THE WATER QUALITY AND ECOLOGICAL STATUS OF THE DIEP RIVER CATCHMENT, WESTERN CAPE, SOUTH AFRICA

Tovhowani Brenda Ndiitwani

A minithesis submitted in partial fulfillment of the requirements for the Degree of Masters (M.Phil.) in Integrated Water Resource Management in the Faculty of Biology Conservation and Biodiversity,
University of the Western Cape.

Supervisors: Dr Richard Knight

Co-Supervisor: Mr. Lewis Jonker

November 2004

THE WATER QUALITY AND ECOLOGICAL STATUS OF THE DIEP RIVER SYSTEM, WESTERN CAPE, SOUTH AFRICA

Tovhowani Brenda Ndiitwani

KEYWORDS

Biotopes

Catchment

Effluent discharge

Land use

Reserve Determination

River systems

Scoring system

Water quality

Water abstraction

Waste sites

ABSTRACT

THE WATER QUALITY AND ECOLOGICAL STATUS OF THE DIEP RIVER SYSTEM, WESTERN CAPE, SOUTH AFRICA

M.Phil. minithesis, Faculty of Biology Conservation and Biodiversity,
University of the Western Cape.

T. B Ndiitwani

The study illustrates the current ecological integrity of the Diep River system, based on the recent river health assessment using the South African Scoring System version 5 (2000-2003) and the water quality data (1996-2002). Some of the major land-use impacts on the river system are highlighted.

Seven chemical parameters were monitored and analysed to assess diffuse and point sources of water pollution in the Diep River system. They are Ammonia (NH_4-N), Chemical Oxygen Demand (COD), Electrical Conductivity (EC), Nitrates (NO_3-N), Phosphates (PO_4-P), pH and Suspended Solids (SS). Analyses were based on sample medians taken over the period of 1996 to 2002 with 73 samples per site, and are compared to the Water Quality General and Special Limits for a Water Resource, and the South African Water Quality Guidelines: Aquatic Ecosystems (SAWQG:AE). The Water quality in the Diep River system indicated ammonia concentration levels from upstream sites, Riebeeks River (R10) to upstream of Malmesbury town (D09) sites and Groen, Phil and M19 sites complying with the Acute Effect Value (AEV) of 0.1 mg/l (according to SAWQG:AE). The highest values above the AEV found were 3.9 and 2.0 at D08 and M18 sites respectively, which are sites downstream of Malmesbury and Kraaifontein WWTW respectively, together with values in sites D07, K15 and Trib. 17. The COD concentration at sites D04-D02, M18-M12, K14 and Trib. 17 (which are below the collection point of organic nutrients from the WWTW,

industrial effluent, agricultural runoff, stock farming and solid waste sites) were over the Effluent Standard limit of 75 mg/l (only effluent standard was compared to because COD is a measure of organic compound related to the availability of contamination with sewage or organic waste). Electrical Conductivity (EC) median values in the whole system did not comply with Effluent General Limit of 70, with the highest of 857 the D02 site, while only site D03 and Phil did not comply with the Target Water Quality Range (TWQR) of 300 mS/m permitted for that particular area. Hyper-saline condition at the D02 site might probably be due to estuarine influences, and was confirmed by the presence of salt marsh plants (*Sarcoconia* spp.). The concentration of NO_3-N is low upstream of the Diep river and the tributaries, together with the recovering downstream sites are the only sites complying with mesotrophic conditions (SAWQG:AE.) of less than 2.5 mg/l. All other sites (Trib. 17, M16, M13 and Groen) with NO_3-N concentration over 2.5 mg/l falls within eutrophic conditions except for the Trib 17 site at 10.3 mg/l (where agricultural runoff and stock farming are concentrated) which falls under hypertrophic conditions (Figure 4.5). A drastic increase in phosphorus levels occurs downstream of Malmesbury WWTW, Kraaifontein WWTW, Fisantekraal (urban fringe and informal dense settlement) and Mellish stock farming. Only upstream sites (R10, D11 to D09) and the Groen site comply with the PO4-P hypertrophic condition limit of 0.3 mg/l. The rest of the river system is hypertrophic with algae and possibility of algal blooms. Readings of pH fluctuated within a range of 7.4 to 8.1, thus the alkaline waters of the Diep River System are within TWQR of 6-8 for well-buffered Aquatic Ecosystems allowable. The Diep River system does not comply with the Aquatic Ecosystem guidelines limits for SS, which is 10 mg/l (except at the R10, Groen and Phil sites). Other than natural riverbank erosion in the catchment, for example around Klapmuts area, there are a number of sand and stone quarries upstream of D03-D02, which together with agricultural fields, brick and pottery factories along the Mosselbank River contributed to sedimentation and therefore high SS. Diep River system comply with the Temperature Range determined by the set RQOs in this study (Table 6.2-6.9) and the TWQR of Aquatic Ecosystems at all the seasons but

Autumn samples increased by 6-11°C range (Table 5.1), probably influenced by the lack of flow in the river during autumn.

On the Diep River system, SASS5 scores, taxa and ASPTs indicate a decrease in trend from upstream going downstream, reaching a low score at D08, which is a site immediately below Malmesbury WWTW. There was an increase of SASS5 scores, taxa, and ASPTs from D07 to D06 due to water quality improvement as the water flows downstream and where there is a supplementary flow from the WWTW. From D06 downstream the scores decreased again due to urban encroachment, stormwater runoff from concentrated agricultural and stock farming areas, sand mining and quarry sites, WWTWs, solid waste sites, and illegal dumping in that part of the catchment. Low scores for SASS and number of taxa were recorded at the D08 and M18 sites, which are below the WWTW and Groen site and receive flow only in winter. Median ASPTs low scores of less than three were recorded at the M16 and Groen sites. Low flow due to abstraction is also a major impact causing low SASS and taxa scores in the Diep River system.

The current level of water abstraction, effluent disposal, and dumping of waste in the Diep River Catchment has had a major impact on the ecological integrity of the river. Indications are that land-use practices such as wineries, crop farming, stock farming, abattoirs, quarries, waste sites and wastewater treatment works have resulted in a significant deterioration in the ecological state of the Diep River Catchment.

DECLARATION

I declare that *The Water Quality and Ecological status of the Diep River Catchment, Western Cape, South Africa* is my own original work, that it has not been submitted before for any degree or examination in any other university, and that all the sources I have used or quoted have been indicated and acknowledged as complete references.

Tovhowani Brenda Ndiitwani

November 2004

Signature: ……………………

ACKNOWLEDGEMENTS

I would like to acknowledge the following institutions and individuals for assistance in writing this thesis:

The University of the Western Cape, especially Dr. Richard Knight, for his guidance throughout the writing of this thesis; Prof. Eugene Moll, for editing; and Mr. Lewis Jonker for coordinating the studies.

Department of Water Affairs and Forestry for funding, Ms Antonia Belcher from the Regional Office for providing the fieldwork training and technical assistance, and the GIS section for assistance in creating maps.

Dr Helen Dallas of the University of Cape Town, for assistance in statistical analysis and guidance.

ABBREVIATIONS

AEV - Acute Effect Value
ASPT – Average Score Per Taxon
ASPTs - Average Scores Per Taxon
Dh: - Desired Health
COD – Chemical Oxygen Demand
DIFR – Drought Instream Flow Requirements
DWAF – Department of Water Affairs and Forestry
EC – Electrical Conductivity
GSM – Gravel, Sand and Mud
IFR –Instream Flow Requirements
IHAS – Invertebrate Habitat Assessment System
IWQS – Institute of Water Quality Studies
MAR - Mean Annual Runoff
MDS – Multi-Dimensional Scaling
MIFR – Maintenance Instream Flow Requirements
mg/l – milligrams per litre
mmol/l – millimole per litre
mS/m – milli-Siemens per metre
Nat. - Natural
NH_4-N - Ammonia
NO_3-N – Nitrates
nd – not dated
PO_4-P – Phosphates
RDM – Resource Directed Measures
RHP – River Health Programme
RQOs – Resource Quality Objectives
RSA – Republic of South Africa
SASS5 – South African Scoring System, Version 5
SAWQG:AE – South African Water Quality Guideline: Aquatic Ecosystems

SIC – Stones-in-current

SOOC – Stones-out-of-current

SoR – State of Rivers Report

SS – Suspended solids

TWQR - Target Water Quality Range

TSS – Total suspended solids

spp. – Species

VEG – Vegetation (Aquatic and Marginal)

WQM – Water Quality Management

WRC – Water Research Commission

WWTW – Waste Water Treatment Works

TABLE OF CONTENTS

CONTENTS: **PAGES:**

Title Page.. i
Keywords.. ii
Abstract.. iii
Declaration.. vi
Acknowledgements.. vii
Abbreviations... viii
Table of Contents.. x
List of Figures... xvi
List of Tables.. xix
List of Appendices... xxi

CHAPTER 1: **Theoretical framework**.................................... 1

1 Introduction.. 1
1.1 Water as a renewable natural resources.......................... 1
1.2 Uses of water... 4
1.2.1 The Reserve... 5
1.2.2 Agriculture.. 6
1.2.3 Industry.. 7
1.2.4 Recreation.. 7
1.3 Deterioration of Water Resources................................. 8
1.3.1 Main types of pollution.. 9
1.4 Resource protection.. 10
1.4.1 Resource Directed Measures (RDM)...................... 12
1.4.2 Biological monitoring (biomonitoring).................. 14
1.4.3 Source Directed Control (SDC)............................. 18

1.4.4 Water Chemistry.. 18
1.4.4.1 Total Dissolved Solids (TDS).............................. 20
1.4.4.2 PH.. 21
1.4.4.3 Ammonium ions (NH_4^+).................................. 22
1.4.4.4 Phosphorus (PO_4^{3-})... 23
1.4.4.5 Nitrates (NO_3^-).. 24
1.4.4.6 Chemical Oxygen Demand (COD)........................ 24
1.4.4.7 Temperature.. 25
1.4.4.8 Dissolved Oxygen (DO).................................. 26
1.4.4.9 Suspended Solids (SS).................................... 26
1.4.5 Microbial properties.. 27
1.4.6 Flow.. 28

CHAPTER 2: DESCRIPTION OF A CATCHMENT............ 29

2.1 Problems in the Diep River Catchment.......................... 29
2.2 Aims of the study.. 30
2.3 Objectives.. 30
2.4 Description of a Catchment.. 31
2.4.1 Introduction... 31
2.4.2 Climate and Hydrology.. 33
2.4.3 Geology, Geomorphology and Geohydrology................. 33
2.4.4 Vegetation.. 37
2.4.5 Activities and Infrastructure in the Catchment................. 38
2.4.6 Population.. 38
2.4.7 Water abstraction.. 38
2.4.8 Water related infrastructure.................................... 39
2.4.9 Water chemistry.. 39

CHAPTER 3: METHODOLOGY **44**

3.1 Sampling materials 44
3.2 Sampling method 44
3.2.1 Localised sampling sites/points and reference sites 44
3.2.2 Sampling procedure and protocol 48
3.2.2.1 South African Scoring System, Version 5 49
3.2.2.2 Invertebrate Habitat Assessment System 50
3.2.2.3 Other data 51
3.2.2.4 Water Quality 51
3.2.3 The availability of data 51
3.2.4 Analysis Tools 51
3.2.5 Sampling frequency 52
3.2.6 Data analyses 53

CHAPTER 4: RESULTS **56**

4.1 Chemical Assessment (Water Chemistry) 56
4.1.1 Ammonia (NH$_3$-N) 57
4.1.2 Chemical Oxygen Demand (COD) 58
4.1.3 Electrical Conductivity (EC) 59
4.1.4 Nitrates (NO$_3$-N) 60
4.1.5 Phosphates (PO$_4$-P) 61
4.1.6 pH 62
4.1.7 Suspended Solids (SS) 63
4.1.8 Temperature 64
4.2 Biological Assessment (Aquatic Invertebrates) 65
4.2.1 South African Scoring System (SASS) Scores 67
4.2.2 Number of Taxa 70

4.2.3 Average Score per Taxon (ASPTs)………………………… 72
4.2.4 Invertebrate Habitat Assessment System (IHAS)………….... 73
4.3 Flow……………………………………………………… 75
4.4 Primer Results…………………………………………………. 76
4.4.1 Cluster Analysis/Classification and Multi-dimensional Scaling (MDS)…………………………………………… 76

CHAPTER 5: DISCUSSION…………………………………… 81

5.1 Chemical Assessment (Water Chemistry)……………………. 81
5.1.1 Ammonia (NH_3-N)………………………………………….. 81
5.1.2 Chemical Oxygen Demand (COD)………………………… 81
5.1.3 Electrical Conductivity (EC)……………………………... 82
5.1.4 Nitrates (NO_3-N)…………………………………………… 83
5.1.5 Phosphates (PO_4-P)………………………………………… 84
5.1.6 pH…………………………………………………………... 85
5.1.7 Suspended Solids (SS)……………………………………… 85
5.1.8 Temperature…………………………………………….... 87
5.2 Biological Assessment……………………………………….. 89
5.2.1 South African Scoring System (SASS)………………….... 92
5.2.2 Number of Taxa…………………………………………….. 93
5.2.3 Average Score Per Taxon………………………………... 94
5.2.4 SASS Discussion……………………………………………. 94
5.2.5 Invertebrate Habitat Assessment (IHAS)………………..... 95
5.2.6 Reference conditions……………………………………... 96
5.2.7 Differences between the Diep River System and other rivers in Western Cape……………………………………… 97
5.3 Primer Results…………………………………………………. 98
5.4 Links between flows and macroinvertebrates communities...... 99
5.4.1 Seasonal changes…………………………………….... 99

5.4.2 Low Flow.. 100
5.4.3 Moderate flow.. 101
5.4.4 Flushing.. 101
5.5 Biotope (Habitat)... 102
5.5.1 Sandy biotope.. 102
5.5.2 Vegetation biotope... 102
5.5.3 Riffle and bedrock biotope...................................... 103

CHAPTER 6: RESOURCE DIRECTED MEASURES (RDM).. **104**

6.1 Classification of River Reaches/Management Reaches.......... 104
6.2 Water Quantity (Flow) Reserve.................................... 107
6.3 Resource Quality Objectives (RQOs)............................ 108
6.3.1 Environmental Water Quantity (Flow) and Quality Requirements.. 109
6.3.2 Other User Requirements.. 118
6.3.3 Biological Indicator of Water Quality........................ 119
6.3.4 Habitat.. 120
6.3.5 Monitoring Requirements.. 120

CHAPTER 7: SUMMARY AND RECOMMENDATIONS...... **121**

7.1 Summary.. 121
7.1.1 Water Chemistry.. 121
7.1.2 Major impacts in the Diep River Catchment.................. 122
7.2 Recommendations.. 122
7.2.1 Management Actions in the Diep River Catchment........... 122
7.2.2 Recommendations for future studies.......................... 123

CONCLUSIONS……………………………………………………… 124

REFERENCES………………………………………………………… 126

APPENDIX A…………………………………………………………. 138

APPENDIX B…………………………………………………………. 140

APPENDIX C…………………………………………………………. 144

APPENDIX D…………………………………………………………. 150

APPENDIX E…………………………………………………………. 152

APPENDIX F…………………………………………………………. 153

APPENDIX G…………………………………………………………. 154

APPENDIX H…………………………………………………………. 155

APPENDIX I…………………………………………………………... 156

APPENDIX J…………………………………………………………... 157

APPENDIX K…………………………………………………………. 158

LIST OF FIGURES

Figure 2.1 Catchments in the City of Cape Town

Figure 2.2 Geology of the Diep River Catchment

Figure 2.3 Geomorphological Zones of the Diep River Catchment (DWAF)

Figure 2.4 Industrial water use and wastewater disposal in the Diep River Catchment

Figure 3.1 Biomonitoring sampling points/sites in the Diep River Catchment after Dallas (1997)

Figure 4.1 Median Ammonia concentrations (1997-2002) in the Diep River and its tributaries

Figure 4.2 Median COD concentrations (1996-2002) in the Diep River and its tributaries

Figure 4.3 EC Concentrations (1996-2002) in the Diep River and its tributaries

Figure 4.4 Median EC concentration (1997-2002) in the Diep River and its tributaries

Figure 4.5 Median Nitrate concentrations (1997-2002) in the Diep River and its tributaries

Figure 4.6 Median Phosphate concentrations (1997-2002) in the Diep River and its tributaries

Figure 4.7 Median pH readings (1997-2002) in the Diep River and its tributaries

Figure 4.8 Median SS concentrations (1996-2002) in the Diep River and its tributaries

Figure 4.9 The Temp readings in the Diep River and its tributaries

Figure 4.10 Median Temp readings (2000-2003) in the Diep River and its tributaries

Figure 4.11 The distribution of SASS5 scores in the Diep River and its tributaries

Figure 4.12 The median SASS5 scores (2000-2003) of the Diep River and its tributaries

Figure 4.13 The distribution of Number of Taxa found in the Diep River and its tributaries

Figure 4.14 The median Number of Taxa (2000-2003) found in the Diep River and its tributaries

Figure 4.15 The distribution of ASPTs found in the Diep River and its tributaries

Figure 4.16 The median ASPTs (2000-2003) of the Diep River and its tributaries

Figure 4.17 The distribution of IHAS found in the Diep River and its tributaries

Figure 4.18 The median IHAS (2000-2003) of the Diep River and its tributaries

Figure 4.19 The maximum water levels in meters (2000-2003) of the Diep River at Malmesbury, hydrology station G2H012

Figure 4.20 SASS4 Taxa 2000 (summer) Dendrogram and MDS ordination of the Diep River System biomonitoring sites

Figure 4.21 SASS5 Taxa 2001 (spring) Dendrogram and MDS ordination of the Diep River System biomonitoring sites

Figure 4.22 SASS5 Taxa 2002 (winter) Dendrogram and MDS ordination of the Diep River System biomonitoring sites

Figure 4.23 SASS5 Taxa 2003 (autumn) Dendrogram and MDS ordination of the Diep River System biomonitoring sites

Figure 4.24 SASS5 Taxa (four sites sampled each year – all seasons) Dendrogram and MDS ordination of the Diep River System biomonitoring sites

Figure 6.1 Summary map of SASS and Water Quality icons of the Diep River System monitoring sites

Figure 6.2 Preliminary IFR Results-Monthly distribution at Riebeeks River

Figure 6.3 Preliminary IFR Results-Monthly distribution of Diep River at Paardeberg

Figure 6.4 Preliminary IFR Results-Monthly distribution of Diep River at Malmesbury Town

Figure 6.5 Preliminary IFR Results-Monthly distribution of Diep River at Kalbaskraal

Figure 6.6 Preliminary IFR Results-Monthly distribution at Groen River

Figure 6.7 Preliminary IFR Results-Monthly distribution at Klapmuts River

Figure 6.8 Preliminary IFR Results-Monthly distribution at Mosselbank River

Figure 6.9 Preliminary IFR Results-Monthly distribution of Diep River at N7 bridge

LIST OF TABLES

Table 1.1 Levels of RDM procedures for various levels of Reserve Determinations (DWAF 1999c)

Table 2.1 Industrial water use and wastewater disposal and their coordinates in the Diep River Catchment

Table 3.1 The Diep River Catchment Biomonitoring sampling points, descriptions and coordinates (Dallas 1997a)

Table 3.2 SASS Sampling dates and frequencies

Table 4.1 Biotope availability per season/sampling date per site

Table 5.1 TWQR for water temperatures in the Diep River system as determined by the set RQOs

Table 5.2 Preliminary guidelines for the interpretation of SASS4 data in the Western Cape, separated on the basis of sub-regions (H.F. Dallas pers. comm.)

