminary findings and their understanding or perception of the main factors influencing their component at a workshop. These included:

- Catchment hydrology (Gerald Howard, presented by Geordie Ratcliffe)
- Groundwater (Roger Parsons, presented by Henk van Kleef)
- Estuarine hydrodynamics and sedimentology (Julia Beck, Gerrit Basson)
- Estuarine water quality (Eckart Schuman, Susan Taljaard)
- Micro algae (Guy Bate)
- Macrophytes (Lee Jones, Charlie Boucher)
- Invertebrates (Tris Wooldridge)
- Fish (Barry Clark, Lara Atkinson)
- Birds (Jane Turpie)

Workshop participants were then asked to participate in the construction of a model sketch of the Berg River system by dividing their component into subcomponents and identifying the principle drivers of each. Biota were described in terms of abundance or biomass. The sketch, or draft conceptual model, was then used in conjunction with the existing information on the system and the estuarine literature as the basis to derive a conceptual model of the Berg River estuary. This involved describing assumptions about components of the ecosystem or relationships that had hitherto not been properly described, due to lack of data or perceived importance. The conceptual model and accompanying draft document was then re-circulated to the specialists involved in the baseline study for their comment, particularly on some of the more novel assumptions generated about their components.

3.1.4 Structure of the report

After defining what is meant by a conceptual model, the report provides a brief description of the catchment and estuary. A brief outline of each component of the ecosystem is then provided, with emphasis on the factors that influence it. More detailed descriptions of the components are provided in the final baseline study report. Finally, the linkages between the different components are pulled together to construct an overall conceptual model of the estuary, with flow as the ultimate driver. Non-flow related influences are described separately. Finally, the implications of the findings for reserve determination and monitoring of the impacts of the Berg River Dam are discussed.

3.2 WHAT IS A CONCEPTUAL MODEL?

Models are particularly useful tools for synthesising data, exploring how systems function and predicting the effects of human activities on the environment (Underwood 1990, Constable 1999). They need not be complex in order to make predictions about ecological changes. Jorgensen (1986) identifies three “basic” classes of ecological model (Figure 3.1): (a) conceptual, (b) deterministic and (c) statistical models. These different types of models are designed to generate different levels of predictions.
Different levels of prediction depend on which of the following elements are specified (Peters 1991, Constable 1999):

- The direction of the change in condition;
- The magnitude of the change;
- The probability of the change occurring

Qualitative predictions give the direction of an effect, and involve a simple statement that the condition will change (usually in a specified direction) e.g. deposit-feeding organisms will increase growth and reproductive output with an increase in nutrient rich particulate in their local environment. Semi-quantitative predictions specify the magnitude and direction of effect. They generally specify the minimum magnitude and direction of an effect that is considered important, e.g. deposit-feeding organisms will at least double reproductive output with a 20% increase in nutrient rich particulates in the local environment. Quantitative predictions specify direction and magnitude of an effect expected for prescribed conditions as well as a probability of occurring, the probability encapsulating natural variability and uncertainty in the knowledge of the prescribed conditions, e.g. probability of 0.5 (50%) that deposit feeding organisms will at least double reproductive output with a 20% increase in nutrient rich particulates into the local environment.

(a) Conceptual

(b) Deterministic

(c) Statistical

Figure 3.1  (a) Conceptual, (b) deterministic and (c) statistical models and their accompanying predictions for the example of the effect of an increase in nitrogen on the biomass of deposit feeders. The first column shows a graphical representation of each model and the second column shows the probability densities of the predictions arising from the respective models. After Constable (1999).
3.3 THE BERG RIVER CATCHMENT AND ESTUARY

3.3.1 The Catchment

The Berg River Catchment covers an area of almost 9000 km$^2$ in the Western Cape Province, and is subdivided into 12 quaternary catchments ranging in size from 125 km$^2$ near the headwaters to 2000 km$^2$ in the drier western parts of the catchment (Figure 3.2). The river runs northward for 285 km, and drains into St. Helena Bay on the west coast of South Africa, where it interacts with the Benguela upwelling system (Shillington 1998). Much of the catchment is relatively flat, except in the uppermost reaches.

3.3.2 Location, shape and extent of the estuary

The Berg River estuary extends about 69km from the mouth, based on the extent of tidal influence (Slinger & Taljaard 1994), although seawater does not penetrate this far (Schumann 2007). Tidal range at the mouth is 0.5 – 1.5 m, in the middle of the estuary (Railway Bridge) is 0.2 – 0.8 m, and in the upper estuary (Jantjiesfontein), is less than 0.2 m. Tidal flows in the lower estuary (at the R27 bridge) are 50-100 m$^3$.s$^{-1}$ and 200-300m$^3$.s$^{-1}$ during neap and spring tides, respectively (Beck & Basson 2007). Tidal action attenuates rapidly upstream, and inter-tidal areas occur mainly downstream of the Railway Bridge. Upstream of the Railway Bridge, the estuary is flanked by a seasonally-inundated floodplain that varies in width from 1.5 to 4 km. The estuary, including floodplain, is estimated to cover an area of 61km$^2$. The estuary’s shallow gradient and extensive floodplain make it atypical in relation to most South African estuaries (Schuman 2007).

The main channel at Veldrif is about 100-200 m wide, becoming progressively narrower and shallower upstream (Figure 3.3). Depth is about 3-5 m on average, up to 9 m in places. The total volume of the estuary is estimated to be about 12 Mm$^3$ (Beck & Basson 2007).

Figure 3.2 The catchment of the Berg River. Main river flows south to north (Source: Parsons 2004).
In 1966, a new estuary mouth was cut through the sand dunes and stabilised between concrete walls (Slinger & Taljaard 1994). The original mouth has silted up and the former channel currently forms a blind arm or lagoon running parallel to the coast. The lower 4 km of the estuary is also dredged to a depth of at least 4 m to allow for boat navigation. However, these developments are not considered to have had a significant effect on the hydraulics and sediment transport in the estuary, except at the mouth. Bridges lead to some local scouring of banks. Much of the lower estuary floodplain has been reclaimed for salt production.

### 3.4 PATTERNS OF FLOW INTO THE ESTUARY

The natural runoff from the catchment amounts to 931 Mm$^3$.y$^{-1}$, nearly half of which (45%) is generated in the top three quarternary catchments which cover 7% of the area. There are already two major dams in the catchment - the Wemmershoek Dam (66 Mm$^3$) and the Voelvlei Dam (170 Mm$^3$), and numerous small farm dams. These, together with afforestation of catchment areas, have reduced the runoff to some 682 Mm$^3$.y$^{-1}$. Flow and quality characteristics have been severely modified, with dry season releases, interbasin transfers and agricultural return flows exacerbating the effects of abstraction from the system.

Precipitation is largely cyclonic (associated with frontal weather systems), occurs mainly in April to October, and ranges from 300 mm along the coast to 2600 mm in the southern mountains. Evaporation is five times higher in summer than winter (about 250 vs 50 mm). The estuary is fed primarily by surface flows, and the floodplain also benefits directly from rainfall. Groundwater depth ranges from about 3 to 6m below the estuary and floodplain, with levels fluctuating by about a metre between summer and winter. Groundwater discharge into the estuary is considered to be relatively constant and unlikely to be affected by the construction of the Berg River Dam.

![Bathymetry of the Berg River estuary](image-url)

**Figure 3.3** Bathymetry of the Berg River estuary. (Source: Beck & Basson 2007).
There are five critical components of the flow regime that regulate ecological processes in rivers: magnitude, frequency, duration, timing (or predictability) and rate of change (flashiness) of hydrological conditions (Poff et al. 1997). Increasing from the upper to lower reaches; low flows in the Berg River vary from 0.2 to 2.0 m$^3$.s$^{-1}$ in summer (Nov-Feb) and 4 to 15 m$^3$.s$^{-1}$ in winter (May-Aug). During floods, flows reach 150 to 600 m$^3$.s$^{-1}$ along the river. There is also considerable interannual variability (Figure 3.4). Note that the smallest flow on record over the last 20 years actually occurred during the 3-year baseline monitoring period.

![Figure 3.4](image-url)  
**Figure 3.4** Interannual pattern of flow at Misverstand (Source: Schuman 2007).

![Figure 3.5](image-url)  
**Figure 3.5** Relationship between annual rainfall and total annual volume of flow at Misverstand dam (Source: Schuman 2007).
Flows recorded at Misverstand Dam (some 100km upstream of the head of the estuary) are well correlated with rainfall in Franschhoek, both interannually (Figure 3.5), and seasonally. While flows are largely natural in the upper reaches, there are substantial decreases in downstream flow during the winter months compared with the natural condition, and increases in summer flow along parts of the river.

However, by the time the river flows through Drieheuwels (gauging station G1H013), some 145 km from the mouth, flows are lower in all months compared to the natural state (Howard & Ractliffe 2007), and overall flow into the estuary has been reduced by 30% (Basson & Beck 2007).

Flows into the estuary have not been recorded, but have been modelled on the basis of G1H013 data, coupled with estuary bathymetry data (Beck & Basson 2007). An estimated 604 Mm$^3$ flows into the estuary annually on average. Current flows into the estuary range from an average of 1.5 m$^3$.s$^{-1}$ in summer to an average of 35 m$^3$.s$^{-1}$ in winter (Figure 3.6). Flows of >25 m$^3$.s$^{-1}$ probably make up less than 15% of the total volume of water entering the estuary, based on data for BRM 6 below the Misverstand Dam (Beck & Basson 2007). A typical annual flood peak into the estuary is about 90 m$^3$.s$^{-1}$, with a 1:10 year flood measuring about 622 m$^3$.s$^{-1}$ (Beck & Basson 2007). The impact of a flood depends on the base flow, with a greater flooding impact when base flows are higher (Beck & Basson). For example, Beck & Basson (2007) report that under normal tidal conditions the area inundated by a 290 m$^2$/s flood is 30.4 km$^2$. However, if the starting water level in the upper estuary is high (say 1.8 above MSL), the flooded area could increase to 65.6 km$^2$. By comparison, a much larger (3x larger) flood of 893 m$^3$/s with a starting water level of 1.45 m above MSL in the upper estuary would only flood an area of 55.5 km$^2$. This has important implications for the timing of artificial flood releases in terms of achieving maximal impact.

### 3.5 THE INFLUENCE OF FLOW ON PHYSICO-CHEMICAL CHARACTERISTICS

#### 3.5.1 Water levels

While water levels in the lower estuary are predominantly influenced by tidal fluctuations, while those in the upper estuary (e.g. Jantjiesfontein) are predominantly influenced by freshwater flows and longer period variations in the sea level that propagate up the estuary (Schuman 2007). These longer period variations in the sea level are amplified as they enter the estuary and propagate almost undiminished all the way to the top of the estuary, which stands in marked contrast to the tidal signal that decays rapidly on its way upstream (Figure 3.7). These longer period variations can be responsible for water level changes of more than 0.5 m at the top of the estuary, which is generally considerably greater than the tidal signal at this point. At Kliphoek (~30 km from the mouth) (above which most of the significant floodplain areas of the Berg River estuary are located), the magnitude of the longer term variations in water level roughly matches that of the tidal signal (Figure 3.7). Note therefore, that these longer term variations in sea level are likely to contribute significantly to the “starting water levels” referred to in §3.4 above, and that inundation of these floodplain areas is likely to be a function of the combined effects of river flow and these longer term variations in sea level rather than river flow and tidal height as might be expected.
Figure 3.7 Measured water level relative to msl at Saldanha Bay, Laaiplek, Kliphoek and Jantjiesfontein. The blue lines show the longer-period fluctuations, while the red ellipse highlights an instance where the height of the high tide on one day is actually lower than the height of the low tide on the following day due to the longer period fluctuations in water level. (From Schumann 2007)

Figure 3.8 Measured sediment d50 distribution along the length of the estuary (Beck & Basson 2007)
3.5.2 Influence on sediments and bathymetry

There is little data on the sediments of the Berg estuary or on historical sedimentation processes. Estuaries contain a mixture of river and marine sediments, the balance of which is determined by the size of the tidal prism (amount of water moving in and out of the estuary during a tidal cycle), riverine base flows and floods. The size of particles that can be transported from the catchment increases with increased velocity, and larger particles are deposited before small particles as flow is reduced. Base flows carry relatively little sediment, mostly fine silts, and this is deposited when freshwater flows are slowed by the pushing effect of incoming sea water. Organic matter also flocculates out of the freshwater when it mixes with salt water. These processes probably lead to accumulation of fine sediments in the lower to middle estuary, so that the channel and inter-tidal areas become muddier and shallower with time (Figure 3.8). Floods carry a lot of silt from the catchment, and this is deposited wherever floodwaters slow down significantly, such as on the floodplain. Floods scour away the sediments that have built up in the channel and in the lower inter-tidal areas, and very large floods may scour the floodplain as well. The area of scouring versus deposition is likely to depend on the size of the flood.