Table 5.3 Summary of the Ecological classes assigned on the basis of SASS Scores

Table 5.4 Habitat evaluation table (Thirion *et. al.*1995)

Table 6.1 Summary table of Desktop Flow Reserve and SASS and Water Quality icons's Present and Desired states.

Table 6.2 River Unit 1: Riebeeks River

Table 6.3 River Unit 2: Diep at Paardeberg

Table 6.4 River Unit 3: Diep at Malmesbury

Table 6.5 River Unit 4: Diep at Kalbaskraal

Table 6.6 River Unit 5: Groen River

Table 6.7 River Unit 6: Klapmuts River at Mikpunt

Table 6.8 River Unit 7: Mosselbank at Goedontmoeting

Table 6.9 River Unit 8: Diep at N7 bridge

LIST OF APPENDICES

Appendix A Summer (Nov-Dec 2000) macroinvertebrate community SASS4 data in the Diep River Catchment

Appendix B Spring (Oct-Nov 2001) macroinvertebrate community SASS5 data in the Diep River Catchment

Appendix C Winter (Jun-Jul 2002) macroinvertebrate community SASS5 data in the Diep River Catchment

Appendix D Autumn (Mar 2003) macroinvertebrate community SASS5 data in the Diep River Catchment

Appendix E Summary of Descriptive Statistical Analysis for NH_3-N data (1997-2002) per sites in the Diep River system

Appendix F Summary of Descriptive Statistical Analysis for COD data (1996-2002) per site in the Diep River system

Appendix G Summary of Descriptive Statistical Analysis for EC data (1996-2002) per site in the Diep River system

Appendix H Summary of Descriptive Statistical Analysis for NO_3-N data (1997-2002) per site in the Diep River system

Appendix I Summary of Descriptive Statistical Analysis for PO_4-P data (1997-2002) per site in the Diep River system

Appendix J Summary of Descriptive Statistical Analysis for PO_4-P data (1997-2002) per site in the Diep River system

Appendix K Summary of Descriptive Statistical Analysis for SS data (1996-2002) per site in the Diep River system

CHAPTER 1: THEORETICAL FRAMEWORK

1. Introduction

1.1 Water as a renewable natural resource

The water molecule is comprised of two atoms of hydrogen and one of oxygen, and moves from solid to liquid to gas depending on temperature. Water is an essential component of the biosphere and dominates our planet: covering approximately 70% of the total surface of the planet and very little of it is directly available as freshwater. High evaporation and transpiration reduce available water and therefore influence water scarcity (Agnew and Anderson 1992).

There is a misconception that water is unlimited, and that it just flows at the turn of a tap, and that water left to run out to sea is water wasted (Davies and Day 1998).

The arrangement of landmasses, mountain ranges, cold and warm currents in the oceans, prevents equal distribution of rain around the world. Water is unevenly distributed worldwide. Globally dry lands consist of semi-arid areas (200 to 500 mm of rain a year); arid areas (25 to 200 mm of rain a year); and hyper-arid areas (less than 25 mm of rain a year) (Davies and Day 1998).

Almost all of Southern Africa is classed as a dryland by world standards, with climate ranges from semi-arid to hyper-arid, with few humid parts of rainfall exceeding 500 mm per year (Davies and Day 1998).

South Africa experiences a wide range of climates, from winter rains and warm windy summers in the south-western Cape; to erratic, non-seasonal rainfall and extreme temperatures in the Karoo; to hot summers with thunderstorms and cold winters on the highveld; and subtropical and mesic conditions on the Kwazulu – Natal coast (Davies and Day 1998). More than half of South Africa is rated as potential desert with an overall average rainfall of 452 mm per year, and most parts receive less than that, for example, large areas of Cape Province and the Northern Transvaal (Limpopo Province) are at risk. The recent drought of the 1980's has made us aware that we are living in a water-poor country (Allanson 1995).

Water is becoming more and more scarce each day; it is a limited resource. It is estimated that by the year 2020, demand for water will probably exceed supply and resources from well-watered neighboring countries will need to be handled with care (Allanson 1995). The increasing scarcity of water for both its human and environmental benefits as well as the scarcity of the financial resources required humans to develop water infrastructure and policies. Economic consideration plays a key role in public decisions on water projects.

In South Africa, the Minister of the Department of Water Affairs and Forestry (DWAF) (who is the custodian of water) established a pricing strategy which differentiates between geographical areas, categories of water users and/or individual water users in 1999. Water use charges are used as a means to encourage reduction in waste, as provision for funds for costs of water management, and as incentives for efficient and effective water use. Setting the differentiated charges is meant to achieve social equity, equitable and efficient allocation of water, to ensure compliance with prescribed standards and water management practices; according to the user pays and Polluter Pays Principles (NWA 1998). A rising block tariff method is used for water payment for the following major sectors: domestic, industrial, mining, energy, agriculture, and forestry. The advantage of a rising block tariff method is that it accommodates free basic water for all the people, and then water charges increase exponentially as water use increases. Currently the charges range from 0.2 to 0.3 cents per cubic meter of water used depending on the Water Management

Area (DWAF 1997; NWA 1998). Non-payment of water use charges attracts penalties in the form of restriction or suspension of water supply (NWA 1998).

With increasing population growth rates and improved life styles, the competition for scarce water resources is increasing. For example, World Resources (2001) indicated that rapid population expansion in metropolitan areas like Cape Town is threatening to create a regional water crisis. Researchers have predicted that in parts of the Cape, water demand in the year 2010 could be 70-106 percent higher than in 1990; and that about a third of the total surface water in the region was already being used by agriculture, urban dwellers and forestry (World Resources 2001). The threat of water shortages and the equity in water distribution is said to have motivated a re-evaluation of South Africa's land management practices (DWAF 1990; World Resources 2001). This is another reason why in South Africa we have a Constitution, a legal framework, and strategies and principles for safety and security of the water resource. The New Water Act, National Water Act (NWA), 1998 (Act 36 of 1998) has caused a paradigm shift towards the understanding and management of water. The NWA recognizes that water resources need to be managed in a sustainable manner. Integrated Water Resources Management is an evolving process for the coordinated planning and management of water, land and environmental resources. It is based on the concept that different water resources (rivers, wetlands, reservoirs, and groundwater) are linked by the hydrological cycle to each other, to the surrounding environment, and to human activities that influence them (DWAF 2002b). According to the NWA, a water resource includes a watercourse, surface water, estuary or aquifer. A watercourse means a river (including its bed and banks), spring, wetland and a lake (NWA 1998).

Due to high evaporation rates over utilization as well as limited surface water, groundwater is increasingly becoming the most important resource to meet the growing needs for water in South Africa. Braune 2000 (in Stephens and

Bredenkamp 2002) indicated that South Africa is among the 20 most water-stressed countries in the world. Groundwater plays an important role in water supply, especially in semi-arid areas, supplying rural communities, smaller towns, and agricultural activities. Groundwater also feeds the ecological habitats associated with springs, streams and wetlands through baseflow. These ecosystems depend on groundwater in terms of fluctuations of quality and quantity. For example groundwater bodies supply vegetation in the near surface zone (Stephens and Bredenkamp 2002). Surface water resources also depend on groundwater for replenishment, because groundwater resources have the ability to store water long after recharge has taken place.

DWAF has changed from an effluent standard approach to a Receiving Water Quality Objectives (RWQO) approach in managing water resources (both surface and groundwater). Groundwater management is complex because it is unseen and the availability is difficult to quantify. The whole concept of Integrated Water Resource Management and the international standard of management are important in groundwater protection, because unlike surface water groundwater is not regionally bound or bound by international borders. These include both quantity and quality of water, in a state of “fit for use” taking into account all five categories of water users, namely, the Reserve (aquatic ecosystem and basic human requirement), domestic, industrial, agricultural and recreational use (DWAF 1995; NWA 1998).

1.2 Uses of water

According to section 21 of the NWA, *water uses include consumptive as well as non-consumptive uses. Consumptive uses are taking, storing, and/or diverting the flow resulting in streamflow reduction; and non-consumptive components are discharging waste or wastewater into a water resource or on land by irrigation, disposing of heated water, altering the bed and banks of water* *courses, and removing underground water by mining and for recreational purposes* (NWA 1998).

The main water users are the Reserve (Ecological and Basic Human needs), domestic, agriculture, industries and recreation. According to the NWA the use of water requires authorization prior to abstraction (Existing Lawful Water use, General Authorisation, ad hoc licences, and Compulsory licensing), except for Reserve and Schedule One use. Schedule One uses are those that have low or minimal impact on water resources, which include water for emergency like fire fighting, water for non-commercial or domestic stock, gardening, and recreation. These authorisations are regulatory tools and strategies to address equity, maintain sustainability and access of water for different water uses (NWA 1998).

1.2.1 The Reserve: Ecological and Basic Human needs

According to the NWA (1998), the Reserve is the water required to meet basic human needs and maintain environmental sustainability. This is guaranteed as a right and is given a priority over all other water uses.

The Reserve means that quantity and quality of water required –

(a) to satisfy basic human needs by securing basic water supply, as prescribed under the Water Services Act, 1997 (Act No. 108 of 1997) for people who are now or in the near future will be relying upon, taking water from, or being supplied from the relevant water resources; and

(b) *to protect aquatic ecosystems in order to secure ecologically sustainable development and use of the relevant water resources* (NWA 1998).

South Africa has a high population growth rate and therefore there is an increase in water demand for domestic use. More than half of 15% of water consumed in South Africa is used domestically (Davies and Day 1998). Changing living standards already have a pronounced effect on domestic water demand. Total water usage for 2000 in Western Cape Province alone was estimated to be 3 720 million m^3 per annum (DWAF 2000b). In order for the South African Government to ensure equity, even for poor people to get their adequate share of domestic water, the government developed a "Free Basic Water Policy". In the Free Basic Water Policy the water charges are structured to provide the first 6 000 litres per household per month free of charge (World Summit 2002). This policy is derived from the Reconstruction, Development and Planning (RDP) provision of 25 litres per person per day stated as a short-term target, or minimum water supply for basic human needs (DWAF 1997). The operating costs are covered by a combination of a rising block tariff above that consumption and a subsidy from the national budget to the local government specifically for basic service provision. This method was meant to ensure that people's right of access to basic water supply is not limited by affordability (World Summit 2002).

1.2.2 Agriculture

Irrigation is the largest consumer of available water in South Africa, consuming approximately 75% of water (Rogers and Feiss 1998). According to the CSIR (1999), South African agriculture is estimated to use 90% of the 1.8 m^3 of groundwater extracted. Most farmers (over 75% in South Africa) depend on water for production. Groundwater offers an advantage in agriculture by supplying water for irrigation (DWAF 2000a; Stephens and Bredenkamp 2002).

Irrigation farming plays an important role in the socio-economic dispensation in South Africa. Irrigation is the largest consumer of available water in South Africa. This trend will increase in future and farmers will suffer by getting less water due to the degraded quality of water flowing downstream as well as falling supplies resulting from the over abstraction of groundwater. It is therefore essential that new irrigation development be assessed taking competing water demands, like industrial use, domestic use and recreational use into consideration (DWAF 1996a).

According to (DWAF 2000b), in the Western Cape Province, alien vegetation and afforestation in the river catchments is estimated to consume approximately 250 million m^3 per annum of valuable water, which poses a threat to all water users.

1.2.3 Industry

Many industries use water for production. This is where most effluent is generated through the production process. Water is used in great quantities in the manufacture of paper and rayon, and as a cooling agent in the manufacture of steel and fruit canning. About 40% of all water used in industries is surface water taken from the rivers and returned, with or without contaminants (Deming 1975). Mining beyond the water table is regarded as groundwater use, because of the dewatering and/or abstraction of water from the operation to the surface (DWA 1986).

1.2.4 Recreation

The recreational use of water includes swimming, hiking, skiing, boating and golf courses. Golf courses are one of the major recreation users of water. Development requires economic growth, which may render sustainability impossible, by further depleting the environment and polluting the biosphere (Trzyna 1995).

1.3 Deterioration of Water resources

Human activities such as over abstraction and disposing waste into the water resources in such a way that the water resources become degraded and rendered unfit for use abuse water resources. South Africa has few rivers which are not over utilized, degraded or polluted. Previously perennial rivers like Diep River are utilized to such an extent that they now only flow seasonally and have a reduced water quality (Myburg 2000). Decreased releases from the reservoirs are the primary cause responsible for the nutrient enrichment downstream (Camargo *et. al.* 2004). Ecosystems that depend on water have also being abused and lost much of their diversity (DWAF 1999a). If the utilization of water resources remains at a level within the limits that can protect ecological resilience, then that level of utilization can be sustained indefinitely (DWAF 1999a). Sustainable development is also critically dependent on water availability and impacts associated with pollution. Anthropogenic activities, which negatively impact on groundwater, are depletion of groundwater. Such activities include over abstraction of water, water clogging, salinisation and pollution, all of which lead to the general problem of declining water tables and deterioration of quality. For example there is already groundwater over-exploitation in the Sandveld area in Western Cape Province (DWAF 2002a). Loss of recharge area due to urbanization and disturbance of wetland by overgrazing or deforestation also causes groundwater exploitation (Stephens and Bredenkamp 2002). Depletion of coastal aquifers is said to have lead to the risk of saline intrusion into groundwater; for example, over abstraction of water from the Robben Island aquifer.

Water pollution means the alteration of the physical, chemical and/or biological properties of a water resource so as to make it less fit for other uses. The signs of water pollution are sometimes obvious, even to the casual observer. For example, drinking water may taste bad, masses of aquatic weeds may grow uncontrolled in many water bodies, ocean beaches, rivers and lakes emit disgusting odours, fish numbers decrease, and oil can be seen floating on the surface of water or deposited as scum on beaches.

Water can be an agent of pollution if we fail to manage and protect our precious water from being polluted. Water is a potential carrier of pathogenic microorganisms which are a threat to human life. Those pathogens are responsible for infection, and cause water-borne diseases like cholera, dysentery, and typhoid. The pathogens are present in the faeces and urine of infected warm-blooded animals and are discharged into the water (Myburg 2000).

There is a need for pollution prevention and control of the water resources to sustainable needs. Sustainable management of groundwater is needed to prevent groundwater depletion before it becomes a regular occurrence in South Africa, just as in China and west and south Asia. Excessive lowering of groundwater levels by over-abstraction may cause formation of sinkholes, leading to the degradation of the environment in a broader sense (Stephens and Bredenkamp 2002).

1.3.1 Main types of pollution

Main types of pollution are point source and non-point (i.e. diffuse) source. Point source type of pollution is caused by effluent generated by sewage treatment works and industries, as well as leachates generated by waste disposal sites and mines. These points are normally in a form of a pipeline or a discharge point, and are easy to detect and monitor. Diffuse pollution sources occur when water flows over the surfaces collecting particles and dissolved soluble material from the rocks and plant cover and discharges this into the river (Allanson 1995). This type of pollution is mainly from storm water runoff from towns, informal settlements, villages, agricultural areas, and through dumping waste directly into the water. This is mainly connected to the pollution of organic waste, siltation, nutrients fertilizers and pesticides (Shieh *et. al.* 1999). Stephens and Bredenkamp (2002) indicated that irrigation return flows might become contaminated with fertilizers and salts into the water resources. When irrigating with wastewater, some may percolate through the soil and ions from wastewater may contaminate the groundwater or runoff into surface water (DWAF 1995; Pearce and Schumann 2001)

1.4 Resource protection

The definition of a water resource according to DWAF (1999b) includes three compartments of habitat (sediments, instream and riparian), aquatic biota and water, as well as the physical, chemical and ecological processes which link these components of the aquatic environment. The sustainability of the ecosystem depends on the ecological interactions between the physical, chemical and biotic components of water. An integrated approach is now applied to water resource management, which links aquatic ecological compartments and their different management requirements. These incorporate all the components of aquatic ecosystems, as well as the water quality needs of the various users.

Chapter 3, part 1 of the NWA (1998) provides for the development of a classification system that will provide guidelines and procedures for determining different classes of water resources. The classification system is to be used to determine the class and resource quality objectives of all or part of the water resources. The importance and sensitivity of the water resource is used to guide or influence the decision on the level of protection required for the ecological integrity of the river system. The Resource Quality Objectives (RQO) aim to provide clear goals for the quality of water resources, understanding the need for some balance between protection and sustainability, and use and development. Provision is made in the Act for the preliminary determinations of the class and resource quality objectives before the formal classification system is established (IWQS 1999).

Chapter 3, part 2 of the NWA (1998) deals with the classification of water resources and RQO through classification systems. The purpose of RQO is to establish goals relating to the quality of the relevant water resources (NWA 1998). The RQO can be allocated for each ecological indicator group after a management goal for a particular river is already allocated (Roux *et. al.* 1999).

Chapter 3, part 3 of the NWA (1998) deals with the "Reserve", which refers to both the quantity and quality of water in the resource, and which consists of the basic human needs reserve and the ecological reserve. The basic human needs reserve is the water essential for the needs of individuals, and includes water for drinking, preparation of food and personal hygiene. The ecological reserve is that water required for protecting aquatic ecosystems. The reserve will vary depending on the class of the resource. According to DWAF (2002b) the proposed classification of the water resources are:

(i) *Natural*

No or minimal changes to biological communities, hydrological characteristics, or the bed, banks and channel of the resource. Chemical concentrations are not significantly different from background concentration levels for naturally occurring substances.

(ii) *Good*

Resource conditions are slightly to moderately altered from the Natural class conditions.

(iii) Fair

Resource conditions that are significantly changed from the Natural class conditions.

(iv) Poor

Resource in a condition below Fair and considered unable to sustain functional ecosystems.

(v) Severely Modified

Water resources so severely and permanently physically modified (e.g. rivers that have been canalized through urban areas, or for flood protection) that rehabilitation is not possible. These will be classified as Severely Modified, and will not be considered as functional ecosystems.

1.4.1 Resource Directed Measures (RDM)

According to DWAF (1999b), RDM is a regulatory activity defining a desired level of protection for a water resource by setting clear goals for the Resource Quality Objectives (RQOs). Three core concepts of RDM are Classification, The Reserve and RQOs. Classification for water resources is grouping water resources into classes representing different levels of protection, as discussed under "Resource Protection" above. Resource Quality Objectives for a water resource are a numerical or descriptive statement of the conditions, which should be met for a particular water resource in order to ensure its protection. The Reserve is the quantity and quality of water catering for Ecological and Basic Human needs.

The River Health Program (RHP) is another regulatory activity forming an integral part of the SASS rapid bioassessment, which monitors the status of the water resource (river system) on a continual basis to enable managers to modify programs for resource management and impact control when necessary. An important aspect of the RHP is the development of biological monitoring and assessment tools (Kemper 2000; Vos *et al.* 2002). River Health refers to the ability of ecosystem to function more like its natural state and any reduction leads to a decrease in integrity (Vos *et al.* 2002). There are four (4) levels of RDM procedures (Table 1.1):

Table 1.1 Levels of RDM procedures for various levels of Reserve Determinations (DWAF 1999c)

Level Term	Characteristics	Use
1 Desktop estimate	Very low confidence, about 2 hours per water resource	for use in National Water Balance Model only
2 Rapid determination	Low confidence, desktop and quick field assessment of present status, takes about 2 days	Individual licensing for small impacts in unstressed catchments of low importance and sensitivity; compulsory licensing
3 Intermediate determination	Medium confidence, specialist field studies, takes about 2 months	Individual licensing in relatively unstressed catchments
4 Comprehensive determination	Relatively high confidence, extensive field data collection by specialists, takes 8-12 months	All compulsory licensing, individual licensing, for large impacts in any catchment. Small or large impacts in very important and or sensitive catchments.

1.4.2 Biological monitoring (biomonitoring)

Biological monitoring or biomonitoring is a valuable tool in determining the short-term water resource quality history of a system in contrast to chemical analysis data, which only portrays the momentary conditions at the time of sampling. Biomonitoring is based on the premise that a measure of the health of the biota can be used to assess the health of an ecosystem. Biological indicators are used to determine the effect of changing environmental conditions, caused by natural causes, changes to habitat, or point and non-point sources that impact on the water quality (IWQS 2000). Aquatic biota is defined as all biotic communities in the aquatic ecosystem, which are fish, macroinvertebrates, plants (riparian vegetation, algae and macrophytes) and macro-organisms; and they are used as biological indicators when assessing the river systems (Malan and Day 2002). Biotic community structure and composition in river systems is determined by interacting factors such as flow, food source, habitat structure, biotic interactions and water quality (chemical and physical) of the water body (Dallas *et al.* 1994). The interaction between surface and groundwater also supports and sustain the rare and endemic flora and fauna in the catchment (Stephens and Bredenkamp 2002).

According to the National RHP biomonitoring may be used to assess the ecological state of aquatic systems, the spatial and temporal trends in ecological state, emerging problems, set objectives for rivers, assess the impact of developments, predict changes in the ecosystem and to determine the Reserve (Dickens and Graham 2002).

There are different indices used for the Ecological Reserve determination and for biological monitoring, which are the following:

i) SASS – South African Scoring System

South African Scoring System (SASS) is a field-based, rapid bioassessment method that uses information on aquatic macroinvertebrates specifically to assess the impairment of water quality in rivers, as well as providing a useful standard index of riverine health. SASS method is designed for low/moderate flow hydrology and is not applicable in wetlands, impoundments, estuaries and other lentic habitats (Dickens and Graham 2002). SASS was adopted from the United Kingdom for use in South African streams and rivers and is presently in Version 5. SASS is easy and fairly reliable way of assessing pollution (Chutter 1998; Dallas *et al.* 1999; Dickens and Graham 2002). Macroinvertebrates are used to examine the effect of water quality in the aquatic community because of the major role they play in the food chain and possession of many useful features (Malan and Day 2002). Macroinvertebrates may also be used both as quantitative indicators of environmental conditions at multiple scales and of land cover optima to establish priorities for conservation and restoration efforts (Black and Munn 2003).

An advantage of using macroinvertebrates as indicators of environmental pollution is because they are rapid to respond to pollution. Macroinvertebrates are permanently available and abundant in unpolluted waters, and are sensitive to low concentrations of pollution or stress. Macroinvertebrates are easily visible, easy to identify, relatively non-mobile, have a rapid life cycle, and are representative of a sample site which easily indicates disturbance and pollution (Dallas *et al.* 1994; Palmer *et al.* 1996; Dickens and Graham 2002.). Another advantage is that macroinvertebrates are useful when information is required quickly and when a large number of sites need to be investigated (Hose *et al.* 2002). The aquatic ecosystem integrity will be protected by means of resource management through RDM (IWQS 1999).

The disadvantages of using macroinvertebrates as indicators of environmental pollution is that they may not be sensitive to all pollutants, and that there are other factors affecting their availability other than water quality, such as flow, habitat, food availability, climate and other biotic interactions.

SASS uses the presence or absence of macroinvertebrates, each taxon being assigned a score related to its sensitivity or tolerance of pollution. The higher the score, the more sensitivity the taxon is to pollutants. Interpretation is based on SASS Score and Average Score per Taxon (ASPT), which is the SASS score divided by the number of taxa found. ASPT is said to be the most consistent over all biotopes (Dickens and Graham 2002).

SASS can be used to indicate and reference the least-impacted sites, the higher the scores the more suitable the water quality is for riverine organisms (Dallas *et al.* 1998; Dallas *et al.* 1999).

SASS is assumed to reflect water quality at a site based on an individual taxon's sensitivity and tolerance to water quality impairment (water quantity not taken into account). SASS is assigned to detect, monitor, and assess water quality in the river system, enabling long term analysis of continuous or incidental discharges, variable concentrations of pollutants, single and multiple pollutants. Land-use activities affect water quality, which is in return reflected in SASS scores. SASS helps to indicate water quality requirements for aquatic assessment as well as the setting of RQOs to ensure a certain level of protection to aquatic ecosystems (Chutter 1995; Dallas *et al.* 1994, 1998). SASS provides key information pertinent to the management of river basins for sustainable utilization (Chutter 1995). The less altered the water quality the higher the SASS score and ASPT, and the more polluted the water is the lower the SASS scores become (Chutter 1998).

ii) RVI – Riparian Vegetation Index

Riparian vegetation forms an integral and important part of any river ecosystem. It is influenced by geomorphological, ecological and human impacts, which have a bearing on the condition and long-term functioning and sustainability of the river. These roles include the stabilization of river channels, banks and floodplains, flood attenuation, maintenance of water temperature and quality, provision of habitat for terrestrial and aquatic fauna, breakdown of pollutants and provision of fuel, building materials, and medicines for local community (Kemper 2000).

Vegetation monitoring techniques have been designed and implemented for terrestrial applications for the sake of wildlife management and forestry. Riparian systems are monitored in response to the management of releases of water for the provision of the ecological reserve for rivers (Kemper 2000).

iii) FAII – Fish Assemblage Integrity Index

Fish comprise a major biological component of aquatic ecosystems. They are relatively long-lived, mobile and are important to the food chain. Fish indicate long-term environmental changes. Fish Index is a biomonitoring tool, using indigenous fish species to assess the health of the rivers in terms of water quantity and quality (IWQS 2000).

iv) IHAS – Invertebrate Habitat Assessment System

According to Dallas *et al.* (1994), one reason that species of organisms in aquatic systems vary regionally is because of variation in the type of biotopes available. A biotope can be described as individual habitat and niche requirements of a community of species. The number of available biotopes such as stones-in-current, stones-out-of-current, marginal vegetation, aquatic vegetation, gravel, sands and mud; may influence the SASS scores. IHAS scores are based on the number of biotopes. Habitat availability is an important variable for comparison of invertebrate abundance, diversity, and certain taxa are more commonly found in one biotope than another (IWQS 2000). The total number of taxa decline as forest (vegetation) land cover within the local scale declined below 80 to 90% (Black and Munn 2003).

1.4.3 Source Directed Control (SDC)

Source Directed Control (SDC) is the measure controlling impacts (at their source) on the water resource through the use of regulatory measures such as registration, authorization, tariffs and fees in order to ensure that RQOs are met. A component of SDC is aimed at preventing or minimizing the impact of point and non-point sources on water resources, and it is for this reason that it is related to Water Quality Management (WQM). WQM is the management of the quality of the water resulting from different water uses and its impact on the water resources (surface and ground water) directly and/or indirectly (DWAF 1999a).

1.4.4 Water chemistry

DWAF (1996a) refers to water quality as the "physical, chemical, biological and aesthetic properties of water that determine fitness for a variety of uses, and for the protection of the health and integrity of aquatic systems". Naturally, the physical and chemical constituents of water are determined by climate, geology, geomorphology and the biota. Water quality constituents refer to any properties of water and/or the substances suspended or dissolved in it, which are as follows:

- System variables – temperature, pH, Dissolved Oxygen (DO)
- Non-toxic inorganic constituents – Suspended Solids (SS)

- Nutrients – phosphates, nitrite, nitrate and ammonia
- Toxins and pollutants – metal pollutants and organic substances like pesticides and effluents.

Diversity in aquatic communities differs regionally, according to the historical distribution of the species and different chemical and physical characteristics of water. Each species of aquatic biota is adapted to water of a certain chemical concentration range. For example, certain species of amphipods are adapted to Cape mountain rivers with Total Dissolved Salts/Solids (TDS) of less than 50 mg/l (Dallas *et al.* 1994).

Point and non-point sources of pollution reduce the quality of water in the water resources. Water quality degradation may either be chemical, physical or microbial.

A decrease in water quantity in the river will change instream concentrations of water quality and physical variables (Malan and Day 2002). Water quality can vary due to seasonal or daily (day and night) difference, for example, temperature, DO and dissolved CO_2 vary diurnally (DWAF 1996b), while flow levels are more seasonally affected. Temperature and Dissolved Oxygen (DO) are system variables, which regulate essential processes within the aquatic ecosystems (Dallas *et al.* 1998).

Concentration of chemical constituents in the river water varies from region to region, river-to-river, and even between different subregion/zones within the same river (headwaters of a river to its lower reaches (Dallas *et al.* 1994). Chemical monitoring is an effective way or tool to assess groundwater quality (Stephens and Bredenkamp 2002) or surface water quality.

1.4.4.1 Total Dissolved Solids (TDS)

Total Dissolved Solids (TDS) is a measure of all salts and organic materials dissolved in water. All natural waters have different levels of dissolved solids depending on the geological formation in the area, dissolution of minerals from different types of rocks, soil and decomposing plant materials in the area (Dallas *et al.* 1998). The level of TDS in water determines its salinity (Stephens and Bredenkamp 2002).

Allanson *et al.* (1990) defines salinisation as the process whereby the concentration of TDS increases in inland waters.

The effect of rising salinity levels on freshwater ecosystems is of concern in many parts of the world, including Australia and Southern Africa (Kefford *et al.* 2004). Salinisation, eutrophication and micro-pollution are said to be the most problematic factors affecting water quality in South Africa, with salinisation rating the highest (Davies and Day 1986). Zokufa *et al.* (2001) also indicated that salinity in South Africa is seen as one of the problems facing future water use and causing the deterioration of water quality. Salinity is a potential problem in the lower reaches of the Breede and Olifants/Doring (Sandveld) River systems in Western Cape Province, and is limiting further agricultural development in these areas (DWAF 2002a).

Human activities such as effluent and industrial discharges and irrigation return flow increase TDS levels. Very low or very high pH values also contribute to the increase of ionic discharges. Changes in TDS cause changes in ecosystem structure and function in aquatic organisms such as community structure, microbial activity, and physiological and ecological processes (rate of metabolism and nutrient cycling). Low-salinity habitat adapted organisms are generally sensitive to TDS concentration. For all inland water, TDS should not differ by more than 15% from the natural state (Dallas *et al.* 1998).

1.4.4.2 pH

The pH value is the measure of the hydrogen ion activity in a water sample (Dallas *et al.* 1998). In natural waters pH is determined by the geology and atmospheric influences. The pH of pure water at 24°C (water without solutes) is 7.0, and the water is said to be neutral. The neutral pH of 7 is changed by the acids and bases solutions introduced into the water system. The pH of most fresh waters is relatively well buffered or neutral and ranges between 6 and 8 (Dallas *et al.* 1994). Low pH values are normally caused by human activities such as acidic point source effluents from industries, mine drainage and acid precipitation from atmospheric pollution (burning coal, sulphur dioxides emission and nitrogen oxides from exhausts of combustion engines). High pH values may be caused by increased biological activity in eutrophic systems (Dallas *et al.*1998).

In South Africa surface water pH ranges from 4 to 11 (Dallas *et al.* 1998) and the water quality of rivers can be divided into two categories in relation to pH. Those categories are the calcium-poor rocks of the Table Mountain Group that are acidic (pH 4.5-6) and peat stained because of the organic materials from the fynbos plants (e.g. Western Cape rivers) and eastern areas rivers that are usually alkaline (pH more than 7) (Allanson 1995; Dallas and Day 1993; DWAF 1996b).

In naturally acid waters of the Western Cape waters, where pH values are mostly less than 5.5, vegetation (e.g. fynbos) organics and their salts may form the major buffering systems. Biota in these rivers is often adapted to these conditions (Dallas *et al.* 1998).

pH may vary naturally from season to season, for example, in Western Cape rivers, pH decreased more (more acidic) during winter due to leaching of organic acids from fynbos vegetation, for example, the first flood flush in Eerste River in Cape Town leads to a decrease in pH. Under anthropogenic circumstances, during winter, pH mostly increases due to the dilution of organic compounds (DWAF 1996b). Alkaline conditions may be enhanced by the increased number of un-ionised ammonia (NH_3), which may lead to an increase in phosphate concentration, pH and temperature (Dallas *et al.* 1998).

According to Dallas *et al.* (1994), the rate of change of pH is determined by the buffering capacity (i.e. carbonate-bicarbonate system) of the water. Changing of water pH changes the H^+ and OH^- ions concentrations, which affects the osmotic balance of aquatic organisms. Rapid change of pH may have severe effects on aquatic biota, changes in ecosystem structure, and function and biodiversity (Dallas *et al.* 1998). pH changes in a river system can influence the distribution of Baetidae (Ocon and Capitulo 2004).

1.4.4.3 Ammonium ions (NH_4^+)

Ammonia exists in two forms, that are a toxic un-ionized form (NH_3) and a non-toxic ionized form as the ammonium ion (NH_4^+) which contributes to eutrophication if in excess (DWAF 1996a; Madikizela *et al.* 2001). The proportion of each form that is present in a sample of water is dependent on dissolved oxygen, temperature and pH, the proportion of NH_3 increases with temperature and pH, particularly above 8.5. Toxicity of ammonia to fish increases as dissolved oxygen decreases and un-ionised ammonia affects the respiratory systems of many animals by either inhibiting cellular metabolism or by decreasing oxygen permeability of cell membranes, for example mayfly larvae *Ecdyonurus dispar*. Ammonia associated with clay minerals enters the aquatic bodies through soil erosion. Commercial fertilizers contain highly soluble ammonia and ammonium salts, and if applied in excess, can be carried by irrigation return-flow into aquatic systems. Other sources of ammonia include sewage discharge, industries and mining effluents, and biological degradation of manure (Dallas *et al.* 1994; DWAF 1996b).

The Target Water Quality Range (TWQR) for NH_3 in aquatic ecosystem is 0.015 mg/l for Chronic Effect Value (CEV) and 0.1 mg/l for Acute Effect Value (AEV) (DWAF 1996b).

1.4.4.4 Phosphorus (PO_4^{3-})

Phosphorus naturally occurs through weathering and leaching of phosphate salts in rocks but is seldom found in high concentration in unimpacted streams as it is readily taken up by plants, and adsorbed onto particulate and inorganic material (Dallas *et al.* 1994). Surface run-off and return flow from commercial agricultural activities, and laundry effluent, may increase phosphorus concentration in the water resources. Phosphorus is a nutrient related to eutrophication in aquatic systems it occurs in excess. (Dallas *et al.* 1994; Madikizela *et al.* 2001). There are four phosphorus concentration trophic statuses of the water system, Oligotrophic, Mesotrophic, Eutrophic and Hypertrophic conditions. Oligotrophic conditions system (<0.005 mg/l) usually has moderate species diversity and no growth of nuisance aquatic plants or blue-green algae. Mesotrophic conditions system (0.005-0.025 mg/l) usually has high levels of species diversity and growth of nuisance aquatic plants and blue-green algal blooms. Eutrophic conditions system (0.025-0.25 mg/l) usually has low levels of species diversity and growth of nuisance aquatic plants and toxic blue-green algal blooms. Hypertrophic conditions system (>0.25 mg/l) usually has very low levels of species diversity and growth of nuisance aquatic plants and toxic blue-green algal blooms (DWAF 1996b).