We hypothesise that under normal conditions the floodplain and inter-tidal areas of the Berg estuary will increase gradually in height and muddiness over time, but that the accumulated sediment is washed away sporadically by large floods (Figure 3.9). The size of the flood required to do this depends on the amount of sediment that has built up. Floods may scour some of the deposited material, or they may be large enough to "reset" the system. If base flow is reduced, the build-up of sediments will be slower, but if floods are also reduced then scouring is weaker and off-channel areas will become higher and drier over time (Figure 3.9). Vegetative encroachment onto the floodplain and inter-tidal areas will exacerbate this by preventing scouring of these areas (by reducing flow speed), leading to a gradual reduction in inter-tidal area. Floodwaters would be expected to be increasingly channelled, possibly even deepening the channel over time.

![Figure 3.9](image-url) (a) Hypothetical build-up of sediments on inter-tidal areas and floodplain after a major flood, shown in cross-section, and (b) build-up of and scouring of sediment at a particular spot over time under natural conditions (solid line) and under reduced-flow conditions (dotted line).
3.5.3 Influence of flow on turbidity

The relationship between flow and sediment load also means that there is a positive relationship between flow and turbidity of inflowing water. Since seawater is comparatively clear, there is a negative relationship between estuarine salinity and turbidity (Figure 3.10). Thus, reductions in freshwater flows lead to decreased turbidity and increased light penetration in the system (largely a seasonal effect). Note also that turbidity maxima were also frequently recorded at the head of the salt intrusion.

3.5.4 Influence of flow on estuary water quality and nutrients

The estuary is very well mixed. During the summer low-flow period, saline water penetrates the estuary up to at least 40 km from the mouth, depending on the tidal state. Freshwater inflow to the estuary during winter is sufficient to push the salt water entering the estuary back to within 10 km of the mouth (Schumann 2007) (Figure 3.11).

River inflow and sea level together determine the penetration of seawater into the system, thereby determining the salinity profile of the estuary, and the extent of saltwater penetration for any given freshwater inflow depends on tidal phase (spring vs. neap and ebb vs. flood tides). Although pushing back and forth with the tides, salt water tends to work its way up the system over the dry season, penetrating further upstream with each tidal cycle. The system then resets with winter floods.

The estuary is well-oxygenated throughout the year, but is slightly lower in summer (down to about 5 mg/l in the upper reaches) than winter (9-10 mg/l) (Schuman 2007). Low oxygen water occasionally enters from the sea following intense upwelling events, which can very occasionally reach extreme conditions (Pitcher & Calder 2000).

Temperature is fairly uniform along the estuary during winter, typically 12-15°C (Schuman 2007). In summer, the river water is warmer than the sea, and temperatures are typically above 20°C throughout the estuary except in the lowest reaches. Temperature in the lower estuary varies with tidal state, and can be as low as 12°C after up welling at sea.
Nitrogen enters the estuary in both sea and freshwater, with sea inputs dominating in summer (low flow season), and river inputs dominating in winter (high flow season) (Clark & Taljaard 2007). Little change is evident in nutrient inputs to the estuary during the low flow season between 1990 and the present day (where inputs from the sea are clearly dominant – Figure 3.12. However, nutrient inputs during the high flow season (where riverine inputs are clearly dominant) have escalated dramatically between 1975 and the present day (Figure 3.12).

Total nitrogen concentration at the head of the estuary has increased from less than 300 ugl-1 prior to 1980 (which was roughly equal to the input from the sea) up to almost 2000 ugl-1 in 2005. Thus, riverine inputs of nitrogen is overarchingly dominant, nitrogen content being highest in the upper reaches in winter, decreasing downstream as it is used up, and exhibiting an inverse linear relationship with salinity. Under low flow conditions, nitrogen concentration is highest at the mouth because of nitrogen input from the sea and decreases upstream.

Under natural conditions, inorganic N and P inputs to the estuary from the Berg River was probably low considering that much of the catchment, especially that part from which perennial flow are derived, is comprised of Table Mountain Sandstone (TMS) which typically leaches very few ions (Bath 1993, Day 2007). Over time, human activities in the catchment have increased runoff of nutrients into the Berg River, hence increasing contributions from this source to the estuary. Principal amongst these have been land clearing (mostly for agriculture), application of artificial fertilizers, discharge of human wastes, and animal production (Bath 1993, Day 2007).
Sea water is the main source of phosphate in the estuary, with reactive phosphate levels being correlated with salinity, but the linear correlation suggests that this is not a limiting nutrient in the estuary, since there is no evidence of it being used up (Clark & Taljaard 2007).

Silicate levels are higher in freshwater than seawater, and declines linearly with salinity, suggesting that it is simply diluted by seawater and is not utilized significantly in the estuary (i.e. not limiting; Clark & Taljaard 2007).

Key factors influencing nutrient concentrations in the estuary are catchment activities and upwelling conditions. The degree to which nutrients in the catchment are moved into the river may be positively influenced by rainfall, especially early on in the rainy season. These nutrients would stay in the system for longer under reduced flow scenarios. Flow rates could theoretically also affect the amount of marine nutrients that can penetrate from the sea (important during summer upwelling periods), but flows are generally too small in summer to push seawater back.

In addition to the external nutrient sources, there are a number of in situ chemical and biochemical processes that influence nutrient supplies to the Berg estuary estuaries.
These include remineralisation (the process whereby nutrients N and P are released from ‘labile’ organic matter through heterotrophic bacterial decomposition) and dissolution (a process where certain marine organisms with siliceous skeletons die, settle to the bottom and undergo dissolution, releasing Si into the water.

Anthropogenic inputs of nutrients along the estuary channel are probably also important, and include run-off from adjacent farmland (which is also an important anthropogenic source affecting concentrations in river inflow), wastewater from human settlements along the banks of the estuary concentrated mostly around the mouth and effluent from industries (e.g. fish factories) situated near the mouth of the estuary. Wastewater (domestic and industrial) tends to be very rich in both nitrogen and phosphorous containing compounds and can act as an important contributor of these nutrients in an estuary.

Our understanding of the influence of river inflow on physical factors and nutrients is summarized in Figure 3.13. Of the three water inputs into the system, groundwater is considered insignificant (groundwater flow is mostly effluent in the lower reaches of the Berg River – Parsons 2007), seawater is a given, and river inflow can be seen as the main driver of estuarine conditions.

Salinity is assumed to decrease with increased flow, but has little effect at low flows when the tidal flow is stronger. Higher flows push salt water out of the estuary.

Flow indirectly affects intertidal area and its muddiness through its impacts on deposition and scouring (see Figure 3.13 above). Increased flow leads to increased turbidity of the estuary due to sediment transportation, with water of higher velocity carrying more sediment with it. N is assumed to be the most important nutrient, and this increases in the estuary with increased flows. The difference is felt mainly in winter when freshwater contains more N than seawater. Detritus increases with increasing flow, as it is being transported down river in freshwater. This introduces another source of N. Finally, the lower the flow, the higher the water residence period is in the estuary (Figure 3.13).
3.6 BIOTIC COMMUNITIES AND FLOW-RELATED DETERMINANTS OF THEIR STRUCTURE AND PRODUCTIVITY

3.6.1 Micro algae

The micro algal community of the Berg estuary appears to be typical of South African estuaries in terms of community composition, and reflects the physical conditions of the estuary. This group includes phytoplankton communities which occupy the water column and benthic micro algae communities, the latter including communities living on plant matter (epiphyton), mud (epipelton) and stones (epilithon). Micro algae take the form of flagellates (water column only), blue-green algae (benthic only) and diatoms (both).

Very little is known of the micro algae of the Berg River estuary, and the community composition had not been adequately described at the time of this study (Bate presentation).

Studies on the Berg and other South African estuaries shows that micro algal abundance is strongly influenced by water retention time, which determines how much of the production is retained in the system rather than being flushed out. In the Sundays Estuary, the highest phytoplankton biomass occurred when flow rate into the estuary was equivalent to a "residence time" of 3 spring tidal cycles (or 42 days). In the Gamtoos, highest chlorophyll $a$ concentrations occur in the zone of 10 – 15ppt, which has been termed the River Estuary Interface (REI) zone (Snow 2000). This probably occurs because of a combination of high enough nutrient levels and high enough salinity to support marine micro algae. Residence times are also likely to be highest in the middle reaches of the estuary.

Applying the “42-day optimum” rule, flow rate required to support the maximum biomass $\pm$ 10% is $3.3\ m^3.s^{-1}$. Actual flow data show that optimum flows in the Berg estuary only occur for 6% of the time, and are exceeded 84% of the time at present. This implies that by decreasing the flow, the estuary might increase its productivity.

Patterns of nutrient abundance in the estuary give some indication of which nutrients may be limiting for primary production. In winter, the decay of nitrates is linear along the estuary, suggesting it is not being used up.

In summer, there is an exponential decay towards the middle reaches from both ends of the estuary, which suggests that it is being used up by primary production. Nitrogen appears to be a limiting nutrient in the middle reaches of the estuary during summer.

Thus, during high flow periods, nutrients are plentiful, but the system is more turbid, which means that light could be limiting for phytoplankton. During summer low flow periods, the water is clear but nutrients could become limiting.

Micro algal abundance appears to be higher in winter than summer, in spite of lower water retention time, lower temperatures and higher turbidity in winter.
In winter, chlorophyll a concentrations do not vary up the length of the estuary, averaging 4.1 and 6.1 μg/l at the mouth and head of the estuary respectively. In summer, concentrations varying strongly up the length of the system, starting at around 0.3 μg/l at the mouth, increasing to around 6.6 μg/l at the head of the estuary (Bate & Snow 2007). This suggests that micro algal biomass is driven mainly by nutrient availability. Interestingly, micro algal abundance appears to be particularly high in autumn (with water becoming visibly green, pers. obs.), when nutrients have been presumably flushed into the system by freshettes but flows are still low and water retention is still high.

Nevertheless, it can be hypothesised that although micro algal abundance is lower in summer, it makes a greater contribution to overall production in the estuary at this time because the biomass is more available to higher trophic levels as it occurs in slower-moving water. Most of the winter production is most likely exported to St Helena Bay.

Note that it might be assumed that more of a certain habitat may lead to more of a particular component of micro algae.

However, the spatial distribution of productivity is not of concern at this stage, only the overall level in the system. It is assumed that the habitat determines the way the productivity is used further up the trophic chain, so the spatial element is captured later on.

Figure 3.15 Hypothetical relationships between nutrients, salinity and micro algal abundance (chlorophyll a concentration), ceteris paribus.

3.6.2 Macrophytes

The macrophyte communities of the Berg River estuary have been described by several authors (Harrison & Elsworth 1958, McDowell 1993, O’Callaghan 1994, Boucher & Jones 2007). The plant communities are largely distinguishable in terms of sub tidal, intertidal and floodplain communities.

Sub tidal vegetation is dominated by Eel Grass Zostera capensis in the lower estuary, which is replaced by Fountain Grass Potamageton pectinatus in the fresher upper reaches.

Both Zostera and Potamageton also extend into intertidal areas, collapsing into dense mats at low tide. Structurally and functionally similar, these communities are largely separated by their salinity requirements.

The extent of these two communities is strongly linked to flow, in that they readily replace one another when salinity distribution changes for any significant period.

The intertidal area is largely within saline reaches of the estuary. In the lower estuary, intertidal Zostera competes for space on mudflats with the various filamentous algae.
The presence of Cladophora is highly seasonal, proliferating in spring and drying up over summer before being washed out of the estuary in winter (Kaela & Hockey 1991, Clark et al. 2007).

At higher elevations, Zostera gives way to low-growing intertidal salt marsh. Salt marsh composition is strongly zoned by elevation (i.e. degree of tidal inundation), with characteristic species progressing from Cord Grass Spartina maritima at lower elevations to Southbos Bassia diffusa, Daisies Cotula spp and Brakbos Sarcocornia perennis.

Above the intertidal area of the lower estuary, the intertidal salt marsh gives way to supratidal salt marsh, dominated by a characteristic Brakbos Sarcocornia pillansii and interspersed with bare patches. These areas are typically flooded in winter.

Further upstream in the fresher reaches of the estuary, the narrow intertidal and adjoining floodplain areas are mainly occupied by sedge marsh, dominated by Schoenoplectus spp. and Cyperus textiles or by taller reed marsh, mainly monospecific stands of Phragmites australis. Reed marsh tends to replace sedge marsh on the silt-rich soils which are deposited on inner river bends. Behind the reed marsh, many of the inner river bends also contain extensive lower-lying sedge marshes that are flooded during winter, creating sheltered water bodies, hereafter referred to as backwater areas.1

The floodplain also contains numerous pans. These are either open pans, with scattered saltpan plants such as Salicornia meyeriana, or sedge pans, which are characterised by monospecific stands of sareegras Juncus maritimus and Waterblommetjie Aponogeton distachyos. The latter are usually at a lower elevation and tend to be linked to the river channel by drainage lines.

At higher elevations, the floodplain is occupied by a xeric floodplain community which contains elements of terrestrial strandveld and is dominated by succulents, such as Aizoaceae, and Asparagaceae, as well as other drought-adapted species. This community depends on annual floods to reduce salinity levels and deposit soils.

In the uppermost reaches of the estuary, the riverbanks are lined by riparian woodland, with species such as Salix mucronata, Rhus tomentosa, Olea spp. and Metrosideros angustifolia. Alien species such as Eucalyptus, Acacia and Populus spp. are also common.

The way in which the two main flow-related variables act together to structure the vegetation communities on the estuary and floodplain is summarised in Figure 3.16.

Together with sedimentation and erosion processes, the plant communities described above play a major role in determining the nature of the estuary as habitat for other biota. Three main animal groups are described for the Berg River estuary: the invertebrates, fish and birds.

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1 Note that this habitat is not specifically named as such in the botanical reports but is a functionally very distinct habitat that resembles the backwater habitats associated with large rivers.
3.6.3 Invertebrates

Invertebrate communities include the zooplankton and benthic invertebrates, the latter being separated into intertidal and sub tidal benthos. Hyperbenthos is the temporary community formed when benthic invertebrates move into the water column just above the sediment.

The zooplankton in the Berg estuary are numerically dominated by copepods (~98%), the remainder being made up of fish larvae, brachyuran larvae, mysid shrimps, amphipods and other organisms (Wooldridge 2007). *Pseudodiaptomus hessei* is the most abundant zooplankton species and is a major component in the diet of zooplanktivorous fish. Its distribution follows the typical pattern found in freshwater rich estuaries, being most abundant in the upper-middle reaches. The euryhaline zooplankton community composition is similar to estuaries in other biogeographical provinces, possibly because of the general similarity of water temperatures within seasons in middle and upper estuarine reaches.

*Schoenoplectus scirpoideus* Sedgeland   Photo: Lee Jones
Figure 3.16  Salinity and degree of inundation as the main drivers of estuarine vegetation communities

The hyperbenthos is dominated by larvae and post larvae of the crab *Hymenosoma orbiculare*, mysid shrimps and fish larvae. Mysid shrimps (mainly *Mesopodopsis wooldridgei*) and amphipods (mainly *Corophium triaenonyx*) dominate the hyperbenthos in winter.

The sub tidal benthos is numerically dominated by amphipods (mainly *Grandidierella lutosa* and *Corophium triaenonyx*) and polychaetes (mainly *Capitella capitata*) in summer and winter. Amphipods make up half to three quarters of the overall numbers of benthic invertebrates, with polychaetes dominating the remainder. Polychaetes tend to be more abundant in the lower half of the estuary, but both polychaetes and amphipods are most abundant in the middle reaches. Within groups, species replace one another along the estuary, according to their salinity tolerance. For example the amphipod *Grandidierella lutosa* is dominant in the lower estuary and is replaced by the highly abundant *Corophium triaenonyx* in the middle reaches. Mudprawns *Upogebia africana* are also abundant in the lower reaches as evident from the densities of burrows, and probably make up a very significant proportion of sub tidal invertebrate biomass (pers. obs.).

Polychaetes (82%) (mainly *Ceratonereis erythraensis*), amphipods (11%) and isopods (4%) numerically dominate the inter-tidal benthos. Density of inter-tidal invertebrates is highest in the lower estuary, as is overall abundance due to the distribution of inter-tidal area in the estuary. While not numerically dominant, mud prawns probably make up a significant proportion of biomass (pers. obs.)

Invertebrate community structure is influenced primarily by salinity and sediment characteristics, both of which are influenced by flow. Abundance is influenced by sediment more than salinity, since the latter determines species composition based on salinity tolerance. Highest densities are associated with intermediate sediment size, since coarse sediments (e.g. at the mouth) are unsuitable for burrows and contain little organic matter, and fine sediments are poorly oxygenated. Temperature may also affect species composition in that certain species tend to survive better at different temperatures. However, temperature is unlikely to be significantly altered by changes in flow in the Berg estuary.

Macrophytes also influence invertebrate composition and abundance, inasmuch as they define the type and variety of habitats available for invertebrates.
For example, the abundance of certain invertebrates is positively correlated with the presence of Zostera, while others are associated with salt marsh species. Both diversity and biomass of invertebrates are influenced by the relative abundance of mud and vegetated habitats.

Micro algae is the main trophic influence on invertebrate density, affecting filter feeders, grazers and detritivores which account for most of the invertebrate fauna. The abundance and productivity of invertebrates is expected to be positively correlated with that of micro algae.

### 3.6.4 Fish

Fish of the Berg River estuary have been well studied, particularly in recent years (Bennett 1994, Clark 2007). The ichthyofauna is typically dominated by the Southern Mullet *Liza richardsonii*, with the estuarine Round-herring *Gilchristella aestuaria* being second most abundant and occasionally dominant. These, together with Bald Goby *Caffrogobius nudiceps*, Silverside *Atherina breviceps*, Sand Goby *Psammogobius knysnaensis* and Mozambique Tilapia *Oreochromis mossambicus* dominate the ichthyofauna. Of these, the latter is a freshwater species and *Gilchristella* is confined to estuaries. The others are marine species that occur in estuaries.

Marine migrants and estuarine residents are more-or-less equally abundant in summer, although the balance shifts from year to year, sometimes considerably in favour of the former (Clark 2007). The relative abundance of these two groups can shift quite dramatically from year to year in winter, with marine migrants contributing up to 75% of numbers in some years, and the reverse true in others. Much of the variability is due to major fluctuations in the abundance of *Liza richardsonii*.

*Liza richardsonii* is a marine species that opportunistically uses estuaries. It is most abundant in the lowest 10 km, but extends all the way up the estuary in winter and summer. Other such opportunistic species, including elf *Pomatomus saltatrix* and white Stumpnose *Rhabdosargus globiceps*, are confined to the lower reaches and are more common in summer than winter. *Gilchristella* (entirely resident in estuaries) occurs throughout the estuary during all seasons but is most abundant between 15 and 50 km upstream. Other estuarine residents (not confined to estuaries), such as *Atherina breviceps* and *Psammogobius knysnaensis*, tend to be most abundant in the lower 30-40 km of the estuary, some showing a distinct preference for higher salinities. The Flathead Mullet *Mugil cephalus*, the only commonly-occurring marine species dependent on the estuary as a nursery area, is widely distributed throughout. Freshwater species, viz. *Oreochromis mossamicus* and Carp *Cyprinus carpio* (both alien invasive) are found in the upper reaches in winter and tend to move down into the lower estuary during the dry summer months.

From a trophic perspective, fish in the estuary can be divided into four major groups (Figure 3.17). The largest of these in terms of biomass (80% of the total) feed on micro algae and detritus and include *Liza richardsonii*, *Mugil cephalus*, and two freshwater species - *Oreochromis mossamicus* and Carp *Cyprinus carpio*. Zooplankton feeders make up the second largest trophic group (10% of total biomass) and include *Atherina breviceps* and *Gilchristella aestuaria*. Benthic and hyper benthic invertebrate feeders and piscivores account for most of the remaining biomass of fish in the estuary, each accounting for approximately 5% of the total. Dominant species in these groups include the Gobies *Psammogobius knysnaensis*, *Caffrogobius nudiceps* and *C. gilchristi* and White Steenbras *Lithognathus lithognathus* in the former group and Elf *Pomatomus saltatrix* and Leervis *Lichia amia* in the latter group.

The ichthyofauna tends to change gradually up the estuary as species with different salinity tolerances replace one another.

There are no distinct communities associated with different parts of the estuary, but overall biomass and density of fish (grams per square metre) declines slowly with distance upstream.
Freshwater flow into the Berg estuary exerts a strong controlling influence over biomass and abundance of fish in the system through its effects on recruitment, availability of food and habitat in the estuary. Marine migrant species make up over 80% of the biomass of fish within the system. Adults of these species all spawn at sea and juveniles must recruit in through the mouth of the estuary in order to take up residence in the system. Adults also need to be able to exit back to the sea in order to spawn and complete the cycle. While freshwater flow is not required to maintain an open mouth in the case of the Berg River estuary (due to engineering), it does provide olfactory cues for fish seeking to enter the system. Some of the marine species in the estuary are known to spawn and recruit into the system throughout the year but most have a distinctive spawning and recruitment season. The latter group tend to spawn at sea at the end of winter and juveniles tend to recruit into the Berg and other south-western Cape estuaries during spring (September to November). There is also considerable evidence to suggest that many resident species also spend some time at sea, although it is not obligatory for them to do so. Larvae of estuarine resident species have been observed exiting estuaries in large numbers where they take up residence in the surf zones of adjacent sandy beaches before recruiting back into estuaries as post larvae or young juveniles, often at the same time as the marine migrant species are recruiting into estuaries. Olfactory cues provided by freshwater is critical for guiding fish into the estuary. This largely takes place in the low flow season, which means that maintenance of base flows during this period is important for facilitating fish recruitment. Reduction in flows would have significant consequences for fish fauna of the estuary. Through its effects on the salinity structure of the estuary, freshwater flow will also affect the distribution and composition of fish in the system, but not necessarily overall biomass or abundance.

Figure 3.17 Schematic diagram showing how the biomass per unit area and composition of different guilds of fish change in relation to salinity changes along the estuary. The relative contribution to biomass by the different groups is dynamic, but is roughly 80% micro algae/detritus feeders, 10% zooplankton feeders, 5% hyper benthic/benthic invertebrate feeders and 5% piscivores. Species shown are dominant species within each guild.
The availability of food in the estuary presumably also limits fish biomass and abundance to some extent.

Links between flow and micro algae, detritus, zooplankton, and invertebrates have already been discussed and need not be reiterated here. The dominance of micro algae- and detritus-feeding fish means that changes in flow affecting micro algae have the greatest significance for fish biomass (we assume that detritivores benefit largely from the micro algal film associated with detritus). Similarly, flow affects the availability of habitat for fish in the estuary. By far the bulk of the fish in the Berg estuary are juveniles, most of which show a preference for the shallow marginal and intertidal areas of the estuary where water tends to be warmer, slower-flowing and well oxygenated. Any reduction in availability of such habitat (potentially a result of reduced scouring of the estuary by floods) will also negatively influence fish biomass in the system. Submerged and emergent vegetation also provides shelter (cover) and feeding habitat for many fish species. Water temperature in the estuary is also likely to be important for some species, particularly in that high temperatures might limit the upstream penetration of some temperate species (e.g. *Liza richardsonii*) in summer.

3.6.5 Birds

The Berg River estuary is recognised as one of the most important estuaries in the country in terms of its avifauna (Turpie 1995). It supports the highest recorded density of shorebirds on the East Atlantic Seaboard (Velasquez *et al.* 1991, Hockey *et al.* 1992), and supports nationally important populations of several species. The avifauna is relatively well-studied, with numerous mid-summer and mid-winter counts having taken place (Summers *et al.* 1976, Hockey 1993, Taylor *et al.* 1997, ADU unpublished data, Turpie 2007). There are fewer data on seasonal trends (Velasquez *et al.* 1991, Murison 2007, Turpie 2007). The estuary is counted bi-annually in thirteen counting sections.