1.4.4.5 Nitrates (NO_3^-)

Nitrate is the end product of the oxidation of organic nitrogen and ammonia, and is more stable and abundant in aquatic environment. Under natural conditions, oxidized forms of inorganic nitrogen, usually nitrate can sometimes be present in high concentration in groundwater due to mineral salts from rocks and soil. Other sources of nitrates are seepage from sewage systems and leaching of organic and inorganic fertilizers from agricultural runoff (DWAF 1996b). Decomposition of animal faeces in stock farming may lead to an increase in nitrate concentrations in water resources (Madikizela *et al.* 2001). Excess inorganic nitrogen concentration may cause eutrophication (nuisance growth of algae and free-floating aquatic macrophytes -Water Hyacinth). There are four inorganic nitrogen concentration trophic statuses of the water system, Oligotrophic, Mesotrophic, Eutrophic and Hypertrophic conditions. Oligotrophic conditions system (<0.5 mg/l) usually has moderate species diversity and no growth of nuisance aquatic plants or blue-green algae. Mesotrophic conditions system (0.5-2.5 mg/l) usually has high levels of species diversity and growth of nuisance aquatic plants and blue-green algal blooms. Eutrophic conditions system (2.5-10 mg/l) usually has low levels of species diversity and growth of nuisance aquatic plants and toxic blue-green algal blooms. Hypertrophic conditions system (>10 mg/l) usually has very low levels of species diversity and growth of nuisance aquatic plants and toxic blue-green algal blooms (DWAF 1996b).

1.4.4.6 Chemical Oxygen Demand (COD)

Chemical Oxygen Demand (COD) is a measure of organic compound related to the availability or contamination with sewage or organic waste in the water system and is associated with oxygen depletion in organically polluted waters. Main sources of organic waste are effluents from domestic sewage, food processing industries, abattoirs and animal feedlots. Excess organic compounds in water reduce species richness, diversity and community composition of the aquatic biota (Dallas *et al.* 1994).

COD measurement is used for effluent and is a measure of the amount of oxygen likely to be taken up in the breakdown of organic waste. It is used for determining water quality requirements of effluent discharged into a river system, and is inappropriate for aquatic ecosystems.

1.4.4.7 Temperature

Temperature is one of the major factors affecting the distribution of aquatic organisms, and a critical factor in insect development (Munn and Brusven 1991). All organisms associated with freshwater are poikilothermal, and are dependent on ambient water temperature. Thermal characteristics of surface water resources differ in terms of hydrology and climate of the area. Different species of aquatic organisms have different optimal temperature range in which they survive and reproduce effectively. Indigenous organisms are adapted to the natural water temperature variation which occurs on a daily and seasonal basis (Dallas and Day 1993). Natural water temperature variation occurs due to seasonal changes and organisms need these for migration and spawning (Myburgh 2002).

Anthropogenic activities or land-use activities such as heated industrial or power station discharges, flow reduction (water abstraction, dams), water transfers and removal of riparian vegetation may increase water temperature (Dallas and Day 1993). Increased water temperature increases toxicity of certain chemicals, metabolic rate and reduces oxygen solubility, leading to O_2 stress of sensitive invertebrates. Lowered temperature reduces metabolic rate and increases the life span of aquatic animals (Dallas *et al.* 1994).

1.4.4.8 Dissolved Oxygen (DO)

The main source of oxygen in the water is from the atmosphere and as a by-product of photosynthesis. Dissolved oxygen (DO) solubility depends on temperature and depth of the water resource for example, anaerobic conditions usually occur at the bottom of a dam or a reservoir. Low concentration of DO in the water proves to be the major problem in the surface water resources because that may limit oxygen for aquatic fauna (Hammer and Mickichan 1981). Madikizela *et al.* (2001) indicated that sediment load might decrease the concentration of dissolved oxygen in the river systems.

1.4.4.9 Suspended solids (SS)

Suspended Solids (SS) are dead organic materials, silt, sediment and any other small, suspended particles. High SS reduces light penetration, decreases primary production and food availability, and may clog the seta of filter-feeders (Dallas and Day 1993; King 1983).

Turbidity in rivers may be a natural cause, often changes seasonally, influenced by the hydrology or geomorphology of a region or a catchment. In South Africa, after heavy rains or floods, soil erosion and sedimentation in the rivers usually causes water to become turbid and laden with suspensoids (Dallas *et al.* 1994; Allanson, 1995). According to DWAF (1996b), natural causes of high SS in South Africa are due to high runoff from the land during storms in the rainy season especially the first surface runoff, called the “first flush”.

Land-use activities such as removal of riparian vegetation, overgrazing, and non-contour ploughing may contribute to soil erosion and sedimentation. In South Africa, on the floodplains of big river systems, for example the Berg River system, developments within the 100-year floodplain and cultivation is causing overgrazing, leading to soil erosion and sedimentation (Allanson 1995).

Anthropogenic activities such as Inter-basin Transfers, effluent discharges, road construction and dam/reservoir releases may also contribute to an increase in SS. Reservoirs provide storage for sediment and water, which disrupts the normal downstream trend in sediment transport and results in channel adjustment and increased erosion in downstream channel banks.

1.4.5 Microbial properties

Microbiological quality of water refers to the presence of microorganisms such as protozoa, bacteria and viruses in the water bodies, which are associated with transmission of infectious waterborne diseases such as gastro-enteritis, typhoid and cholera. Micro-organisms are tiny life forms which are invisible to the naked eye. Water resources can be contaminated by faecal sources through runoff from rainfall or wastewater irrigation events, dense settlement (informal, formal and rural) without adequate sanitation system, or from activities such as sewage waste/effluent and intensive animal feedlots. Microbial indicators (e.g. faecal coliforms, *Escherichia coli*) are used to indicate faecal pollution and potential risk of infectious diseases from the water (DWAF 1998; Stephens and Bredenkamp 2002).

Providing adequate sanitation to people remains a major challenge in all developing countries. Approximately 18 million South Africans or 3 million households did not have access to adequate sanitation (DWAF 2001). Inadequate sanitation and poorly designed or mismanaged water-borne sewerage systems are the major microbiological polluters of water. As DWAF preventative measures, boreholes used for water supply should not be drilled at distances closer than 100 m to septic tanks and cattle feedlots.

1.4.6 *Flow*

Natural flow fluctuations are important to maintain the diversity and abundance of invertebrates. Flow disturbance as a result of human impacts is detrimental to the river ecosystem. Constant flows caused by impoundment (water abstraction) are detrimental to invertebrate taxa, which are adapted to either low or high flows. Un-seasonal high flows (e.g. releases from the dam or the discharge of treated wastewater) have been shown to be detrimental to aquatic invertebrates (Palmer 1997). There is an assumption that aquatic invertebrates are likely to respond to changes to river flow within 2-3 weeks (Palmer 1997).

CHAPTER 2: DESCRIPTION OF A CATCHMENT

2.1 Problems in the Diep River Catchment

Diep River catchment is one of the fast growing catchments of the Berg Water Management Area (WMA) and the flat topography of the catchment makes it attractive to urban development (low-income housing developments), cultivation (wheat and other grain crops), vineyards, orchards, and livestock farming (pigs, cattle and sheep) contributing to its economic value (RHP 2003). The main ecological importance of the Diep River system is the water quantity contribution to the Rietvlei Wetland Reserve which is currently declared a Protected Natural Environment with a future plan of being declared a Provincial Nature Reserve and awaiting recognition as a Ramsar wetland site. Rietvlei Wetland Reserve is a host for both freshwater and coastal birds, fish, strandvelt flora and fauna, small number of mammals like otters, mongoose, and moles (RHP 2003).

The current level of water abstraction from surface and ground water resources, effluent disposal and waste dumping into the Diep River System is of a nature that the ecological integrity of the river is threatened. The present ecological status of Diep River System is deteriorating. Factors contributing to the deteriorating ecological status of the Diep River System are the land-use practices like wineries, stock farming, abattoirs, crop farming, quarries, waste sites and wastewater treatment works along the river system (IWQS 2000).

In the context of the NWA, the preliminary Ecological Reserve (Quality and Quantity) needs to be set, and then flow and water quality requirements in terms of the RQOs need to be managed so as to comply with the Reserve. Preliminary determination of the Reserve will be made until a system for classifying water resources has been prescribed or a class of a water resources has been determined (NWA, 1998). Part of this process involves determining the

Ecological Reserve Class (Category); the Reserve requirements in terms of flow and water quality and the RQOs. Hence this thesis managed to assess the health of the aquatic ecosystem, to determine the Ecological Reserve Class (Category), RQOs, and the monitoring requirements as requested by section 137 of the NWA, Act 36 of 1998 stating that a national monitoring system must be established for the collection of data and information necessary to assess the health and integrity of the river system. In order to outline the impacts of human activities, possible achievable management actions for the Diep River system are provided in Chapter 7.

2.2 Aims of the study

2.2.1 To assess the current status of water quality, quantity and aquatic ecosystem integrity within the Diep River catchment.

2.2.2 To use current knowledge to develop monitoring requirements to enable effective resource management and sustainable development.

2.3 Objectives

2.3.1 To assess the health of the aquatic ecosystem.

2.3.2 To determine the Ecological Reserve Class, Reserve requirements and Resource Quality Objectives.

2.3.3 To outline the impacts of human activities in the Diep River System and provide some possible actions for the management of the resource.

2.4 Description of the Diep River Catchment

2.4.1 Introduction

Diep River is one of the major catchments which fall within the Berg WMA (Figure 2.1). The Diep River rises in the Riebeek-Kasteel Mountains, north-east of the catchment, and then flows in a south-western direction through Malmesbury. The Diep River discharges into Table Bay in the Atlantic Ocean, north of Cape Town, and has a total length of about 86 km. The catchment has a total area of about 1 495 km^2. The Diep River Catchment is low lying and flat with isolated mountains on its eastern boundary, namely the Perdeberg, Kasteelberg and Paarlberg (IWQS 2000).

The Mosselbank River, which drains the catchment areas north of Durbanville and Kraaifontein, forms the major tributary to the Diep River with the Diep-Mosselbank River System eventually discharging into Rietvlei. Part of Rietvlei is declared a Nature Conservation Area and is of ecological importance. The Mosselbank River has tributaries called the Klapmuts River and Platklip River (IWQS 2000).

Other tributaries include the Riebeek River, Groen River, Sout River and Philadelphia stream.

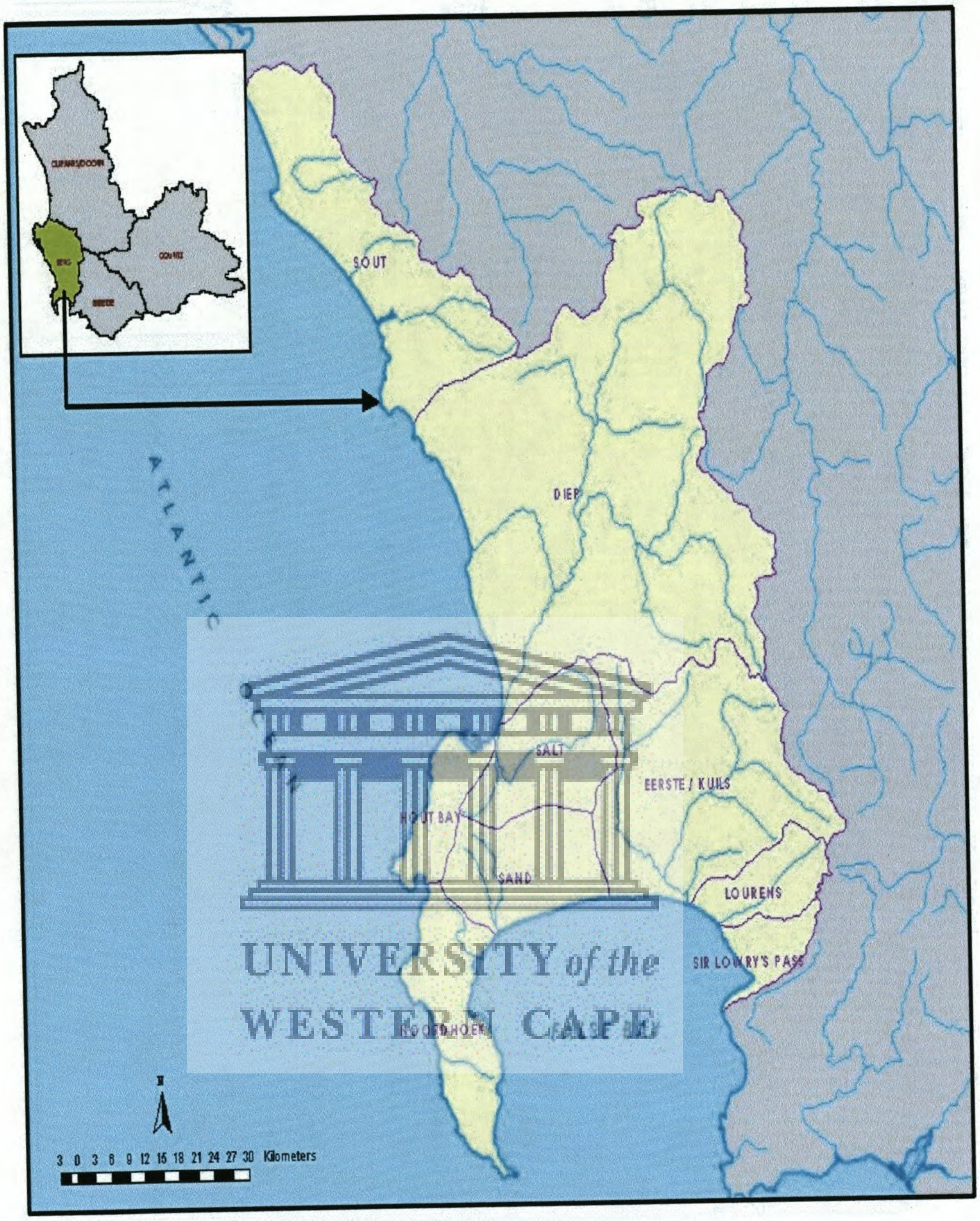


Figure 2.1 Catchments in the City of Cape Town.

2.4.2 *Climate and Hydrology*

Climatic conditions in the Diep River Catchment are characterized by a southwestern Cape winter rainfall regime with high summer evaporation (Allanson 1995). Precipitation is of a frontal nature with cold fronts approaching the catchment from the west. The mean annual precipitation in the catchment varies from approximately 1200 mm in the northeast to 400 mm in the southwest. The seasonal variability of evaporation and rainfall shows that high rainfall is associated with low evaporation and high evaporation is associated with low rainfall (IWQS 2000).

2.4.3 *Geology, Geomorphology and Geohydrology*

The geological formation underlying the Diep River Catchment is mainly the Malmesbury Group (Tygerberg Formation, Moorreesburg Formation and Porseleinberg Formation). This is interspersed with the Cape Granite and Klipheuwel Group, while Quaternary deposits [Qs (Springfontein formation - sandy soils), Qf (alluvium) and calcrete] are found on the coastal plain. There is also Table Mountain Group (sandstones) and Franschoek formation in the headwaters. The Malmesbury rock sediments consist of shales, greywackes, chert, basic lavas, and tuffs (RSA 1997) (Figure 2.2).

In South Africa, three levels of classification are determined for bioassessment, a biogeographic regional classification (Level I – bioregions or ecoregions), a sub-regional classification (Level II – geomorphological zones) and river types (Level III) (Brown *et. al.* 1996; Dallas 2002). Ecoregions are a way of grouping areas of similar ecological characteristics, and are defined according to factors such as climate, geology and terrain. The two main ecoregions in the Western Cape Province are the Cape Folded Mountains and the Southern Coastal Belt. The Cape Folded Mountains consist of high plains, mountains and hills with an altitude ranging from 200-1 750m above sea level. The Diep River falls within the Southern Coastal Belt ecoregion, which is typified by plains, hills and mountains with al altitude ranging from 0-600m above sea level. The geomorphological river zones are groups of rivers or reaches within an ecoregion sharing geomorphological features such as channel morphology, bed material, and gradient (Kleynhans and Hill 1999; Rowntree *et. al.* 2000; RHP 2003). Figure 2.3 indicates three geomorphological zones under which the Diep River system fall: Upper Foothill Zone (Foothill Cobble-bed - river reaches moderately steep with cobble or mixed bedrock cobble bed, pool and rapid/riffle lengths); Lower Foothill Zone (Foothill Gravel-bed – lower gradient zone with alluvial bed of sand and gavel); and Lowland River Zone (lower gradient alluvial channel river meandering within a floodplain, characterized by high silt on the banks or river bed). All the sampling sites falls under the Lower Foothill Zone, but only sites D03 and D02 are on Lowland River Zone.

Geohydrology is strongly influenced by the geology of the area, for example, the natural occurring erodible Malmesbury shale of the lower reaches of the Diep River, Klapmuts and the Mosselbank Rivers, resulting in saline water with high concentrations of dissolved solids (Millard and Scott 1955). According to the geology this area can be divided into two distinct aquifer systems, which are the upper primary aquifer located in the unconsolidated alluvial gravel and surface scree on the banks of the river; and the secondary aquifer which is unconfined to a semi-confined deeper aquifer located in the Granites and Malmesbury Group Rocks. These aquifers are separated by a clay aquiclude (Figure 2.2) (IWQS 2000).