Some 127 water-associated species have been recorded on the estuary and floodplain and 93 non-passerine water birds have been regularly recorded over the past 10 years (excluding exotics and vagrants). Numbers average 14 400 birds in mid-summer and 1 600 birds in mid-winter. The avifauna is dominated by waders in summer, and has a relatively even representation of different taxonomic groups in winter. About 90% of waders occurring in summer are long-distance migrants, with the young of some species remaining to over-winter on the estuary. Other numerically important groups in summer are Flamingos, Ducks, and to a variable extent the Pelecaniformes (cormorants, darters and pelicans). In winter, the dominant groups are Flamingos, Gruiformes (Rails, particularly Redknobbed Coot) and Waders (mostly resident species). Ducks and Pelecaniformes are also more numerous in winter than summer. Nevertheless, there is considerable inter-annual fluctuation in the numbers of individual species (Turpie 2007).

Many species are associated with particular habitats or micro-habitats, and some are more sensitive to salinity than others. There is a marked spatial variation in bird community composition along the estuary. Distinct communities occur at the mouth (dominated by cormorants, gulls and terns), the lower estuary (dominated by waders and flamingos in summer and flamingos, coots and waders in winter), and the upper estuary (dominated by ducks and waders and wading birds in summer and ducks, flamingos, coots and resident waders in winter; Turpie 2007).

The spatial and temporal variability in the composition and numbers of water birds suggest several relationships that are ultimately linked to freshwater flows through their influence on habitat and food. One exception is the marine cormorants, gulls and terns that dominate the mouth area, largely using the artificial habitats in this area as a roosting area, and their numbers are higher than they might have been under natural conditions.

While birds on the lower estuary are typical of estuaries and tend to be associated with saline conditions or have a wide salinity tolerance, those of the upper estuary are much more typical of freshwater wetlands, with many species in this area having a narrow salinity tolerance. As with other biotic groups, salinity affects community composition, rather than abundance or biomass.
Temporal variation in the numbers of many species appears to be flow related. This is particularly true of certain waterfowl (e.g. Shelduck) and piscivorous species (e.g. White Pelican, Reed Cormorant) that tend to increase in years of good rainfall. Freshwater terns also tend to be more numerous in good flood years (Turpie 2007). These trends may be related to habitat, food, or both. The most immediate effect of flow on habitat is that of flooding on wetlands in the floodplain. The inundated backwater habitats provide the favoured habitat for many waterfowl species and include the Kersefontein heronry, where high water levels guarantee a safe breeding site throughout the breeding period. Inundated sedge pans also provide sheltered feeding and breeding habitat for many waterfowl species, and open pans attract waders while drying out. Flamingos take advantage of the larger pans while inundated.

Apart from Egyptian and Spurwinged Geese and Cattle Egrets which use the estuary for breeding and roosting, most of the birds found in the lower and upper estuary depend on the estuary for food. Thus the overall numbers of birds are likely to be influenced by the level of productivity of the estuary. Water birds feed on the full spectrum of organisms from micro algae to fish, all of which are positively influenced by freshwater flow up to a point (see preceding sections).

### 3.7 A CONCEPTUAL MODEL OF THE ROLE OF FLOW IN DETERMINING ECOSYSTEM CHARACTERISTICS

The relationships described in the previous sections are integrated and summarised to form a conceptual model of the Berg River estuary in (Figure 3.18). It is noteworthy that every component of the ecosystem is linked directly or indirectly to the amount of freshwater inflow into the estuary. The most important relationships are summarised as follows.

#### 3.7.1 The influence of flow on productivity, biomass and diversity

Freshwater enters the estuary in the form of base flows and floods. Base flows affect salinity structure, water residence time, turbidity and sediment deposition in the system, as well as influencing the amount of nutrients introduced into the system by determining the ratio of inputs from the catchments versus from the sea. The amount of flooding affects the degree of inundation of the floodplain and sediment scouring, and also the salinity structure and the total nutrient input into the estuary.

Base flow and flood velocities affect the nature and amount of physical habitats (sand and mud) while salinity and the degree of inundation affect the nature and amount of biotic habitat (e.g. mud flats, reed beds, salt marshes).

Salinity affects the species composition of all of the biotic components, with different species having different salinity tolerance ranges. Abundance and productivity are largely influenced by availability of food. Freshwater flows bring the bulk of the nutrients into the system which directly or indirectly feed all of the biotic components, and base flows and tidal state determine the water residence time which allows the nutrients to be used in micro- and macrophytic production. It is hypothesised that there is an optimal base flow which maximises micro algal productivity, all else being equal. Micro algal productivity is the most important determinant of overall biomass of estuarine biota, with most trophic pathways originating in micro algal rather than macrophyte (plant) productivity.

The temporal patterns of flow are also an important factor shaping the nature of the system. For example, aseasonal flooding may not benefit floodplain birds or facilitate fish recruitment into the estuary.

The biomass of all consumer groups is determined by a combination of food and habitat, either of which may be limiting, but both of which are influenced by some aspect of flow.

Given the artificially high nutrient inputs into the system, it is likely that habitats requiring higher levels of inundation or scouring constitute the most significant limiting factor in the system, or might become so. Any reduction in flow will have a greater impact on the fauna and flora of the system through loss of habitat rather than reduction in food supply.
Species diversity is primarily determined by habitat but is also a function of overall system productivity and stability. While variable habitats may support high instantaneous diversity at times, when conditions attract opportunistic species, specialist resident species will only occur when specific habitats or conditions are permanently available.

Figure 3.18  Conceptual model showing how riverine inflow influences physical and biotic components of the Berg River estuary. Only key components and relationships are depicted. Boxes with dotted edges are copies of variables elsewhere in the diagram to avoid excessive leader lines.
3.7.2 Influence of non-flow related biotic interactions

While the above model describes the forward trophic linkages in the ecosystem, a complete ecosystem model would also have to take into account the effects of predation and competition in shaping these estuarine communities. Competition occurs once any resource is limiting, and may involve competition for space, food or mates. While the latter is probably of little consequence for this model, competition for space and food have important influences.

For example, certain waders need a considerable amount of space in order to locate their invertebrate prey visually. They thus defend territories which they defend from conspecifics. Thus space requirements may determine the upper limit of the number of birds of that species, even if abundance of food were to increase. An upper spatial limit will be met irrespective of feeding method. These effects are built into the conceptual model in most instances by the assumption that increases in food lead to an asymptotic increase in the consumer group.

While productivity in one trophic level contributes to growth in another, this predation can shape the food community, often preventing any one species or group from becoming dominant because of the laws of optimal foraging. (Predators tend to focus on the most abundant prey species available). Thus predation tends to maintain higher diversity within prey communities. Predation pressure relative to production affects the standing biomass of any food group. However, as food becomes limiting due to predation, so consumer populations decline, allowing food populations to recover again. This results in typical predator-prey population cycles that would be expected without other external influences. In some cases, populations may remain relatively constant by cycling between prey sources. The conceptual model is not drastically altered by this consideration, except in as much as most populations would be expected to be oscillating in some way.

3.7.3 Influence of external factors on biotic communities

A number of other important factors have an influence on the trophic and ecological functioning of the Berg estuary. These influences are considered external to the system and include both natural and anthropomorphic influences. They also include historical anthropogenic changes to the system, the effects of which are still evident.

Anecdotal reports suggest that the realignment of the estuary mouth which was completed in the 1960’s to facilitate movements of larger fishing vessels in and out of the mouth had a profound influence on the salinity structure of the estuary. Until 1966 the Berg River mouth was naturally located approximately 1 km to the south of its current position (Harrison 1997), but a new mouth was cut through the sand dunes in 1966 and the channel stabilized between three concrete breakwaters. Seawater is reported to have begun penetrating much further upstream following this event than it ever did before. Effects of this would have been exacerbated by the abstraction of freshwater from the system (equivalent to a 30% reduction in freshwater inflow) and periodic dredging of the mouth which would facilitate the ingress of seawater at high tide. Indeed, the now defunct Berg River pump station situated upstream of Kersefontein can no longer provide water of a suitable quality for irrigation. Effects of these changes on the biota of the Berg estuary must have been profound, but the complete absence of detailed information on the biota of the estuary prior to this time precludes making any direct comparisons in this respect.

Development around the Berg River over the last few decades has also taken its toll on the natural habitats of the estuary. In particular, salt marshes have been significantly transformed and threatened by anthropogenic disturbance (O’Callaghan 1994, McDowell 1993). In addition, invasion by alien plant species has significantly altered habitats particularly in the upper reaches of the estuary (Boucher & Jones 2007).

The Berg Estuary has also been subject to a long history of fishing pressure which would also have had a profound influence on fish fauna of the estuary.
Fishing operations started in earnest on the Berg estuary and in St Helena Bay shortly after the Dutch established a permanent trading station at the Cape, but would probably have been fished by the indigenous Khoi Khoi for many years prior to this (Hutchings et al. 2007). Commercial beach seine and gill net fisheries accounted for most of the fishing effort in the early years and are reported to have yielded a considerable biomass of fish. It was not long, however, before the high level of exploitation took its toll on fish stocks in the river. The average annual catch of fish from the Berg estuary and adjacent marine environment prior to 1900 was in the order of 102 tonnes, but declined dramatically to an average of only 16 tonnes thereafter (Hutchings & Lamberth 2002). Use of beach seine nets in the estuary were banned shortly after this time and various attempts have been made to reduce gill netting effort in the river, mostly without success. In 1998, a total of 200 licensed gill net fishers were still operating on the river, landing catches in the region of 25-45 kg of fish per day (Hutchings & Lamberth 2002). Gill nets used by these fishers mostly comprise mesh sizes in the range of 44-48 mm and catch a high proportion of bycatch in addition to the southern and flathead mullet which are purported to be their primary target. The effects of the gill net fishing in the estuary are likely to have depressed overall biomass of all of the larger fish in the estuary, particularly the larger piscivores (Elf and Leervis) and benthic feeding species (White Steenbras, White Stumpnose, etc.). Since gill net fishing was officially banned in the estuary in 2003, there has been some evidence for increase in the abundance of these species, particularly of the larger southern and flathead mullet and White Steenbras (Hutchings et al. 2007, Clark 2007). However, it is expected that it will take many more years before these species are able to recover properly.

Fishing activities outside of the estuary have also had a significant effect on fish populations within the Berg estuary. Direct effects of such fishing activity are primarily confined to the marine migrant species frequenting the Berg estuary that are directly targeted by the fisheries in question but indirect effects are also felt by other species through biological interactions between species within the estuary (i.e. predation and competition). Species of prime importance here include White Steenbras, White Stumpnose, Harder, Flathead Mullet, Elf, Leervis and Cob. Total populations of all of these species have been drastically reduced through the effects of over fishing and estuarine degradation around the country, to the extent that it has compromised reproductive output for the species’ as a whole. Biomass of these species in the Berg estuary has been dramatically reduced as a consequence with concomitant effects on other fish species in the estuary (through competition and predation) as well as on invertebrate resources (through predation).

External influences also include natural cyclical processes or sporadic events beyond the estuary. Nutrients entering the estuary from sea water are influenced by up welling events, the frequency of which is thought to be changing as a result of global climate change. Similarly, longer term variations in sea level which have been shown to propagate very effectively up the estuary (see 0 and Schumann 2007 for more details on this) are likely to have a profound influence on the degree to which a particular flood inundates the floodplain.

Other external influences on the estuary extend as far as the northern arctic, where predator prey cycles lead to regular fluctuations in the breeding success of the migratory waders that dominate the estuary in summer. Such fluctuations have been well documented on Langebaan lagoon. These wader populations are also influenced by the loss of breeding habitat in the northern hemisphere. At a more regional scale, many of the water birds that use the estuary are highly opportunistic and some make regular seasonal movements which correspond with rainfall patterns in the region. Thus the numbers of birds on the estuary in a given year is probably influenced by regional rainfall patterns which influence the availability of suitable habitats.

This link has not been shown empirically, however. Anthropogenic activity on a regional scale has also influenced bird numbers on the Berg estuary.
In particular, the spread of alien trees and the proliferation of artificial water bodies such as farm dams has allowed the spread of many water bird species into the western Cape which did not formerly occur very commonly, if at all. These include species such as glossy ibis, spoonbill and sacred ibis. Together with the expansion of cultivated areas with grain, numbers of Egyptian and Spurwinged Geese have also proliferated dramatically, perhaps displacing some of the indigenous waterfowl through aggressive behaviour and dominance of loafing sites, although they do not compete with other waterfowl for food.