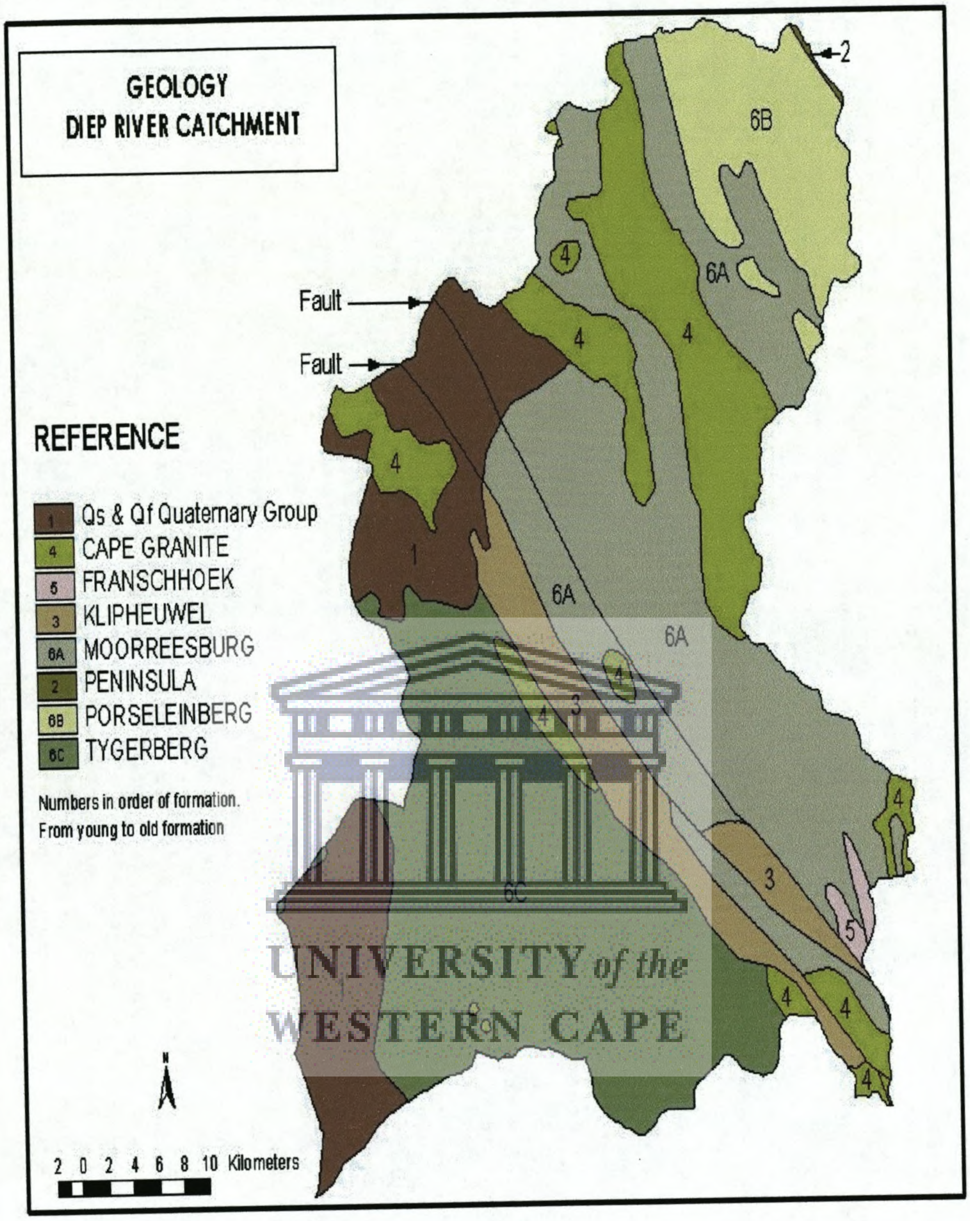


Figure 2.2 Geology of the Diep River Catchment (DWAF).

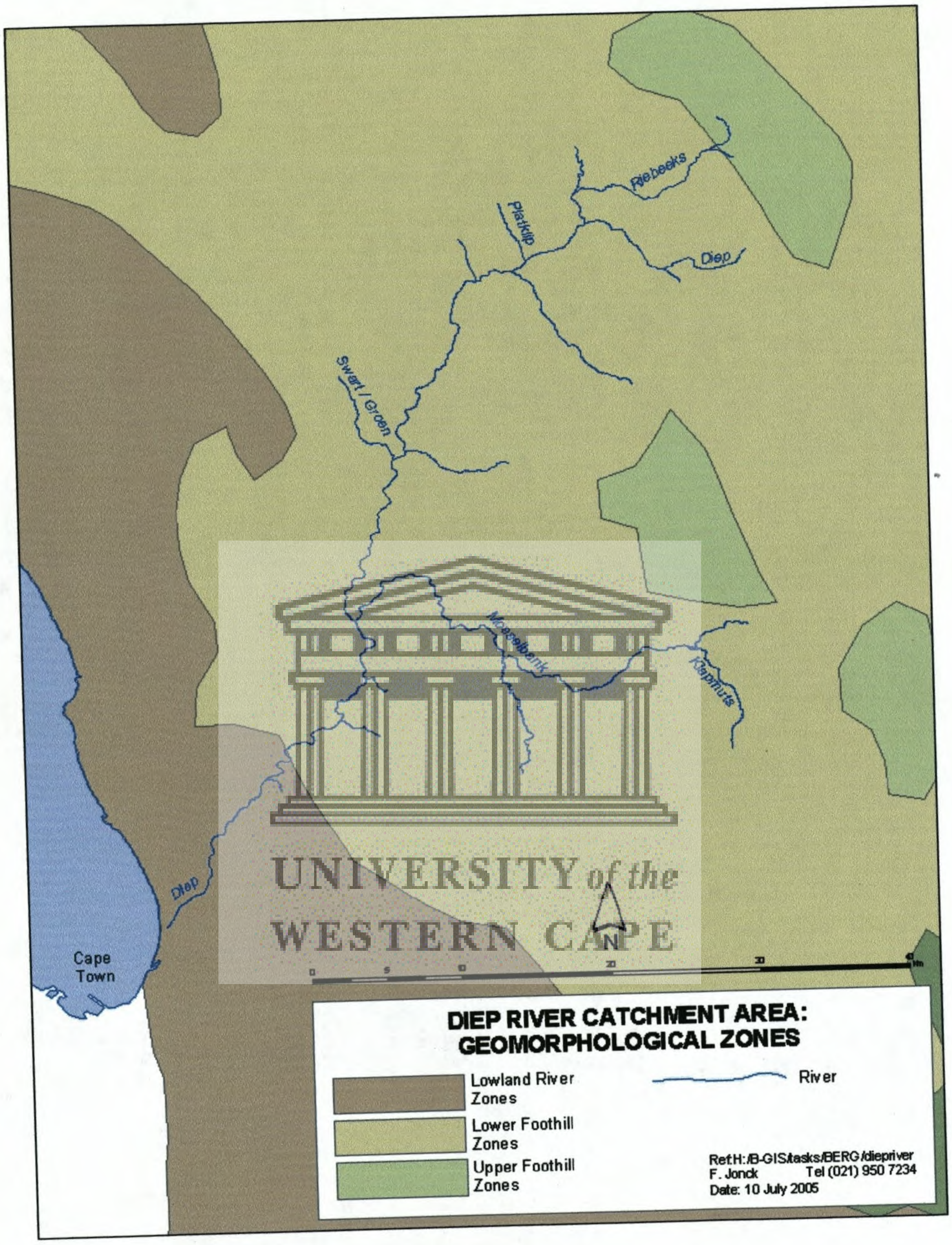


Figure 2.3 Geomorphological Zones of the Diep River Catchment (DWAF)

2.4.4 Vegetation

Natural vegetation types in Diep River Catchment include West Coast Renosterveld, Dune Thicket and Sand Plain Fynbos. Riparian vegetation present is mostly reeds (*Phragmites australis)*, rush (*Juncus kraussii*) and sedges (*Cyperus textiles*) (Boucher 1997 *In*: Day 1998).

There is an extensive alien tree infestation along the river system, for example, gum trees (*Eucalyptus camaldulensis*) in areas like Fisantekraal, Philadelphia and Kalbaskraal; pine (*Pinus pinaster*); oak trees (*Quercus robur*) in Klapmuts area; and wattle (*Acacia longifolia and A. saligna*) all over the catchment. Aquatic alien vegetation found is *Azolla filiculoides* (Boucher 1997 *In*: Day 1998).

More than 90% of the catchment is under cultivation predominantly wheat and other grain crops, and vineyards and orchards. Overgrazing and cultivation within the 100-year floodplain has caused major degradation and extensive loss of indigenous riparian vegetation but the retention of some areas of riverine wetland, for example, along Mosselbank River (IWQS 2000).

In Diep River above Tableview bridge, salt marsh plants, *Sarcoconia* spp. were found on the banks of the river during sampling and this might have been caused by a hyper-saline condition because of either the estuarine (sea water) influence up to that point or geology of the area. Also found in the site was the Water Hyacinth (*Eichornia crassipes*), that known to thrive where eutrophication has occurred.

2.4.5 Activities and Infrastructures in the Catchment

Activities (population growth, water abstraction, water supply and sanitation, land use activities) within an area impacts on both water quantity and quality. Both the water resource developments and land-use activities will therefore influence water resource qualities and quantity (IWQS 2000).

2.4.6 Population

Development of the catchment has occurred mostly downstream of the catchment. The present total population estimation of the catchment is about 157 684, including formal urban areas, rural areas and townships in the catchment (IWQS 2000). The key issues in relation to water quality and human population pressure is that access to treated domestic water in the informal urban settlements, and in the small rural areas, is not adequate; and there is a lack of formal development controls in the vicinity of the river.

2.4.7 Water abstraction

There is an extensive water abstraction from the Diep River system and the groundwater resources in the Catchment. Surface water from Diep River is used for irrigation of racecourses, golf courses, sports fields, parks, and gardens and for industrial purposes (manure composting). Groundwater abstraction is mostly for domestic purposes and industrial processing; for example, Riverlands and Chatsworth communities, some wineries, and abattoirs are supplied from groundwater. More than 70% of the farms in this catchment have one or more boreholes for domestic and agricultural purposes (IWQS 2000).

2.4.8 Water related infrastructure

Water related infrastructure is basically water supply and sanitation services. Water users in the Diep River Catchment are dependent on both surface and groundwater resources. Bulk water supply in the catchment is from Voelvlei Dam. The water supply is from the neighboring Berg River Catchment to various Municipalities who supply to users; Paardeberg Dam, which is situated in the Siebritskloof, 20 km south-east of Malmesbury and ground water. Water supply services did not cover the whole area as yet, small rural areas have 80% of water supply, and while the informal settlements has 0% water supply. There are about 20 dams in the Diep River Catchment, which are used for irrigation (IWQS 2000). Sanitation systems in urban areas of the Diep River Catchment are waterborne sewerage. Rural and farm settlements use a bucket system, septic tanks, soakaways, and conservancy tanks for sewage disposal. Areas like informal settlements with inadequate and/or without sanitation system have a high pollution potential.

2.4.9 Water chemistry

Historically, the natural water chemistry in Diep River system, due to the erodible Malmesbury shale has high TDS (high EC concentrations) in the upper reaches of the river; and more saline in lower reaches as well as the Mosselbank and Klapmuts tributaries (Millard and Scott 1955). pH through out the Diep River system was within the acceptable limit and the SS slightly moderated but still acceptable for irrigation. Nitrate concentration used to be within the TWQR for livestock watering than currently (IWQS 1999).

Typical point sources that contribute to water pollution currently include wastewater treatment works discharge, industries, and waste disposal site runoff. There are five Wastewater Treatment Works (WWTW) or Sewage Works in the catchment, Malmesbury WWTW, Kraaifontein WWTW, Milnerton WWTW, and Riverlands and Kalbaskraal Oxidation Ponds (Table 2.1 and Figure 2.4).

Industries in the Diep River catchment dispose of their waste in different ways, for example, dispose to WWTW, by evaporation ponds, pipes to the sea, and or spray irrigation. The industrial area downstream of the catchment has the greatest potential to further negatively influence water quality in the catchment. Evaporation ponds are susceptible to leakage and leaching, and this is a potential threat to ground water pollution.

The landfill sites or waste sites have a high risk of groundwater pollution from leachates (IWQS 2000). There are two landfill sites in Diep River Catchment, which are Vissershok under Cape Metropolitan Council, and Highlands landfill site under Malmesbury Municipality (Table 2.1 and Figure 2.4).

Currently, salinities in Diep River system are increased by water abstraction and return flow of irrigation water (Dallas 1997a). The sources of pollution are mainly from agricultural fields, quarries and residential areas. The whole catchment is under cultivation with only a few patches of natural vegetation remaining. Grain farming (predominantly wheat) dominated the agriculture and 90% of soil losses in the region could be attributed to this activity during this century. Vines make up most of the irrigated land surface area and are found in the upper catchment area of the Diep River and its tributaries. Fruits and vegetables are found in the middle and lower catchment areas of the Diep River. Livestock farming and vineyards is practiced most in the upper catchment area. Urbanized areas and satellite settlements in the catchment are a potential source of nutrients, pathogens and litter that wash off these areas during rain events and impact on the quality of both ground and surface waters (IWQS 2000).

Table 2.1 Industrial water use and wastewater disposal, their coordinates, and possible major contaminants in Diep River Catchment

Industrial water use and wastewater disposal	Co-ordinates (in Decimal Degrees)	Possible Major contaminants
Anglo Alpha stone, Penn. Quarry	33.80576 S; 18.55165 E	Sedimentation/siltation (SS and TDS)
Bruining Compost, Vissershok	33.772077 S; 18.55324 E	Nutrients and organic wastes (NH_3, NO_3, PO_4, COD)
Caltex-oil, Milnerton	33.840953 S; 18.522016 E	Light hydrocarbons (Oil, Petrol, Diesel) and NH_3
Corobrick Phesantekraal, Durbanville	33.789873 S; 8.690013E	Sedimentation/siltation (SS and TDS)
CPC Tongaat Foods, Durbanville	33.789873 S; 18.690013 E	Nutrients and organic wastes (NH_3, NO_3, PO_4, COD)
County Fair Farm, Kraaifontein	33.872007 S; 18.432712 E	Nutrients and organic wastes (NH_3, NO_3, PO_4, COD)
County Fair Foods, Fisantekraal	33.788463 S; 18.741203 E	Nutrients and organic wastes (NH_3, NO_3, PO_4, COD)
Cramix Quarry, Brackenfell	33.872007 S; 18.719377 E	Sedimentation/siltation (SS and TDS)
Simonsberg Pigery, Klapmuts	33.80.163 S; 8.87383667E	Nutrients and organic wastes (NH_3, NO_3, PO_4, COD)
Strategic Fuel-Fund, Milnerton	34.342273 S; 18.537883 E	Light hydrocarbons (Oil, Petrol, Diesel) and NH_3
Durbanville-Hills Winery	33.819066 S; 18.566686 E	Nutrients and organic wastes (NH_3, NO_3, PO_4, COD)
Golden Groove, Fisantekraal	33.60176 S; 18.592773 E	Nutrients and organic wastes (NH_3, NO_3, PO_4, COD)
Hoechst SA (Polyester), Milnerton	33.818956 S; 18.526026 E	Nutrients and organic wastes (NH_3, COD)
Kalbaskraal Oxidation Ponds	33.568926 S; 18.635113 E	Nutrients and organic wastes (NH_3, NO_3, PO_4, COD)
Kynoch fertilizer, Milnerton	33.840953 S; 18.522016 E	Nutrients and organic wastes (NH_3, NO_3, PO_4, COD)

Table 2.1 Continued

Industrial water use and wastewater disposal	Co-ordinates (in Decimal Degrees)	Possible Major contaminants
Malmesbury WWTW	33.837453 S; 18.521506 E	Nutrients and organic wastes (NH_3, NO_3, PO_4, COD)
Milnerton WWTW	33.8376 S; 18.5219 E	Nutrients and organic wastes (NH_3, NO_3, PO_4, COD)
MijnBurg Winery, Klapmuts	33.8062 S; 18.80096 E	Nutrients and organic wastes (NH_3, NO_3, PO_4, COD)
Riverlands Oxidation Ponds	33.537223 S; 18.592593 E	Nutrients and organic wastes (NH_3, NO_3, PO_4, COD)
Sappi Cape kraft, Milnerton	33.85188 S; 18.52289667 E	Organic wastes (COD)
Swartlandse-koop Winery, Malmesbury	33.442793 S; 18.75217 E	Nutrients and organic wastes (NH_3, NO_3, PO_4, COD)
Tydstroom Plumveeplaas, Durbville	33.786223 S; 18.7002 E	Nutrients and organic wastes (NH_3, NO_3, PO_4, COD)
Vasco cheese-Philadelphia	33.819066 S; 18.566686 E	Nutrients and organic wastes (NH_3, NO_3, PO_4, COD)
Vissershok Solid Waste	33.771416 S; 18.541823 E	Nutrients and organic wastes (NH_3, NO_3, PO_4, COD)