### 3.8 IMPLICATIONS FOR RESEARCH AND MONITORING

Howard & Ractliffe (2007) and Beck & Basson (2007) report that likely changes in freshwater flow reaching the estuary can expected to be significant, primarily because of the removal of small and medium floods in the upper catchment, which translate further downstream into elevated base flow. In addition, flood peaks (from small to large floods) are expected to decline by up to 10%, with a resultant decrease in flooded area of around 4% in the upper estuary, 3-6% in the middle reaches, and 1% in the lower reaches (Beck & Basson 2007). Timing of the floods is probably more critical than the absolute magnitude, as a fairly modest size flood can inundate a much larger area when water level in the upper estuary is high, than a much larger flood (3 x or more) when water levels in the upper estuary are low. This has important implications for the timing of artificial flood releases in terms of achieving maximal impact.

Recommendations for monitoring of a large variety of parameters in the estuary have been included under the various disciplines in this volume. While it is not considered necessary to specify additional monitoring protocols here, it will be important in future to use the conceptual model to identify likely implications of any changes observed in the physico-chemical parameters or lower taxonomic groups (e.g. microalage, vegetation, invertebrates) in the estuary, for higher trophic groups and the estuarine functioning as a whole. Perhaps more than anything else, work on the Berg estuary including that devoted to compiling this conceptual model has highlighted the extreme complexity of the system and reinforces the idea that it is not possible simply to monitor changes in physico-chemical parameters or lower taxonomic groups and use these to project likely changes in the higher taxa. Future monitoring protocols must include physico-chemical parameters as well as all major taxonomic groups if it is going to be possible to identify at an early stage any changes in the system arising from modified flow regime, to assess their significance and to pin point the root cause of such change.
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CHAPTER 4 -
RECOMMENDATIONS FOR FUTURE STUDY AND
MONITORING REQUIREMENTS

B.M. Clark & S.G. Ractliffe
4.1 INTRODUCTION

With the approval to proceed with construction of the Berg River Dam (formerly the Skuifraam Dam) in the Franschhoek catchment area of the Berg River, the Department of Water Affairs and Forestry (DWAF) commissioned Anchor Environmental Consultants CC and The Freshwater Consulting Group to conduct a Baseline Monitoring Programme for the Berg River. The Berg River Baseline Monitoring Programme (BRBMP) was aimed at describing the present-day condition and natural variation of the Berg River, the Berg estuary and other hydraulically linked systems. The programme was initiated in October 2002 and was completed in June 2007.

The BRBMP aimed to provide a clear understanding of changes occurring in the system due to natural fluctuations vs. those induced by water impoundment in the upper reaches of the river. The hydraulic and hydrodynamic modelling, which integrates hydrology with the geomorphology and physics of catchment processes, has been viewed as the key information used by each specialist to evaluate the direct and indirect importance of flow to their particular field.

As part of the development of conceptual relationships between different ecosystem components and the hydraulic / hydrological environment, specialist studies were undertaken over the three-year monitoring programme. The design of the river and estuary surveys was a) to provide detailed information for the description of ecosystem functioning, but also b) to provide baseline data of variables that would be important to monitor in the long term, to measure predicted or identify undesirable change, to facilitate adaptive management of the Berg River.

Recommendations provided by each of the specialists in the individual reports (making up the component chapter of the preceding four volumes of this report), are collated and summarised here in this final chapter. These are thus the final consolidated recommendations of the Berg River Baseline Monitoring Programme.

Consolidated recommendations are ordered within this chapter according to the logic that has informed the layout of this full report. Disciplines like Geohydrology and Hydrology refer to the catchment as a whole, whilst within the riverine or estuarine component, the respective disciplines (hydraulics, water chemistry, vegetation, fish, etc.) are ordered hierarchically in terms of their functional importance to the ecosystem components above them in the hierarchy.

Recommended monitoring protocols contained in this chapter are designed to identify and evaluate potential future changes in the river, estuary and groundwater systems against the baseline developed in the BRBMP that may arise following construction and during operation of the new Berg River Dam. Note that simply monitoring the parameters listed in this chapter at the appropriate intervals suggested is not sufficient on its own. Results of the monitoring need to be checked, analysed and interpreted by an appropriate group of specialists if the significance of any changes detected in the data are to be fully appreciated.

Another critical issue that applies to all recommended monitoring protocols produced from this study is the fact that much of the primary baseline data required for interpretation of changes in the river, estuary and groundwater environments were collected through instruments deployed and maintained by DWAF. During the course of this study it became apparent that many of these instruments were not functioning properly, had not been serviced at recommended intervals, had a data stream that was intermittent or had been interrupted for some reason or other, and/or that data collected had not been archived in a secure format and/or location. It is critical that this not be allowed to recur in the future as it can invalidate time and resources invested in other data collecting efforts.

4.2 CHANGES IN HYDROLOGY AND SEDIMENT TRANSPORT RESULTING FROM THE BERG RIVER DAM

A summary of the changes in hydrology and sediment transport, obtained from hydrodynamic modelling, is provided here as a context for understanding the various specialist recommendations, both for further work and for long-term monitoring requirements. These are presented below.
This hydrological analysis has described two major features of the Berg River: firstly, that there is considerable between-year variability in all aspects of flow, including base flows and the range of different magnitudes of floods. These different flow categories each fulfil different functions in relation to ecosystem processes. Not enough is known about the ecological importance of maintaining variability in flood regime at time scales greater than a year, but there is substantial evidence that extended periods of constant low flow result in a myriad of biological changes, including algal blooms and reduced biodiversity of in stream flora and fauna.

The second feature is the high relative importance of the upper river - the Berg River Dam sub-catchment – in respect of its disproportionately elevated contribution to low flows and small floods in the lower river during the autumn through spring period. This disproportionate contribution of this sub-catchment is a reflection of both its natural characteristics (high rainfall, water producing area within the catchment) but also a consequence of the extent of development elsewhere in the catchment that has removed or reduced smaller flood flows. The Berg River Dam is likely to diminish this contribution of the upper catchment to base flows and smaller floods along the full length of the river. The implications of this for ecological functioning in the river may be high.

The Berg River Dam will have a much larger effect on spillage than most other dams in South Africa for the following reasons:

- A pump-station abstracts water at 6 m$^3$/s (first phase 3 m$^3$/s) when the reservoir storage reaches a certain level and the water is pumped to a new water treatment plant, and to Theewaterskloof Dam through the tunnel. This operating rule has been set in the simulations in this report to allow spillage on average 1 out of 4 years (with artificial flood releases), but with the larger pump capacity it is possible to operate the dam so that it never spills. At best it is estimated that the dam will be spilling once in 20 years on average.

- The spillway length is only 40 m which creates damming in the reservoir and large flood attenuation which has an impact on small and large floods. For example the Probable Maximum Flood (PMF) which is equal to about 1300 m$^3$/s is reduced to only 740 m$^3$/s when it spills at the dam.

- The benefit of winter flows and floods from tributaries downstream of the dam is reduced by the supplement scheme to be located downstream of Dwars River. This pump-station will pump water at a rate of 4 m$^3$/s to the Berg River Dam, abstracting about 21 million m$^3$ per year from the river during winter.

The effect of the dam on the river and estuary flow may be summarised as follows:

- With the above operation the MAR in the post-dam scenario with managed flood releases downstream at BRM2 (upstream of Franschhoek River), will decrease from the present 141 million m$^3$ which includes the interbasin transfers from the Theewaterskloof Dam to only 35 million m$^3$. The managed flood releases are therefore extremely important for the river channel maintenance and ecology. The dam will however have an effect right through to the estuary.

- Due to the adopted dam operating rule the dam spills only in four of the nine years simulated without managed flood releases, which means that the largest flood peak spilling into the river will be only 77 m$^3$/s as compared to an incoming flood peak of 240 m$^3$/s. With the magnified flood releases the dam spills only in two of the nine years, but between one and three artificial flood releases are made each year in addition to the spillage from the dam.

In between the artificial flood releases and natural spillage, the IFR and irrigation releases make up the only flow in the river, until contributions from the tributaries augment these flows. The adopted operating rule with regard to the artificial flood releases ensures that the flood release pattern has a natural variability.

- Hydrodynamic routing of the pre- and post Berg River Dam spillages through the river system indicated that for all the sites the dam has a significant impact on all the flows in the river, but especially at BRM2 as this site relies solely on the releases from the dam.
At the other sites the dam releases are augmented by the tributary flows and the further away from the dam the sites are located the closer the post-dam flow patterns are to the present situation. At BRM2 the decrease in total annual volume of water is almost 79%, while at BRM6 the reduction is only 14%.

Flood attenuation along the Berg River for the present and post-dam scenarios was investigated and it was found that if the managed floods are released in phase with tributary floods, the attenuation is not as pronounced because the main channel does not need to be filled. This shows that it is important to ensure that the flood releases are made in phase with tributary floods. For the post-dam scenario the flood attenuation at low initial flows is not as pronounced as it was for the present day scenario, because of the smaller cross-sections. The main channel fills up more quickly than it did for the present scenario, which means that the flood travels more quickly, without being attenuated to such a degree.

The effect of the Berg River Dam will be most pronounced down to Paarl, it will also have a significant effect on the sediment and water volumes between Paarl and Hermon. As the water contribution from the tributaries increase further downstream the effect will decrease to a minimum at Misverstand Dam.

4.3 RECOMMENDATIONS REGARDING THE REFINEMENT OF THE IFR FOR THE BERG RIVER

In this report only the IFR requirements of the upper Berg River were considered in the dam operation. The IFR required at Hermon is, however, significantly higher and, based on frequency graphs for each month of the year, a decision will have to be made whether the lower Berg IFR should be supplemented from the Berg River Dam or Voëlvlei Dam.

It should be noted that this study assumed Berg River operating rules and IFR requirements as determined in previous studies and proposed flood releases from the dam. Certain impacts of the dam have been identified, which can be mitigated to some extent over the upper 70 km to Hermon where the effects are the most severe. Previous IFR studies on which dam design and operation is based are however outdated - from this study, for example, it is clear that the release of a peak discharge of 160 m$^3$/s as specified in the previous IFR study is not sufficient and larger and possible more frequent floods are required, which should be optimized. Furthermore, no IFR study was carried out at the estuary. At the Drakenstein abstraction works the IFR was based on a desktop level study.

The operating rule decided on in this report to achieve the IFR requirements seems realistic and practical without releasing larger floods than the inflow into the Berg River Reservoir. The rules also provide variability from year to year.

However, they do result in considerably less water volume in the river than that specified in the IFR Refinement workshop and the basis for the Gazetted Reserve.

The present operating rule protocol is to forgo large floods in a “dry” year if the specified IFR flood of a given magnitude is not observed by some cut-off date. However, the analysis of the year-to-year variability in flood flows in this study shows that a given total flood volume may be split quite differently between various intra-annual flood classes from one year to the next, and in “dry” years there may be a considerably greater proportion of flows occurring as class 1 and 2 floods. This is another form of intra-annual variability that maintains the stochastic nature of flow in these rivers. Within-year and between-year, small scale and large scale variability in base flows should be maintained, to emulate the variability observed in the natural flow regime.

With the knowledge and data of the baseline monitoring project, it is recommended that that these flood operating rules should be optimised in a comprehensive reserve determination for the Berg River and Estuary.

The following recommendations are made:

- a rainfall-runoff model of the Berg River Dam catchment and downstream tributary catchments including Franschhoek, Dwars and Wemmershoek Rivers, should be calibrated and verified so that managed flood operation can start once the reservoir fills.
It has been agreed that no major flood release will be made during the first year of filling. A real time flood warning and operation approach is required to ensure:

- that the flood released is not too small for the IFR
- that the flood is in phase with the downstream tributaries and not attenuated by the dam
- that the flood peak released is not larger than the reservoir inflow
- that the flood hydrograph shape and volume is correct
- that the outlet tower can be filled with water prior to the flood release.

- At least the field data of 2003, 2004 and 2005 should be used for calibration and verification purposes.
- It is proposed that the Berg River Baseline Monitoring programme is followed by a monitoring programme from 2007 in order to refine the managed flood releases (flood peaks, volumes and frequency) required.

### 4.4 RECOMMENDATIONS FOR REFINEMENT OF HYDROLOGICAL DATA AND MONITORING

This study makes following recommendations:

- The “hydrology” for the Berg River should be updated to include the recent 7-year period of data not incorporated into the Western Cape System Analysis, and beyond the scope of works for this BRBMP, but which will increase the accuracy of the statistical assessments, substantially in the case of some flow gauges.

- A re-examination of the use of the Annual Maximum Series versus the Partial Time Series to derive flood statistics should be undertaken by the Department of Water Affairs, because of the difference in the values obtained from these two methods for lower-order floods, and the importance of these floods for the ecosystem. This is critical to inform ecological input into a comprehensive reserve or review of the reserve, as recommended above.

- Accurate flow gauging in the river downstream of Misverstand Dam, at the head of the estuary is required for measuring the inflows into the estuary.

- Accurate flow gauges measuring flood flows in the future, upstream of the Berg River Dam, are essential for proper measurement of incoming floods, and for implementation of the IFR. The present weir only measures low flows.

- Flows monitored at the DWAF gauges, with the inclusion of those mentioned above, are deemed to provide adequate data for the assessment.

- During the flood release the flow gauging stations downstream of the dam (new), G1H003 (Franschhoek River), the new stations upstream of Berg River Dam, the Berg River abstraction works at Drakenstein Prison, the Paarl (Dal Josafat) gauge, Hermon gauge, Drieheuwels gauge, and the tributary gauges should be operational. The outflow at Wemmershoek Dam should also be recorded.

- Continuous flow gauging is required at all the existing Berg River stations and tributions, at the Berg River Supplement Scheme, irrigation release at Wemmershoek River, Wemmershoek Dam releases, Berg River Dam inflows (new) (Berg and Wolwekloof Rivers) and Berg River Dam outflow (sleeve valves, spillway and downstream gauging station (new)).

### 4.5 RECOMMENDATIONS FOR GROUNDWATER MONITORING

Monitoring of groundwater levels and quality in the Berg River Catchment since May 2003 has resulted in establishment of a baseline record prior to construction of the Berg River Dam. This baseline data set will allow for impacts to the groundwater system by the Berg River Dam to be observed, should they occur. It is therefore imperative manual monitoring continue on a quarterly basis, and the groundwater level data loggers continue to collect data at a 2 hr interval.
As the groundwater quality logging equipment has yet to provide any meaningful data, it is recommended this monitoring be discontinued.

It is recommended the monitoring network not be adjusted at this time, and should include the following boreholes:

- 19 dedicated monitoring boreholes established as part of the BRBM programme;
- 39 privately owned boreholes monitored since May 2003;
- 23 boreholes in the Robertsvele saddle area (currently being monitored by a contractor on behalf of DWAF); and
- 12 boreholes from the Langebaan Road Aquifer (currently being monitored by DWAF).

Monitoring should include the measurement of groundwater levels, field water quality measurements (EC, pH, temp and Eh) and sampling. To ensure consistency, the DWAF laboratory in Pretoria should continue to do the analyses.

To ensure monitoring proceeds as planned and meaningful data are generated, it is recommended that an annual groundwater monitoring report be prepared. This will ensure problems experienced during monitoring can be identified and corrected before too many data are lost.

4.6 CONSOLIDATED MONITORING RECOMMENDATIONS FOR THE RIVER SYSTEM

4.6.1 Hydrodynamics and sediment transport

This project showed that a fully hydrodynamic model, in this case 1D, can be calibrated and validated for both hydrodynamics and sediment transport in a large river system such as the Berg River.

It can therefore be used for environmental impact assessments, mitigation measures to limit the impact of the dam and dam operation to assess flow and fluvial morphological changes in the river.

Although the Baseline Monitoring Programme was a comprehensive study, the period was too short to obtain reliable baseline data in terms of the fluvial morphology and sediment dynamics of the river system.

The flood peaks and number of floods during the sampling period 2003 to 2005 were also limited due to the relatively dry conditions in the Western Cape during this period. More data should therefore be sampled in future to improve the dynamics of the system. The following monitoring is proposed:

- Detailed resurvey of each BRM site by surveyor: main channel and three transects A, B and C at each site at the beginning of 2008, thereafter every 4 years.

- Survey of main channel fluvial morphology at each site: embeddedness of boulders; bed sediment grading between cobbles at transects A, B and C; deeper bed grading analysis at sections A and C (including boulders/cobbles) in a 0.5x0.5x0.5 m bed volume; flow velocities; flow depths at the beginning of the year. This should be done at all BRM sites, at a frequency of two years for sites 4, 5 and 6 starting in 2008, and at an annual frequency for sites 1, 2, 3 and 3B, also starting in 2008, to be changed to a frequency of 2 years after 5 years.

Environmental flood releases from Berg River Dam are now scheduled from 2008, and it is important that the effectiveness of the two larger releases is monitored. The following are recommended:

- At BRM2, 3A and 3B and BRM4 the survey of the main channel fluvial morphology at each site (as detailed in the second bullet item above) should be repeated during September, after winter of each year for the first 5 years from 2008.
• It is also a requirement to sample suspended sediment and bed load where possible at the dam release gauging weir (new), at the Franschhoek River gauging station (G1H003), at the Road Bridge upstream of Wemmershoek River, at BRM3B and at the Dal Josafat flow gauging station at Paarl. The sampling frequency during the flood release should be 0.5 h at these locations.

• A new BRM site for fluvial morphological and hydraulic assessment is also required at about 300 m to 500 m downstream of the new gauging weir downstream of the Berg River Dam. This is because BRM2 is too far downstream (2 km from the dam) to represent the conditions directly at the dam and became unstable during 2005. Monitoring at BRM2 should however continue.

With the above monitoring programme, it would be possible to investigate the impact of the dam on the river from 2007, by analysing the following:

• Bed level changes at BRM sites
• Bed sediment grading changes and possible armouring
• Bed slope changes along the Berg River
• Hydraulic roughness changes
• Sediment loads
• Changes in sand deposition/erosion patterns
• Effectiveness of the environmental floods to flush sand and move some boulders and cobbles similar to pre-dam conditions
• Wetted area at sites
• Flow depth and velocity changes at sites
• Floodplain inundation frequency changes
• The impact of flushing sand, cobbles and boulders for short durations at the Supplement Scheme and to develop the optimum timing with floods
• Cobble-boulder embeddedness
• Flow duration changes at the sites
• Refine the annual flood releases (peak and volume and timing) from Berg River Dam
• River channel width and depth changes due to the dam

The turbidity meter installed at BRM3B (800 m downstream of the Berg River abstraction works of the Supplement Scheme), should be connected by cable to a river bank hut, and a pressure gauge should be installed near the right bank in line with the turbidity meter, about 10 m upstream of the causeway. The turbidity meter and water level gauge data should be available in real time for the operation of the Berg River Dam scheme. This should be installed this as part of operational system during the summer of 2007/08. The role of the turbidity meter at BRM3B is to monitor the long-term sediment loads in the Berg River, about 11 km downstream of Berg River Dam, and also for the operation of the abstraction works so that flushing of the sand trap can be carried out to limit the impact on the river.

The data obtained from the water level gauge at BRM3B should eventually be correlated with the flow measurement at the Supplement Scheme to determine the flow series at BRM3B. The head of the turbidity meter should be cleaned once a month when batteries are replaced.
4.6.2 Water chemistry

The present monitoring programme has utilised water chemistry and flow data from a combination of DWAF gauging weirs and un-gauged biophysical monitoring points. It was intended to provide baseline information on the Berg River system, with a view to feeding into a future monitoring programme, aimed at elucidating impacts associated with the operational phase of the Berg River Dam.

With this in mind, it is recommended that the following issues / aspects be incorporated into the future monitoring programme:

- Ongoing monitoring of existing DWAF gauging weirs, in terms of water chemistry
- Although the existing DWAF monitoring programme includes a wide range of variables, the most pertinent ones to the present study are those associated with measurement of dissolved salts (TDS and EC), suspended solids, nutrients (both phosphorus and nitrogen-based, including ammonium) and pH.
- During the course of this project, it was found that monitoring of a number of DWAF gauging weirs, in particular those on tributaries, had been suspended, either as a result of deliberate decisions or simply through inefficiency in allocating monitoring personnel to each station. It is recommended that a full audit should be carried out as a matter of urgency, to indicate which stations are being monitored on a regular basis and which are being monitored sporadically or not at all.
- Sites on tributaries where monitoring has stopped should be re-instated, and the implementation of the monitoring programme should be audited on a regular basis. In terms of assessing the impacts of the Berg River Dam, it would be more useful to monitor a greater number of sites for fewer variables (e.g. only the key variables listed above) than few sites for an extensive list of variables.
- Dissolved oxygen data were also included in the monitoring database. However, the actual data collected are patchy and, in fact, since this variable is diurnally highly variable, should ideally be available as continuous data from a number of key points, rather than as monthly or quarterly spot samples, which reveal little about river water quality. It is recommended that, if invertebrate and periphyton specialists are concerned about this variable that it should be measured by means of continuous data recorders, and that oxygen probes should thus be added to existing continuous recording devices at monitoring stations along the Berg River.
- The collection of continuous EC data for the elected monitoring sites on the Berg River main stream has provided a useful indication of daily variability in this key constituent and is considered essential for the ongoing “infilling” of daily salinity values between grab samples (DWAF 2005).
- Continuous flow data were not available for a number of important sites, including several tributaries. The condition of flow measuring devices at each gauging station should be assessed, and appropriate repairs made to render them operational. In addition, new gauging stations are required, to allow adequate monitoring of flows from the Berg River Dam itself (i.e. upstream of BRM2), as well as from the Wemmershoek River and the lower Dwars River sites.
- Water chemistry monitoring is required on the lower Dwars River - the latter has a gauging station only in its upper reaches, providing an optimistic measure of water quality upstream of inflows from a WWTW and other impacts
- Revision of the existing system for water chemistry data collection is also suggested – at present, missing data could be the result of failure to collect samples, failure to analyse samples, analytical error, or simply that there was no flow in the river at the time of sample collection.

It would be extremely useful to be able to elucidate, on the basis of water chemistry data availability, broad inferences on flow regime. This could be achieved if a code was allocated to indicate when no samples could be taken because the river was dry.
• An effective data management system should be instated for the management of continuous EC and temperature data – a large proportion of the latter data had to be eliminated from the analysed database in this report because of poor data management practices – data were mislabelled under the wrong site name; no back-up system was available; data storage appeared fairly ad hoc, and subject to localised computer failure.

• Continuous temperature and EC recording devices at G1H004 and the G1H004-upstream and downstream sites should be inspected and repaired / replaced where necessary, and the monitoring record continued.

• In addition, it is recommended on a broader scale that management objectives for the reaches of the Berg River between Paarl and the Voëlvlei outlet should be established, and that a management plan should be drawn up to address the water quality and flow regime problems in this section of the river, from both an ecological and a human health perspective.

4.6.3 Riparian vegetation

The monitoring programme has measured considerable anthropogenic disturbance of the riparian vegetation during the BRBMP study period, as well as identified qualitatively what is deemed to be a response of the riparian vegetation to below normal flows and reduced flushing floods. However, the tools used, viz. topographic survey of changes in apriori-defined vegetation zones, may not be suitable for long term monitoring. Chiefly, small errors in measuring elevation during the survey render interpretation of changes in these zones near-impossible or qualitative at the very most. Furthermore, the multivariate analysis of vegetation patterns in the Berg River indicated that many of the zones described are not floristically different. The following is thus recommended for long term monitoring:

• Establishment of fixed plots for floristic data collection, ascending up the bank from the water’s edge, at four of the transects established and monitored at each site during the BRBMP.

• Transects should be selected to cover all representative vegetation at the site (natural and disturbed).

• Replicate data plots within the broad vegetation zones described during this BRBMP study (Wet Bank, Lower Dynamic, Dry Bank) located at increasing elevations, to capture changes in community associated with vertical position.

• Sampling should be undertaken annually for the first five years from 2007, during late spring / summer.

• Transects should be surveyed and new stage-discharge levels calculated as necessary, so that correct discharge-linked water levels are available for interpretation of monitoring results.

• Discharge data for the preceding year should be provided for each monitoring site, and through hydraulic relationships, provided for each vegetation transect as a depth time series, to allow for interpretation of vegetation sampling results.