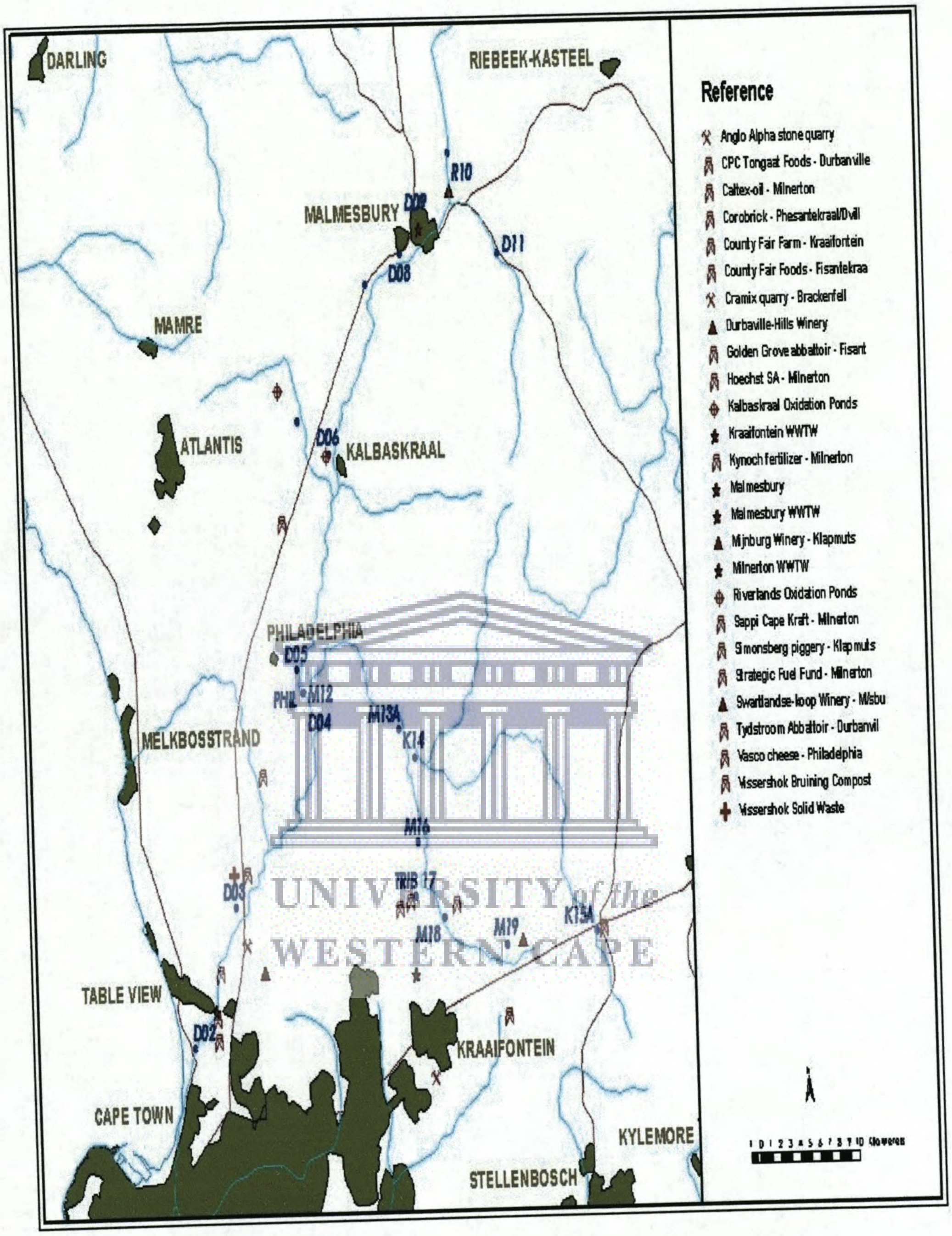


Figure 2.4 Industrial water use and wastewater disposal in the Diep River Catchment. The blue letters/numbers denote sampling points/sites.

CHAPTER 3: METHODOLOGY

3.1 Sampling Materials

Equipment needed includes waders, a standard net (300 x 300 mm frame, 950 µm-mesh), sampling trays, a bucket, magnifying glass, forceps, scoring sheets, a picture field guide and a manual.

3.2 Sampling Method

3.2.1 Localised sampling sites/points and reference sites

Sites selection comprised re-use of Dallas 1997's sites [which were selected on the basis of points of impact such as effluent discharge and river confluences (and marked using a Geographical Positioning System (GPS) based on as close as possible to upstream or downstream points of impact (such as river confluence or effluent discharge) (Figure 3.1 and Table 3.1)]. The sites were used in order to see the changes (negative or positive) on the trend when comparing the data with the current set. Sampling sites usually have diverse biotopes (stones in and out of current; sand, gravel and mud; marginal and aquatic vegetation) forming part of the main river channel, not too deep or fast flowing, and have regular flow.

To provide a reference or control site, another site was established at a less impacted section of the river system. Reference conditions describe the natural unimpacted characteristics of a water resource like seasonal variation (Scherman *et al.* 2003), and may include aspects related to water quality, water quantity, the geomorphologic characteristics of instream and riparian vegetation, and the character, composition and distribution of aquatic biota (DWAF 1999c). A reference condition is a combination of previous data, expert knowledge and/or opinion, and minimally disturbed sites or least impacted sites (Reynolds *et al.* 1997; Roux *et al.* 1999). The interpretation of the South African Scoring System results depends on a variety of components, biotopes sampled, the flow record and the reference conditions expected for that particular site (Palmer 1997). The reference site is expected to have highest species turnover and lowest seasonal variation of macroinvertebrates assemblages. Inorganic nutrients and metals are relatively low and number of taxa relatively high at the reference sites compared to other lower monitoring sites (Shieh *et al.* 1999).

There was no site amongst the sampled which can be considered "natural", but site R10 was chosen as a reference site because is impacted to a lesser extent than Diep River sites and falls within the same subregion of foothill-gravel/lowland with other sites in the Diep River system.

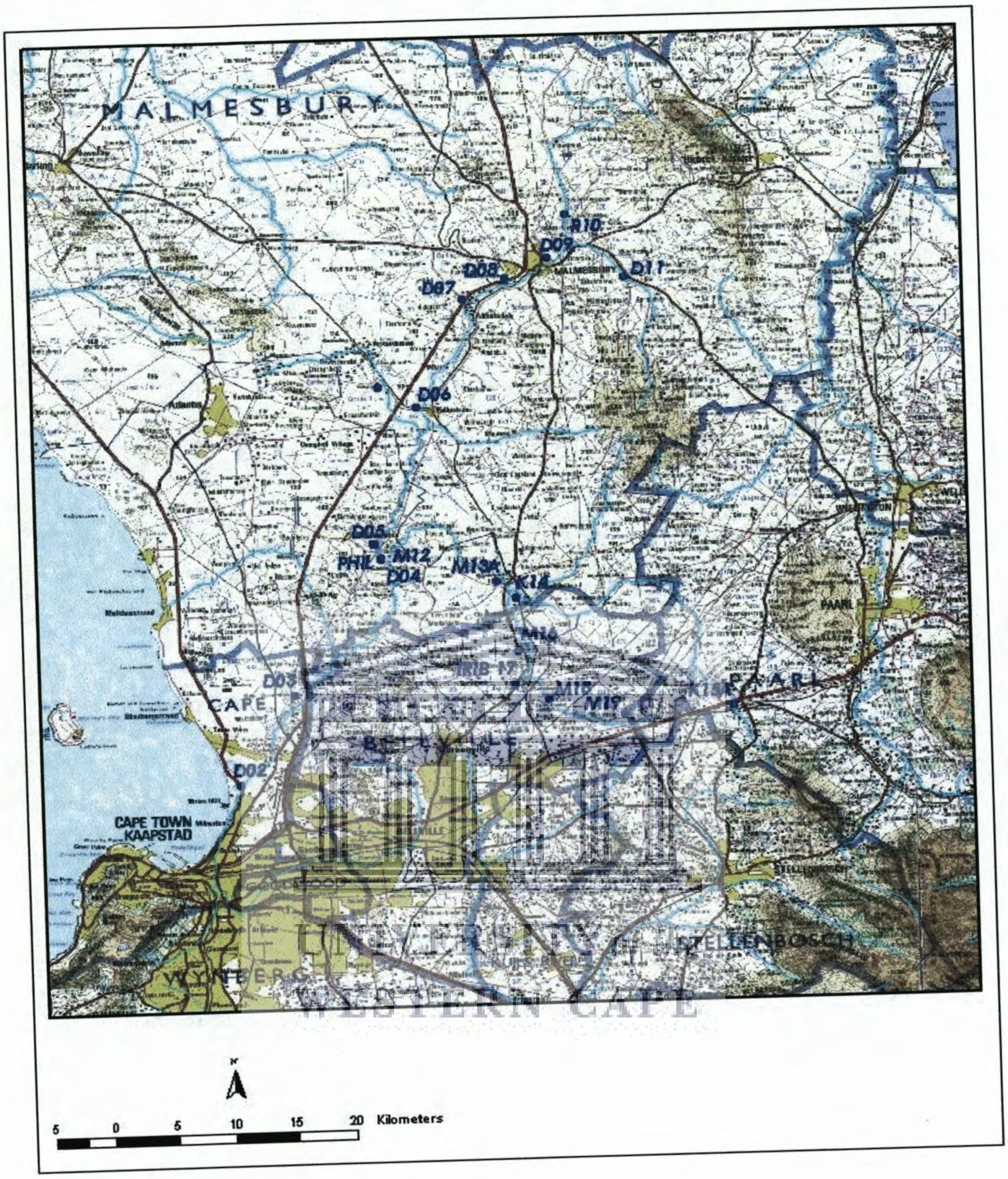


Figure 3.1 Biomonitoring sampling points/sites in the Diep River Catchment after Dallas (1997) (Base map 1:250 000, 3318 and 3319).

Table 3.1 The Diep River Catchment Biomonitoring sampling points/sites, descriptions and Coordinates (Dallas 1997a)

Rivers	Sample codes	Description	Co-ordinates (in decimal degrees)
1. Riebeeks	R10	On farm Skoonespruit, off R45, Rustfontein turnoff	33.424376S 18.75138E
2. Diep	D11	At Paardeberg road bridge	33.473176S; 18.792993E
3. Diep	D09	Above Malmesbury, above weir, next to campground	33.45806S 18.737343E
4. Diep	D08	Below Malmesbury sewage works	33.472556S 18.70526E
5. Diep	D07	At Abbotsdale	33.487553S 18.673476E
6. Diep	DO6	At Kalbaskraal	33.569036S 18.637103E
7. Diep	D05	Before confluences with Mosselbank	33.673186S 18.60308E
8. Diep	D04	At Goedeontmoeting, below R304 road bridge	33.684683S 18.60798E
9. Diep	D03	At N7 bridge	33.787403S 18.541483E
10. Groen	Groen	Below road culvert leading to Riverlands, west of N7	33.5528S 18.60921E
11. Diep	D02	At Tableview /Blaauwberg bridge	33.85522S 18.50022E
12. Mosselbank	M19	On Matjeskuil Farm, near Tygerberg zoo	33.80832S 18.786233E
13. Mosselbank	M18	At road bridge at Fisantekraal	33.805S 18.73E

Table 3.1 Continued

Rivers	Sample codes	Description	Co-ordinates (in decimal degrees)
14. Mosselbank tributary	Trib. 17	Tributary to Mosselbank at bridge, d/s Kraaifontein WWTW	33.783943S 18.70511E
15. Mosselbank	M16	At Bramvoerkrale, leading to Mellish	33.7578S 18.70822E
16. Klapmuts	K14	Before confluences with Mosselbank	33.716746S 18.70711E
17. Mosselbank	M13A	At Klipheuwel bridge	33.70358S 18.693053E
18. Mosselbank	M12	Mosselbank before confluence with Diep river	33.684173S 18.60811E
19. Stream (Phil)	Phil	Philadelphia stream to Mosselbank	33.673276S 18.60298E
20. Klapmuts	K15A	At Klapmuts	33.80314S 18.867096E

3.2.2 Sampling procedure and Protocol

The year 2000 samples were collected and presented as SASS4 data and was sampled according to SASS Version 4 protocol because that year was a transitional year for a shift from using SASS4 to SASS5 which was in full implementation around the year 2001. The rest of the samples from 2001-2003 were collected according to SASS5 protocol, which is currently used and was upgraded from SASS4. Unlike SASS5 procedure and protocol described below, SASS4 protocol had only one set of sample collected on a site, including all the three biotopes at once in one net (Thirion 1995; Chutter 1998).

3.2.2.1 South African Scoring System Version 5 (SASS5) (Chutter 1998; Dickens and Graham 2002)

The SASS5 protocol (Dickens and Graham 2002) requires that all available biotopes be sampled. Three sets of samples were collected for each site according to different biotopes (Table 4.1), which are:

1. Stones-in-current (SIC) and out-of-current (SOOC) – 2 biotopes
2. Marginal and Aquatic Vegetation (VG) – 2 biotopes and
3. Gravel, Sand and Mud (GSM) – 3 biotopes.

SIC and SOOC are both categorized under one set of sample called Stones (S) and sampled using one net. SIC were kicked and disturbed with hands for at least 2 minutes (maximum 5 minutes) for movable stones to be loose and immovable stones were washed, holding the net against the flow to collect the dislodged macroinvertebrates. One square meter of SOOC were kicked or disturbed and the dislodged invertebrates were scooped with the net. Some stones were hand picked for macro-invertebrates identification, as an additional method for the stone sample. The contents of the net from both SIC and SOOC were tipped into an identification or sampling tray.

The Marginal and aquatic vegetation (VG) set of sample was assessed by disturbing and sweeping the vegetation using feet and the net for about two meters. The contents of the net were tipped into an identification or sampling tray.

One square meter of combination of sand, gravel and mud biotopes (GSM) was stirred and disturbed for half a minute and scooped (swept) with a net several times. The contents of the net were tipped into an identification or sampling tray.

Sampling was always done on field, wearing a wader and holding the net against the flow, moving upstream to avoid disturbing organisms before sampling. Half a bucket of water was poured in each sampling tray. The contents of the net were tipped into a tray with water for identification. Debris was thoroughly checked for clinging organisms before they were removed from the trays. A pair of forceps was used to catch and/or hold an organism and a magnifying glass was used for better and bigger visibility. Organisms were identified to the family level, recorded using abundance estimated on the SASS scoring sheet for 15 minutes at each tray. An Illustrations Picture Identification Guide, a Field Guide, and a User Manual were used to help with identification of macroinvertebrates (Thirion *et. al.* 1995; Gerber and Gabriel 2000 nd; 2002a; 2002b). After scoring organisms on the scoring sheet the samples were returned in the river.

3.2.2.2 Invertebrate Habitat Assessment System (IHAS) (Chutter 1998; McMillan 1998; Dickens and Graham 2002)

Habitat assessment was carried out at each site after SASS sampling by standing on the bank of the river facing upstream, in order to determine the left and the right bank of the river. IHAS questionnaire sheet was completed on site. IHAS comprised two categories, which are sampling habitat and stream characteristics used to identify any situation in which changes in habitat were responsible for changes in SASS scores. Sampling habitat assesses SIC, VEG and other habitat like GSM and bedrock. Stream characteristic assesses the geomorphology, stream velocity, physical state of the water and surrounding impacts. In terms of IHAS scores, the addition of sampling habitat score and stream characteristics score give total IHAS score, which is an indication of how suitable the site is for SASS.

3.2.2.3 Other data

Other data were also collected each time the SASS sample was taken at a site. The following variables were measured in situ, pH, EC, Dissolved Oxygen (DO) and Temperature (Temp).

3.2.2.4 Water Quality

Water quality samples were taken every six weeks by taking water using a 2 litre plastic bottle by DWAF (Western Cape Region) officials. Before taking the sample, they first take a little bit of water and rinse the bottle and throw that water out. Sampling was dependent on the availability of the flow in the river and its tributaries, throughout the period 1996-2002. Samples were submitted to South African Bureau Standards (SABS) in Rosebank, Cape Town for analysis. The water samples were analysed for the following determinants, Ammonia (NH_3-N) in mg/, Chemical Oxygen Demand (COD) in mg/, Electrical Conductivity (EC) in mS/m, Nitrates (NO_3-N) in mg/, Phosphates (PO_4-P) in mg/, pH and Suspended Solids (SS) in mg/l.

3.2.3 The availability of data

The SASS, water quality, and flow (hydrology) data is available in the Western Cape Regional Office of DWAF.

3.2.4 Analysis Tools

South African Scoring System Version 4 and Version 5 (SASS4 and SASS5) and Invertebrate Habitat Assessment System (IHAS) indices were used to determine the ecological state of the Diep River System. SASS4 was used in 2000 prior to the inception of the implementation of the updated version

SASS 5. The SASS method is based on the British Biological Monitoring Working Party method, which has been adapted for South African conditions (Thirion 1995; Chutter 1998). SASS is a bioassessment tool, based on aquatic macroinvertebrates. It is used to provide information on the water quality. This study will help to determine the Ecological Class, Reserve Requirements and status of the river in terms of the River Health Programme.

3.2.5 Sampling frequencies

I collected SASS data once a year for four years, from 2000 to 2003. The aim was to sample each monitoring site every season (spring, summer, autumn and winter) but due to lack of flow in some seasons (summer), sampling was done whenever there was flow in the river since most rainfall is restricted to winter months (Table 3.2).

Table 3.2 SASS Sampling dates and frequencies : * indicates the month when samples collected, "n/s" indicates the month when samples were not collected

Sample codes	Nov-Dec 2000 (Summer)	Oct-Nov 2001 (Spring)	Jun-Jul 2002 (Winter)	Mar 2003 (Autumn)
R10	*	*	*	*
D11	n/s	*	*	n/s
D09	*	*	*	*
D08	*	*	*	n/s
D07	*	*	*	n/s
D06	*	*	*	n/s
D05	*	*	*	n/s
D04	*	*	*	*
D03	*	*	*	*
D02	*	*	*	n/s
Groen	n/s	n/s	*	n/s

Table 3.2 continued

Sample codes	Nov-Dec 2000 (Summer)	Oct-Nov 2001 (Spring)	Jun-Jul 2002 (Winter)	Mar 2003 (Autumn)
M19	n/s	*	*	n/s
M18	n/s	*	*	n/s
Trib17	n/s	n/s	*	n/s
M16	*	*	*	n/s
K14	n/s	*	*	n/s
K15A	n/s	*	*	n/s
M13A	*	*	*	*
M12	n/s	*	*	n/s
Phil	n/s	*	*	n/s

3.2.6 Data analysis

Before SASS data analysis, SASS4 data was converted to SASS5 data sheets. Normally a linear regression analysis is undertaken to convert SASS4 to SASS5 scores. The following linear equations are used to convert SASS4 scores into SASS5 scores: $SASS4 = 0.97(SASS5) + 3.08$ and $SASS5 = 1.02(SASS4) - 1.64$ (Dallas 1997b; 2002). The difference between the two SASS versions is that the six taxa which are now in SASS5 were not included in SASS4, the change in scores for ten taxa, Cased caddis, but hydroptilidae have been allocated specific family names and scores accordingly in SASS 5 whereas in SASS4 they were only identified as 1 to 5 different species of Moveable Larvae taxa scoring 8 to 50 respectively according to the number of case types. Converting SASS4 data into SASS5 data in the Diep River was simply done by transferring data from SASS4 score sheets into SASS5 score sheets due to the availability of few tolerant taxa with similar scores in all the SASS Versions.