4.6.4 Periphyton

Together with information on changes to periphyton communities anticipated downstream of the Berg River Dam, periphyton as a tool for monitoring impacts in riverine ecosystems provides a basis for future monitoring of impacts associated with the operational phase of the Berg River Dam.

The following measures for ongoing monitoring are therefore recommended:

• All four monitoring sites sampled during the BRBMP are included in an ongoing monitoring programme. The upper foothill reaches of the Berg River are distinct from the lowland reaches and impacts associated with the dam will vary down the length of the river.
BRM1 provides a good benchmark for unimpacted conditions within the upper foothill reaches of the Berg River and therefore assessment of conditions at BRM2, which is likely to be severely impacted by the operation of the dam, can be undertaken relative to BRM1. Changes in water quality in particular in the lower reaches of the Berg River are anticipated. Thus, ongoing monitoring of changes in periphyton communities at these sites may provide a useful means of assessing differential impacts in these reaches.

- Sampling effort at each site should be reduced by sampling only the run biotope in the upper foothill reaches. Biotopes showed no significant differences in either periphyton biomass or taxon composition at both BRM1 and BRM2 and therefore replicates should be collected at the level of site not biotope at these sites. Because the least variability was measured within the run biotopes, it is recommended that all replicates be collected within the runs. Thus, the number of replicates collected at each site will be considerably reduced.

- Sampling effort in the lower reaches of the Berg River should be increased slightly to reduce the degree of variability associated with the number of replicates taken during the BRBMP. Considering that periphyton biomass and taxon composition among biotopes at BRM5 and BRM6 were significantly different during the low flow period (i.e. the summer), it is recommended that sampling in all three biotopes be continued.

- Sampling should continue in all four seasons to monitor potential changes in the seasonal cycles of periphyton accrual and loss that were evident during the BRBMP.

- Both AFDM and Chlorophyll a data should be monitored at each site because these different measures of periphyton biomass provide useful information that can be used to monitor the extent of organic pollution (not sure this is relevant actually).

- Taxon composition should be monitored at each site because potential shifts in periphyton community structure and diversity provide a useful tool for assessing flow and nutrient related changes associated with the dam.

- The monitoring programme aimed at detecting effects of the dam should recognise that many impacts may become visible only in the medium-term, whilst others might be more rapidly apparent. However, this BRBMP has shown that assessment of changes must account for inter-annual variability, and hasty conclusions – of either negative impacts or a “clean bill of health” should not be made within the first five years of dam operation. Having said this, periphyton because it responds more rapidly to change, should be used as an important “red flag” denoting potential degradation.

- Physico-chemical variables that should be collected at all four monitoring sites to compliment the periphyton biomonitoring programme include water temperature, nutrients (particularly nitrogen and phosphorus), electrical conductivity and depth and velocity. Although no apparent relationship with the latter two variables was evident during this monitoring programme, these variables might qualify as potential outliers in the data set.

- It goes without saying that a discharge time series for the monitoring period under review, should be provided for each site.

Finally, monitoring changes in periphyton community structure need to be linked closely to the invertebrate monitoring programme because changes in periphyton community structure could have knock-on effects to other trophic levels.

### 4.6.5 Invertebrates

The data collected from this BRBMP invertebrate study together with information collected for the Olifants / Doring Reserve Determination (Ractliffe and Dallas, 2004b) has facilitated a description of responses expected in the invertebrate assemblages as a result of changes in flow, habitat characteristics and water quality as a result of the Berg River Dam.
Recommended mitigation measures, which could alleviate the negative impacts associated with the operation of the dam are as follows:

- Flood releases should attempt to coincide with natural floods in the tributaries. This will mean that artificial releases will augment natural flood flows, and lead to discharges and velocities that approximate natural conditions.
- Channel maintenance flows (intra-annual floods) need to be re-assessed during the further Comprehensive Reserve Determinations of the Berg River to be undertaken shortly. It is crucial that these floods be simulated, especially in order to maintain the biological communities in the river reaches between the Dam and the Jim Fouche Bridge.
- Resource quality objectives (RQO's) need to be set for the invertebrates of the Berg River. These objectives should be based both on species level responses to flow changes presented here (and elsewhere), and on the community level responses (as measured / monitored by SASS5 scores).
- In terms of habitat, flows must be set in order to ensure that the full complement of biotopes remain available to the invertebrates. In the upper river, the riffle / run biotopes are important in terms of biodiversity, while the vegetation, slack water and backwater biotopes are critical as refugia. Lower down the river, the run biotope is important in terms of invertebrate diversity and, where the channel becomes confined, fairly diverse riffles are a feature of the river reach. In the lowland river, the vegetation biotopes are also necessary for refuge, oviposition, attachment and feeding, especially in the summer months.

Monitoring of the effectiveness of the IFR on invertebrates should include the following recommendations:

- The river reaches of most concern, in terms of the likely impacts of the Berg River Dam, are those between the Dam and the Jim Fouche Bridge. It is recommended that, in addition to continued monitoring at BRM2, a monitoring site be selected upstream of the bridge.
- Rapid bio-assessments provide valuable, easy to collect data that provide sufficient information to build an adequate picture of the riverine invertebrate assemblages, in terms of their overall condition.
- Key taxa that should be sampled, and identified down to species level where possible, at the foothill zone sites include:
  - Diptera: Athericidae, Simuliidae, Chironomidae;
  - Ephemeroptera: Baetidae, Heptageniidae, Leptophlebiidae, Telagonodidae;
- Key taxa that should be identified to species level at the lowland river sites include:
  - Diptera: Simuliidae, Chironomidae;
  - Ephemeroptera: Baetidae, and Tricorythidae;
  - Trichoptera: Ecnomidae, Hydropsychidae, Hydroptilidae, Leptoceridae.
- It is more accurate to sample the various available biotopes, or major biotope groups, than to collect a cumulative sample for each site. There is clear preference by various taxa for particular biotopes, in addition to the movement of animals between biotopes, as flow conditions change. 
  - It is essential to be able to monitor this preference and movement, in order to be able to predict the responses of invertebrates to changes in flow and habitat availability, and to mitigate against the impacts associated with flow modifications.
- If budget allows, sampling of invertebrates should be done quarterly. However, the seasonal shifts in invertebrates noted during the BRBMP sampling period were not easily determined.
There were clearer differences between summer and winter, than between all four seasons. Thus, sampling should be repeated at least in summer and winter.

- Biotope-specific sampling should be augmented by data on the extent and occurrence of the biotopes. It is likely that biotopes will change over time, especially in the reaches immediately downstream of the Berg River Dam. Both the quantity, or diversity, as well as the quality of the biotopes are of concern.

- The vegetation biotopes are important in all reaches of the Berg River, for different reasons throughout the year. Thus, it is important to monitor this biotope, to ensure that it is not lost, or replaced by invasive or exotic vegetation. For instance, at the lowland river sites, it was discovered that there was a lower diversity of invertebrates in the woody stems and shoots of invasive plants (such as *Phragmites australis*, and *Sesbania punicea*) than in the low-growing sedges and submerged root material.

4.6.6 Fish

Projected changes in flow, aquatic habitat availability and water quality are likely to affect only the alien fish populations in the Berg River. Indigenous fish are confined almost exclusively to the upper portions of the tributaries of the Berg River and the mainstream above the site of the Berg River Dam. The effects of the dam on these species are thus unlikely to be of major significance.

Any future restocking programme of the Berg River would only be viable once some of the alien fish species inhabiting the Berg River, principally small mouth bass *Micropterus dolimieu* and sharptooth catfish *Clarias gariepinus*, have been successfully eliminated from the system or at least a portion thereof. With this in mind, the following is recommended:

- Forward planning to turn the Berg River Dam to an advantage in this respect, making it an alien-fish free zone. Significant benefits could potentially accrue to other indigenous fish species in the Berg River system as well, if bass, catfish and other predatory fish species, can be eliminated from the section of river above the dam during the construction phase, and their reintroduction above the dam prevented in the future. Thriving populations of Berg River Redfin *Pseudobarbus burgi* and Cape Kurper *Sandelia capensis* have existed in the Wemmershoek dam since it was constructed in 1957, and it is quite feasible that a similar situation could be engineered for the Berg River Dam.

- Reintroducing *B. andrewi* to this dam would certainly greatly enhance the benefits of such an initiative, particularly if another successful wild breeding population can be established.

- Ensuring rainbow trout *Onchorhynchus mykiss* along with all other alien fish species are excluded from the new dam will probably not be possible or even necessary, considering that this species already cohabits with indigenous species in the section of river above the dam, and that the indigenous species in question seem to coexist happily together with *O. mykiss* in the Wemmershoek Dam.

- In the event that it is not possible to put such a scheme in place or to ensure that undesirable species do not colonise the Berg River Dam, it is imperative that necessary measures be put in place to ensure that no other alien species are able to access the section of the river above the dam where indigenous species still maintain a foothold.

A small weir situated immediately above the point at which the IBT release from Theewaterskloof enters the Berg is probably instrumental in preventing bass from penetrating further upstream.

This weir should not be removed under any circumstances even if alien fish are prevented from colonizing the Berg River Dam during or immediately after construction, as they may well be introduced illegally at a later stage.
Ideally the height of this weir should be raised to make absolutely sure that no alien species are able to pass up into the tributaries above. It is also imperative also that the IBT outlet from Theewaterskloof Dam be rerouted such that it discharges below the dam site or that the water emerging from it must be effectively screened so as to prevent transfer of *C. gariepinus* from Theewaterskloof to the new dam. Failure to do so would in all likelihood render efforts to conserve indigenous freshwater fish populations in the upper Berg to no avail.

### 4.7 CONSOLIDATED MONITORING RECOMMENDATIONS FOR THE BERG RIVER ESTUARY

#### 4.7.1 General monitoring recommendations

Recommendations for monitoring of a large variety of parameters in the estuary have been included under the various discipline-specific chapters in Volume 3 and 4 of this report. In most cases the recommendations are specific to the discipline in question and do not cross-refer to other disciplines, except possibly with the higher taxa (fish and birds). The net result of this is that many of the monitoring recommendations are asynchronous (i.e. do not necessarily coincide in terms of their timing and/or frequency). From the enhanced understanding that has been developed through the compilation of the estuary conceptual model regarding estuary functioning, it is clear that it is imperative that monitoring of most parameters be conducted in a synchronous manner (i.e. with the same or similar frequency and at the same time) if one is to develop a clear picture of how the estuary as a whole may be changing, and what the root cause of any such changes may be. In addition to this, work on the Berg estuary as a whole including that devoted to compiling the conceptual model, has highlighted the extreme complexity of the system and has reinforced the notion that it is not possible simply to monitor changes in a small number of parameters (be it physico-chemical or ecological parameters) with the hope that changes in these parameters can be extrapolated upwards or downwards to predict likely changes in other co-dependent or underlying parameters or taxonomic groups. Future monitoring protocols must include a range of physico-chemical parameters as well as all major taxonomic groups if it is going to be possible to identify at an early stage, any changes in the system arising from modified flow regime, to assess their significance, and to pin point the root cause of such change.

Some of the discipline specific recommendations included here are taken directly from the respective specialist reports while others are modified slightly to ensure synergy between all disciplines. This is considered acceptable as monitoring requirements for many of the physico-chemical parameters and lower taxa may be more or less comprehensive when considered in isolation, but differ when their effects on higher trophic levels and ecosystem wide effects are taken into account. These monitoring protocol should be taken as the minimum requirements for detecting changes in the Berg estuary arising from construction and operation of the Berg River dam, and should not be further refined without consultation with relevant specialists.

#### 4.7.2 Hydrodynamics and sediment transport

Specific monitoring recommendations in respect of hydrodynamics and sediment transport in the Berg River estuary are as follows:

- Install 8 permanent water level gauges on the floodplain at major pans.
- Ensure that these and other monitoring instruments are checked and serviced regularly, that the data is being logged at appropriate intervals, and that data are archived in a suitable and secure format and location.
- Take weekly suspended sediment samples at gauge G1H023 (Jantjiesfontein).