Water quality and SASS data were statistically analysed using univariate statistics producing mean, median, standard deviation, range, maximum, minimum, and count values (Appendices E-K; Figure 4.1-4.10). Median values were used in both chemical and SASS data figures. SASS data is given for each year and different seasons (due to the availability of the flow in the river), i.e. Nov-Dec 2000, Oct-Nov 2001, Jun-July 2002, and March 2003. SASS data is presented as per sample dates distribution and Median values (2000-2003).

Water quality was monitored in order to control diffuse and point sources of water pollution to ensure compliance with Water Quality General and Special Limits which applies to effluent being discharged into a receiving body. South African Water Quality Guidelines: Aquatic Ecosystems (SAWQG:AE) fitness for use guidelines which applies to the receiving water bodies was used when determining RQOs and/or Water Quality Reserve. Water Quality General and Special Limits was adopted from British standards where there is approximately eight times dilution factor in the water bodies. The reason why General and Special Limits were used to assess water chemistry instead of SAWQG:AE, is the lack of dilution factor for most of the year in the Diep River system. Water users generating effluent while SAWQG:AE are not legally enforceable legally enforce Water Quality General and Special Limits for compliance but provide merely a guideline. The main reason for this study is to enforce effluent compliance in order to reduce the level of pollution.

Primer Version 5 computer software program [Cluster analysis (Bray-Curtis) and Multi-Dimensional Scaling (MDS)] was used to analyse SASS data. The data matrix consists of rows for taxonomic groups (families) and column for samples (sites). The SASS data was transformed using presence (1)/absence (0) biological transformation (Clarke and Warwick 1994).

The aim of cluster analysis is to find "natural groupings" of samples. Groups of samples are joined together at the average level of similarity. Samples within a group have something/s in common (similarity) than samples in different groups (dissimilarity). Hierarchical agglomerative clustering, using group-average linking, was used on the data matrix to produce a dendrogram.

Multi-Dimensional Scaling (MDS) produces an ordination of samples, where placement of samples reflects the similarity of their biological communities. The advantages of MDS is said to be able to handle missing data, replication and non-uniform reliability data. In MDS stress value is calculated in order to assess the reliability of the ordination. A stress value of <0.05 gives an excellent representation with no prospect of a misinterpretation. A stress value of <0.1 indicates a good ordination with no real prospect of misinterpretation. A stress value of <0.2 indicates a useful picture and not a good ordination without any complementary technique, and a value of >0.3 indicates that the points are close to being arbitrarily placed in the 2-dimensional ordination space.

CHAPTER 4: RESULTS

Chemical, biological, and primer data/results of the Diep River system study are presented in this chapter in the form of graphs (for Chemical and biological data) and dendrograms and MDS ordination clusters (for primer data).

4.1 Chemical assessment (water chemistry)

Water quality data used were collected over a period of 1996 to 2002 by DWAF officials as routine monitoring and are available in DWAF Western Cape Regional Office. The water chemistry results were assessed according to the following guidelines:

(i) South African Water Quality Guidelines for Aquatic Ecosystems (SAWQG:AE) (DWAF 1996b), which assesses the ecological integrity or health in the receiving water bodies; and

(ii) General and Special Limits for Effluent Standards (DWAF 1999a; NWA 1998) and in order to determine the different land-use activities compliance to DWAF Effluent Standards or to determine the possible impacts/polluters along the river system.

Only General and Special Limits for Effluent Standards were used to assess COD because it is inappropriate for aquatic ecosystem. COD is a measure of oxygen depletion in the degradation of organic waste and useful for determining water quality requirements of effluent discharges into aquatic systems and the determination of the RQOs in order to limit their impact.

4.1.1 Ammonia (NH_3-N)

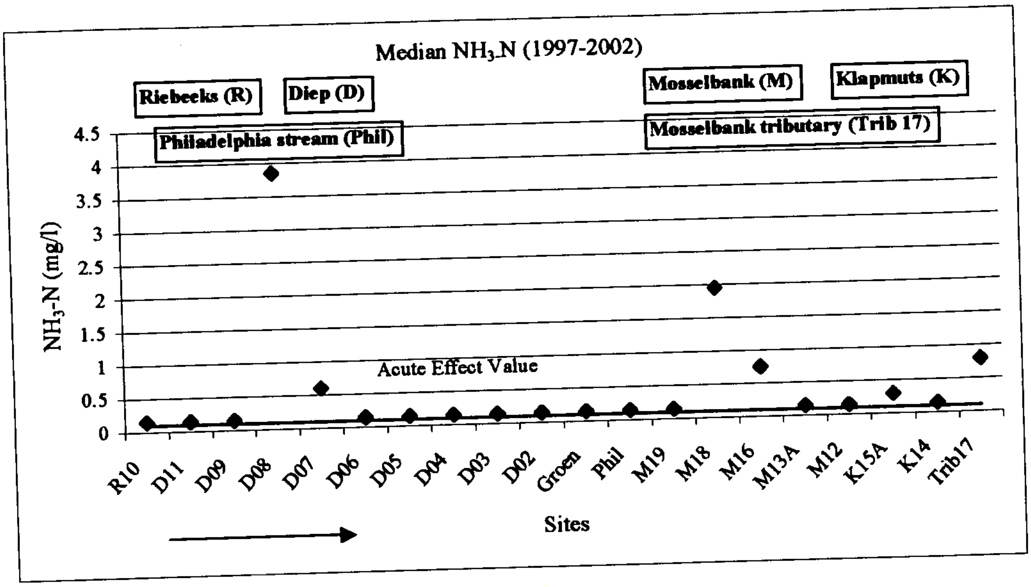


Figure 4.1 Median Ammonia concentration (1997-2002, n = 73) in the Diep River and its tributaries, sites refer to Table 3.1 (R10 – reference site, ⟶ downstream direction).

The ammonia median (1997-2002) graph (in mg/l) above indicates a decrease from D11 to D09 (lowest point less than 0.5), then a sudden increase up to 3.9 at D08 (downstream Malmesbury WWTW), the highest point. Another decrease from D07 to D06 followed, then become constant from D05 to D02, with Groen, Phil and M19 also complying with the Acute Effect Value (AEV) of 0.1 mg/l (according to SAWQG:AE). There is an increase at M18 (2.0) followed by a decrease in values downstream. Values above the AEV were found at D08 and M18, together with D07, K15 and Trib. 17.

4.1.2 Chemical Oxygen Demand (COD)

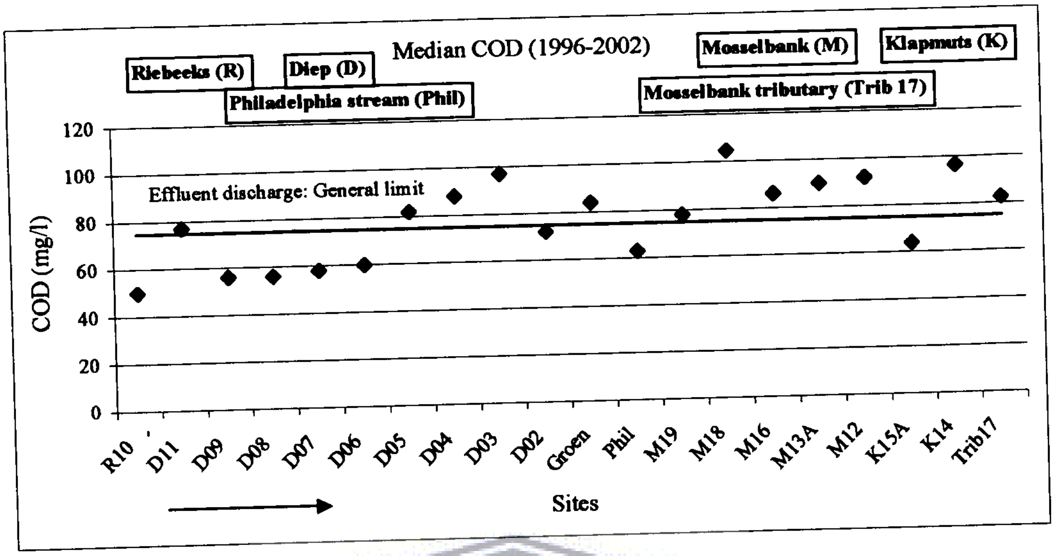


Figure 4.2 Median Chemical Oxygen Demand concentration (1996-2002, n = 73) in the Diep River and its tributaries (R10 – reference site, ⟶downstream direction).

Figure 4.2 indicates that the median COD concentration (in mg/l) fluctuates between 56 and 77 upstream (D11-D06), and is then elevated to over 80 from D05 downstream with high points (over 90) at D03, M18, K14 and M12. Collection of organic nutrients from different land-use activities (WWTW, industrial effluent, agricultural runoff, stock farming and solid waste sites) in the upper part of the catchment starts to show impacts at D05 site.

4.1.3 *Electrical Conductivity (EC)*

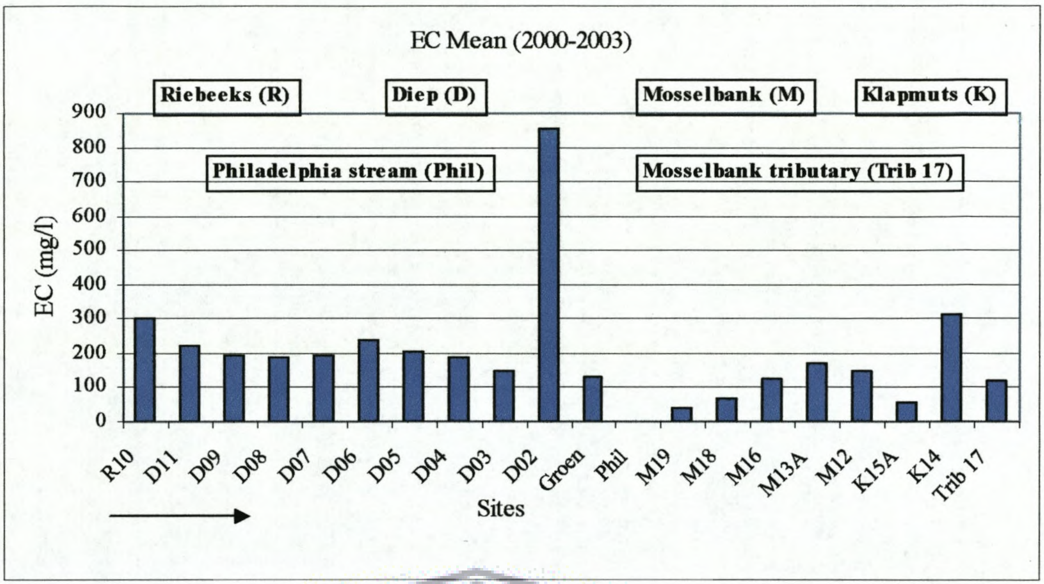


Figure 4.3 Electrical conductivity concentrations in the Diep River and its tributaries (R10 – reference site, *SASS4 data, → downstream direction). Note that some of the sites were not sampled in other seasons because of lack of water.

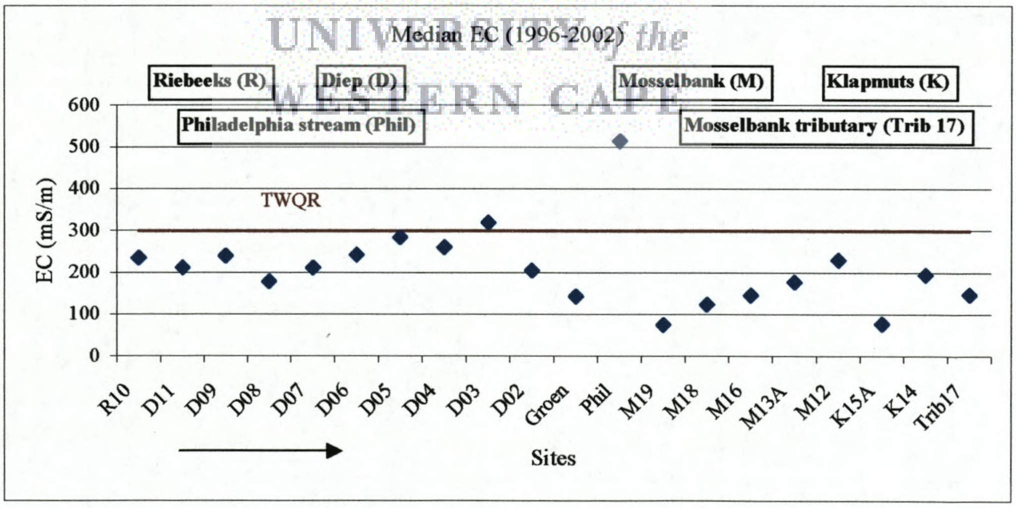


Figure 4.4 Median electrical conductivity concentrations (1996-2002, n = 73) in the Diep River and its tributaries (R10 – reference site, → downstream direction).

In Figure 4.3, indicating seasonal EC concentration (2000-2003) (in mS/m), the Diep River System values ranges from 16 to 340, with the exception of D02 at the highest point of 857. The EC value in D02 indicates a hyper-saline condition because of the estuarine influence as represented by the presence of salt marsh plants (*Sarcoconia* spp.), which confirm the presence of salt in the river system.

4.1.4 Nitrates (NO_3-N)

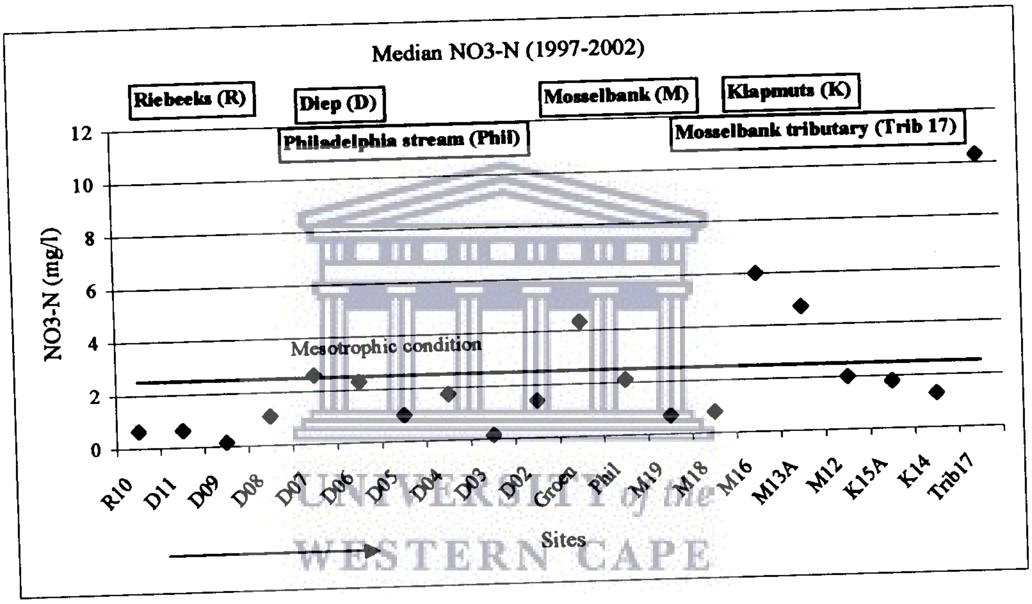


Figure 4.5 Median Nitrate concentrations (1997-2002, n = 73) in the Diep River and its tributaries (R10 – reference site, ⟶ downstream direction).

D11, R10, D09 (upstream sites), D05-D02 (recovering downstream sites), M19, M18, M12, K14 and Phil (upstream of Diep river tributaries) are the only sites complying with mesotrophic conditions (SAWQG:AE.) of less than 2.5 mg/l NO_3-N concentration. All other sites which are over 2.5 mg/l fall within eutrophic conditions in this category except for the Trib 17 site; which falls under hypertrophic conditions (Figure 4.5).

Figure 4.5 indicates mainly low concentrations of NO_3-N according to Effluent standards of 15 mg/l, while at sites Trib 17, M16, M13 and Groen increased levels of nitrates were recorded; with the high point of 10.3 mg/l at site Trib 17.

4.1.5 *Phosphates (PO_4-P)*

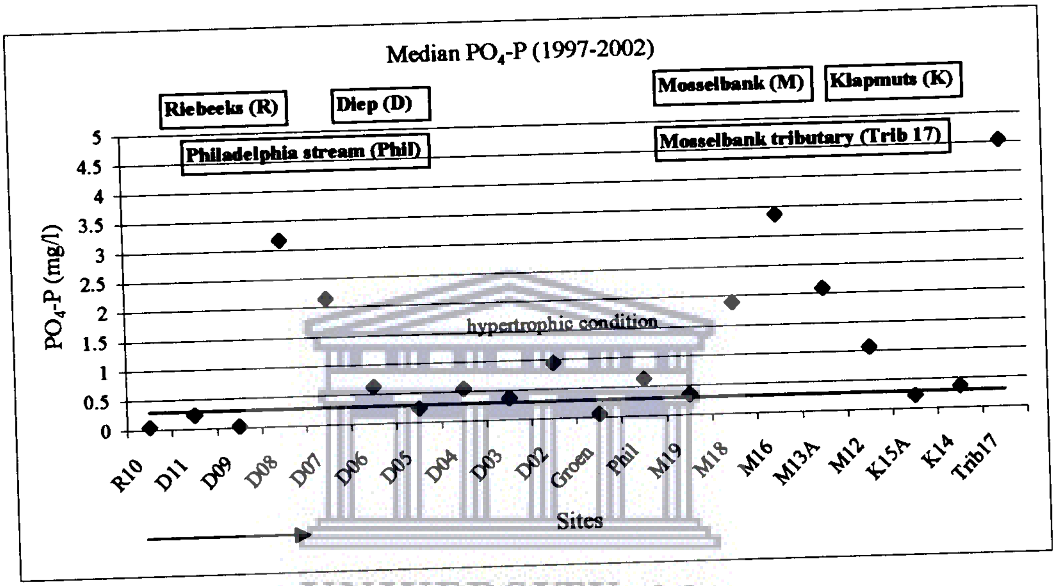


Figure 4.6 Median Phosphate concentrations (1997-2002, n = 73) in the Diep River and its tributaries (R10 – reference site, ⟶ downstream direction).