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2 Original recommendation for three sites has been increased to eight to bring this in line with recommendations from the avifauna report. Specific recommendations for the siting of these gauges is provided in the latter report (Turpie 2007 – Vol. 3, Chapter 10).
• Survey bed of main channel every three years at same cross-sections used in this study.
• Take sediment samples of the bed of the main channel at same locations as in this study, every 3 years.
• Take aerial photographs of the estuary every 5 years.
• The effect of the Berg River Dam flood release on the estuary from 2007, to evaluate the role of the initial water level at the estuary, and on the flushing of sediments through the system.
• Establish a new gauging station upstream of the estuary out of the tidal effect, to measure inflow (including floods) accurately.

4.7.3 Water chemistry

Physicochemical data collected from the Berg River Estuary during the Berg River Baseline Monitoring study has provided important information on seasonal variation and historic changes within the system, and important insights into factors affecting primary production and other biotic components within the system. In respect of nutrient data, clear historical changes have taken place in the system since monitoring was first undertaken in 1975, and these changes could be tracked through time using the data from sampling events spaced at roughly 5-yearly intervals in between (1989/1990, 1995/1996). The lack of any data between the period 1996 and 2005 is seen as a shortcoming in this data set. Similar breaks in the monitoring record for other physico-chemical parameters (e.g. water level, flow), have similarly hampered interpretation of changes observed in the system.

In any recommendations for future monitoring it is important to take the natural variability of the Berg River and Estuary system into consideration.

As a consequence monitoring should take place on a continuous basis wherever possible, so that perceived changes can be put into the context of the overall influence of weather and ocean processes.

It is therefore assumed that the systematic time series data at present available will continue into the future. These include the following:

• Weather data from sites such as Langebaanweg and Franschoek
• Ocean tidal data
• Water level data from the three sites on the estuary, namely Laaiplek, Kliphoek and Jantjiesfontein
• Stream flow data from the Misverstand dam. It would be preferable to have a gauging station at the head of the estuary (see comments included under the section on Hydrodynamics and sediment transport above).

In order to obtain continuous information on the state of the estuary, i.e. the manner in which sea water moves in and out on the tides, as well as the summer salinity ingress and winter flushing, it is recommended that:

• The monitoring station at Kliphoek is resurrected.
• Water temperature and electrical conductivity (salinity) should be measured at a depth of 1 m - this can be achieved from a floating platform, which will accommodate tidal and flood changes in water level. Ideally, these variables should be measured at hourly intervals.
• At a lower priority, the monitoring station at Jantjiesfontein should be resurrected. The measurements should be the same as at Kliphoek.

Obtaining boat section data is a substantial exercise, and has the disadvantage of essentially being an instantaneous snapshot of the estuary.
Nonetheless, it is the only opportunity to obtain detailed longitudinal profiles of the estuary and for understanding processes such as nutrient enrichment and nutrient cycling and re-mineralization in the estuary.

Thus, it is recommended that:

- For the first five years following construction of the Berg River dam, boat sections should be measured in winter (August, after the dam flood release) and summer (February) of every year. Following this, monitoring frequency can be reduced to once every two years for the next 10 years and thereafter to once every 5 years. In all cases, the same monitoring stations and variables should be measured as in this programme (temperature, salinity, oxygen, and pH) at multiple depth intervals through the water column. It is considered necessary only to measure at spring high and low tides, though. Water samples for analysis of DIN (nitrate, nitrite, and total ammonia) DIP (dissolved reactive phosphate) and DRS (dissolved reactive silicate) should be collected from at least 20 stations up the length of the estuary at the same time as the other physico-chemical parameters. These samples should be submitted to an accredited marine/estuarine laboratory for analysis.

4.7.4 Microalgae

Lying at the base of the estuarine food chain, micro-algae are a very important component of the estuarine ecosystem.

They respond rapidly to changes in physico-chemical conditions particularly temperature and nutrients concentrations in the estuary and as such are good early warning indicators of changes in these parameters. Phytoplankton biomass (measured as chlorophyll a) is also easy and relatively inexpensive to monitor. Regrettably, little historic data on micro-algae is available for the Berg River estuary but changes observed between measurements made in 1989/1990 and the present day suggest that phytoplankton abundance has increased substantially, probably in response to observed increases in nutrient concentration over the same time period (Clark & Taljaard 2007). It is critical that micro-algal abundance is more carefully monitored in the future to isolate any changes induced by construction of the Berg River dam. Thus, it is recommended:

- Surface and bottom water samples are collected for analysis of Chlorophyll a concentration of at least 20 stations up the length of the estuary at the same time intervals (and same time) at which the nutrient samples are collected. This would entail collecting samples at spring high and low tide up the length of the estuary during summer (January) and winter (August) for the first fives years following construction of the Berg River dam, reduced to bi-annually (once every two years) for 10 years following this, and then to a five-yearly interval thereafter.

- Inter tidal and sub tidal sediment samples are collected from a series of 10 stations up the length of the estuary for analysis of benthic microalgae (measured as Chla concentration) at the same time intervals as for water column chlorophyll a.

4.7.5 Macro algae and vegetation

Macro-algae form an integral part of estuarine ecosystems not only as primary producers, but also by altering habitat and providing shelter and feeding areas for numerous species.

Valetta and Hockey (1991) found that the abundance of benthic invertebrates in the Berg River estuary fluctuated in response to the seasonal growth of Zoster capensis and macro-algae. These benthic invertebrates are the primary food source for higher trophic level consumers such as fish and shorebirds (Whitfield 1998, Valetta and Hockey 1991). Macro-algae also provide shelter from predators for numerous species of juvenile fish that utilize estuaries as nursery areas (Clark et al. 1994). Excessive algal growth that may occur under atrophic conditions however, can have negative impacts by clogging channels thereby impeding water flow and restricting the movements and behaviour of fish and other estuarine fauna.
Predicted changes in base flow and flood frequency and timing (Howard & Ractliffe 2007, Beck & Basson 2007) associated with the construction of the Berg River dam, may allow macro algae to penetrate further up the estuary and lead to changes in biomass in the lower reaches.

Given that substantial increases in algae biomass and changes in species composition appear to have occurred in the last 15-20 years, this should be monitored on a regular basis (at least every 5 years, for at least two full seasons at a time) using similar protocols to those employed in this report.

4.7.6 Invertebrates

Invertebrates form an important part of the estuarine ecosystem, particularly in their contribution to sustaining populations of predatory fish and birds.

However, there is little historic information on abundance and diversity of invertebrates in the Berg estuary and the brief snapshot of their dynamics in this three-year baseline study does not provide a very firm baseline against which future changes can be assessed.

Collection and processing of invertebrate samples is also time consuming and hence cannot realistically be undertaken as frequently as with other faunal components. Thus, it is recommended that:

- Detailed surveys such as those undertaken for this study are repeated at approximately five-yearly intervals. These surveys should include all components of the invertebrate fauna including inter tidal and sub tidal benthos, hyperbenthos, and zooplankton, to be sampled at least 10 stations extending up the length of the estuary.

4.7.7 Fish

Fish species or fish communities are considered to be sensitive indicators of the relative health of aquatic ecosystems and frequently serve as the basis for biological monitoring to assess environmental degradation (Karr et al. 1981, Harrison et al. 1994). They represent a highly visible, dominant component of estuarine fauna assemblages and because of their key position in the aquatic food web, their abundance and species diversity within a system can portray both natural and anthropogenic changes therein.

Fishes are also highly mobile, enabling them to respond rapidly to both deteriorating and improving estuarine conditions (Whitfield 1996). As such, monitoring of fish communities of the Berg estuary is considered a very important element of any future monitoring programme.

Specific monitoring recommendations in respect of fish communities in the Berg River estuary are as follows:

- Fish assemblages in the Berg River estuary should be monitored using both seine and gill nets in a manner corresponding as closely as possible to that done for this and preceding studies of the estuary.
- Surveys should be conducted on an annual basis in mid summer (February) of each year for at least first five years after the Berg River dam comes on line, following which time monitoring frequency can be reduced to a bi-annual frequency (every second year) for the next 10 years.

Given that monitoring of fish in the Berg estuary is the longest standing monitoring programme of its kind in the country, it is recommended that monitoring frequency be maintained at this level in perpetuity. However, provided no significant changes in fish populations are detected that can be attributed to dam construction and operation, monitoring frequency can be dropped still further at this point to once every 5 years or dropped entirely if sustained funding is not available for this purpose.
• Seine net hauls should form an integral part of these surveys, to be conducted at least 40 stations up the length of the estuary, corresponding as closely as possible to those sites sampled during this study. Survey equipment and methods employed should also correspond as closely as possible to those used in this study (30 m by 2 m, 10 mm stretched-mesh beach seine net, to be laid by boat, and hauled by at least 4 persons).

• Gill net hauls should form an integral part of these surveys, to be conducted at at least 9 stations up the length of the estuary, corresponding as closely as possible to those sites sampled during this study.

Survey equipment and methods employed should also correspond as closely as possible to those used in this study (multi-panel gill net(s) comprising 44, 48, 51, 54, 75, 100 and 145 mm mesh panels of at least 20 m in length).

In addition to acting as an important nursery area and feeding ground for fishes on the South African west coast, the Berg River estuary also supports an active and productive line fishery. This fishery provides several valuable services, including functioning as an important source of protein for impoverished coastal and rural subsistence fishers as well as a socially and economically important recreational activity for both locals and visitors. This Berg River Baseline Monitoring Programme has highlighted the importance of previously unrecorded line fishing in South west coast estuaries as well as the increase in biomass of an estuarine ichthyofauna following the closure of a commercial gill net fishery. As such, it is recommended that any future monitoring programme include a component focussing on the fisheries of the estuary. Such a component should follow protocols established in this study, should span periods of at least two years at a stretch, and should ideally be repeated every five years.

4.7.8 Avifauna

Monitoring of avifauna currently comprises detailed counts of the entire estuary and floodplain twice a year, in July and January/February undertaken by the Avian Demography Unit, at the University of Cape Town. The July count corresponds to the peak numbers of some waterfowl and resident waders. However, this avifauna study undertaken as part of the Berg River Baseline Monitoring study has shown that the summer counts, which are intended to coincide with maximum numbers, have missed the most important periods for birds both on the estuary and floodplain. Peak numbers on the estuary usually occur in about December, and are also higher in March than mid-summer. Peak numbers on the floodplain are in September or October. The timing of the latter peak is linked to the timing of high flows.

Thus, it is recommended that future monitoring should take place three times a year: in June/July, September/October, and December. The timing of the spring counts should be responsive to rainfall and flooding events, and should ideally be timed to take place in the month following the first major flood, but not later than October.

In addition, physical monitoring should include regular recording of the water level on the floodplain, as well as in the river channel, so that bird counts can be interpreted in the light of the amount of flooding that has occurred and the period over which there is water on the floodplain.

Water level in the estuary channel is currently measured on an hourly basis at three localities (Laaiplek, Kliphoek and Jantjiesfontein), except that there have been numerous interruptions in these data prior to 2002 due to equipment failure and human error. If monitored properly, the latter site, in particular, will provide a better measure of flooding than information on flow. On floodplain water level needs to be recorded in such a way as to provide a picture of the extent to which the pans are inundated. This should include a selection of backwater pans alongside the river, sedge pans and the large open pans on the floodplain. It is recommended that eight stations are monitored on a weekly basis, at least from June to December.
The positions of the stations are shown in the avifauna report (Turpie 2007 – Volume 3, Chapter 10). These should be located at the deepest points of the pans indicated.

4.8 MONITORING PROGRAMME LOGISTICS AND REPORTING

The BRBMP has shown, as many studies do, that analysis of data and especially integration of results, requires that “driver” specialist studies be available to inform interpretation of the specialist disciplines that react to each of these “drivers”.

This means that deliverable should be staggered, allowing sufficient lead-in time for specialists to digest the information of those disciplines to which they need to react. It is unrealistic to set less than a 6 – 8 month turnaround time for reporting.

It would also be desirable, on ecological grounds, that the annual monitoring period extend from the start of winter (June month) through to autumn of the following year, with reporting deadlines for December.

The reasons for this is that winter flood flows are key drivers in the response of many biological components of the river ecosystem, and the winter flow period will inform the ecosystem response in spring through to summer. This has been borne out in at least one other IFR monitoring programme in the Western Cape (Koekedouw River).

However, monitoring of the actual implementation of IFR releases should be reported upon on a quarterly basis. Should refinement be required, especially in the releases of floods, then this will require advance planning that should be based on an evaluation of the practice and success of the flood release strategy of the preceding season.

4.9 REFERENCES


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