Figure 4.6 indicates the total Phosphorus Median (in mg/l) for (1997-2002), where the values from R10 to D09 (the lowest point) are less than 0.3 and then there is a sudden increase of up to 3.17 in D08; which is the highest value. There is a decrease from D06 to D03, and an increase again from M19 to Trib 17 (4.5) (which is another high value), and then a decrease again when going downstream of Mosselbank and the other tributaries. Phosphorus values in Diep River system are within the acceptable General Limit (10 mg/l) of Effluent Standards, though not all sites comply with the Special Limit of maximum of

2.5 (DWAF 1999a). D08, D07, M18, Trib 17, M16 and M12 sites are above the Special Limits (1 mg/l) of a water resource values.

4.1.6 pH

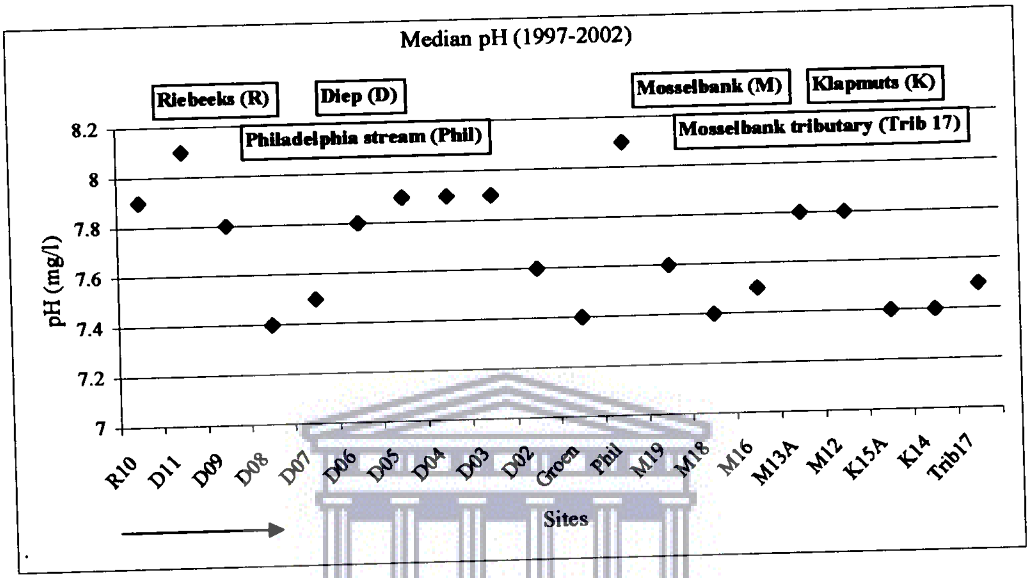


Figure 4.7 Median pH readings (1997-2002, n = 73) in the Diep River and its tributaries (R10 – reference site, ⟶ downstream direction).

A pH median (1997-2002) indicated a fluctuation within a range of 7.4 to 8.1.

4.1.7 *Suspended Solids (SS)*

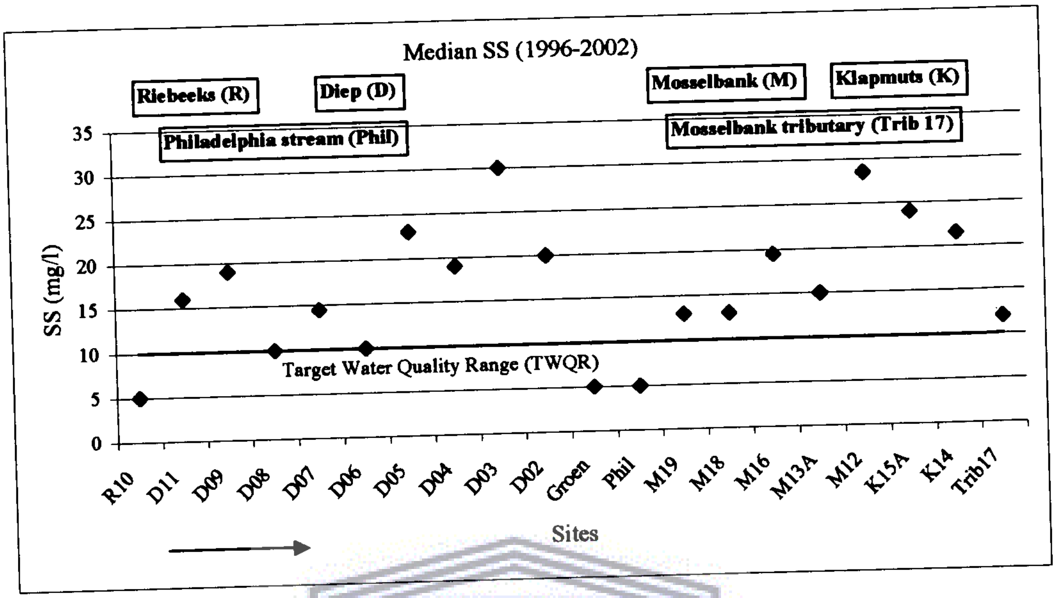


Figure 4.8 Median Suspended Solids concentrations (1996-2002, n = 73) in the Diep River and its tributaries (R10 – reference site, → downstream direction).

There is a fluctuation of SS values within the range of 10 to 23 from site D11 to D04, then elevated at D03 and D02 to 30 and 20 mg/l respectively. Suspended Solids concentration high points (over 20 mg/l) are at D05, D03-D02, M12, K15A and K14.

4.1.8 Temperature (Temp)

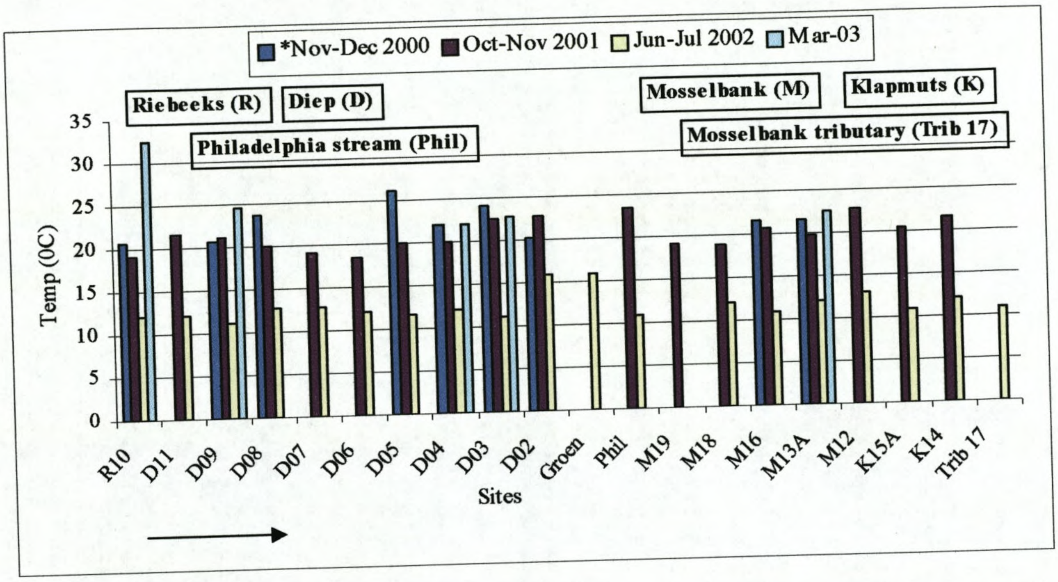


Figure 4.9 Temperature readings in Diep River and its tributaries (R10 – reference, *SASS4, → downstream direction). Note that not all the sites were sampled all the time (sampling dates) due to lack of flow (Table 3.2).

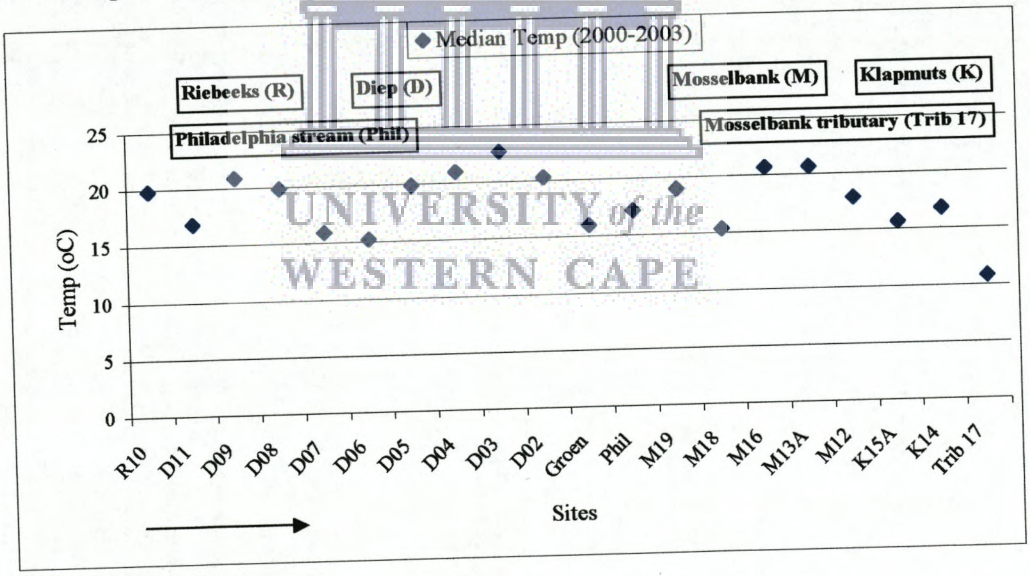


Figure 4.10 Median temperature readings (2000-2003, n = 4) of the Diep River and its tributaries (R10 – reference site, → downstream direction).

The Range of water temperature (in °C) in the Diep River Catchment differs seasonally as indicated in Figure 4.9. In summer, temperature ranges from 21 to 27, in spring 18 to 23, in winter 11 to 16, and in autumn 23 to 33. Figure 4.10 represents Median Temperature readings (2000-2003) of Diep River System ranging from 10.8 at site Trib 17 to 22.6 °C at site D03.

4.2 Biological assessment (aquatic invertebrates)

Table 4.1 Biotope availability per season/sampling date per site (n/s = not sampled): (i) Stones (S) biotope (SIC = Stones-in-current, SOOC = Stones-out-of-current, Bedrock = B);
(ii) Vegetation (VEG) biotope (Mv = Marginal vegetation, Aqv = Aquatic vegetation); and
(iii) Gravel, Sand and Mud (GSM) biotope.

Sample codes	Nov-Dec 2000 (Summer)	Oct-Nov 2001 (Spring)	Jun-Jul 2002 (Winter)	Mar 2003 (Autumn)
R10	Mv, Aqv, GSM	Mv, Aqv, G, S	Mv, S, M	Mv, Aqv, GSM,
D11	n/s	Mv, Aqv, G, S	Mv, G, S	n/s
D09	Mv, Aqv, GSM	Mv, Aqv, G, S, B	Mv, Aqv, S	Mv, SOOC, S,
D08	SIC, Mv, GSM	Mv, G, S	Mv, Aqv, S,	n/s
D07	SIC, Mv, Aqv, GSM	Mv, Aqv, G, S	Mv, Aqv, S,	n/s
D06	SIC, Mv, Aqv, G, S	Mv, Aqv, G, S	Mv, Aqv, G, S	n/s
D05	Mv, Aqv, G, M	Mv, Aqv, GSM	Mv, Aqv, GSM	n/s
D04	SIC, Mv, SOOC, M	SIC, Mv, Aqv, SOOC, G, S	SIC, Mv, Aqv, GSM	Mv, SOOC, M

Table 4.1 continued

Sample codes	Nov-Dec 2000 (Summer)	Oct-Nov 2001 (Spring)	Jun-Jul 2002 (Winter)	Mar 2003 (Autumn)
D03	SIC, Mv, SOOC, GSM	Mv, S, M	Mv, Aqv, S, M	Mv, SOOC, S, M
D02	Mv, Aqv, S, M	Mv, Aqv, S, M	Mv, Aqv, S, M	n/s
Groen	n/s	n/s	Mv, Aqv, S	n/s
M19	n/s	Mv, Aqv, S, M	Mv, Aqv, S, M	n/s
M18	n/s	SIC, Mv, G, S	SIC, Mv, SOOC, S,	n/s
Trib17	n/s	n/s	Mv, Aqv, S, M	n/s
K15A	n/s	Mv, Aqv	Mv, Aqv	n/s
M13A	Mv, S, M	Mv, Aqv, S, M	Mv, Aqv, SOOC, S, M	Mv, SOOC, S, M, B
M12	n/s	Mv, Aqv, GSM, B	Mv, Aqv, S, B	n/s
Phil	n/s	Mv, Aqv, M	Mv, S, M	n/s

SASS data were collected over a period of 2000 to 2003 and were presented in Appendices A-D, and the same data were used in Primer analysis.

Generally the macroinvertebrate data were dominated by Dipterans (Simullidae, Culicidae and Chironomidae), Coleopterans (Dyticidae, Hydraenidae, Naucoridae and Corixidae) and Gastropods (Ancyliidae, Physidae and Thiariidae) (Appendix A-D) mostly in sites dominated with pools and slow moving water.

In most sites, the abundance trends of most Dipterans (Simullidae and Chironomidae) and Coleopterans (Dytiscidae and Gyrinidae) and Gastropods

(Thiariidae) were B and C. B adundance in site R10 were mostly found in Planaria, Hydracarina and Beatids. Most of the Odonata were in 1 and A abundance (Appendix A-D).

4.2.1 South African Scoring System (SASS) Scores

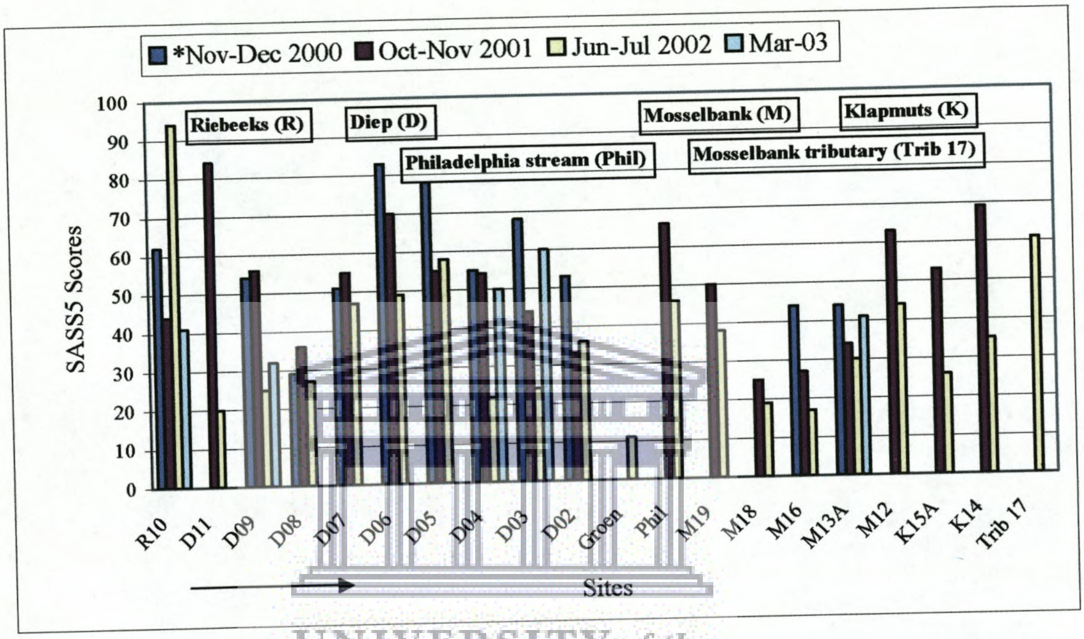


Figure 4.11 Distribution of SASS Scores in the Diep River and its tributaries (R10 – reference site, *SASS4 data, → downstream direction). Note that not all the sites were sampled all the time (sampling dates) due to lack of flow (Table 3.2).

In Figure 4.11 SASS Scores from 2000-2003, indicated a decrease from upstream going downstream; i.e. R10 to D08, reaching a low score at D08 at all seasons (a site below the Malmesbury WWTW). There is an increase of SASS scores from D07 to D06. The SASS Scores from D05 to D04 become constant. There is a decrease of SASS Scores from D03 to D02, which is the last site sampled in the Diep River before Rietvlei and the estuary.

In the Mosselbank River, a major tributary of the Diep River, from its upstream site (M19) there is a decrease in SASS Scores with M18 at a low score. M12 site is at high score compared to its upstream site (M13A). The Klapmuts River, a tributary of the Mosselbank, follows the same trend of the Mosselbank downstream sites (M13 and M12) with K14 being a high score compared to the lower score at K15A. Tributary 17 only flowed in winter, and the sample taken proved to be a high score compared to the Mosselbank sites.

The Philadelphia stream, a tributary of Diep, has a high SASS Scores and also contributed positively allowing for D04 to remain constant.

The Groen River, a tributary of the Diep River, only flowed in winter and sampling was therefore only conducted in winter. There were a lot of *Daphnia* spp. found during sampling, which do not count in SASS5 scoring sheet because they are found in pools rather than in flowing streams, and SASS5 is designed for flowing rivers. The Groen River SASS Score is the lowest of all the sites.

The highest SASS Score recorded was 94 in the Riebeeks River (R10 site) during the winter season of 2002, followed by 84 at site D11 during spring 2001.

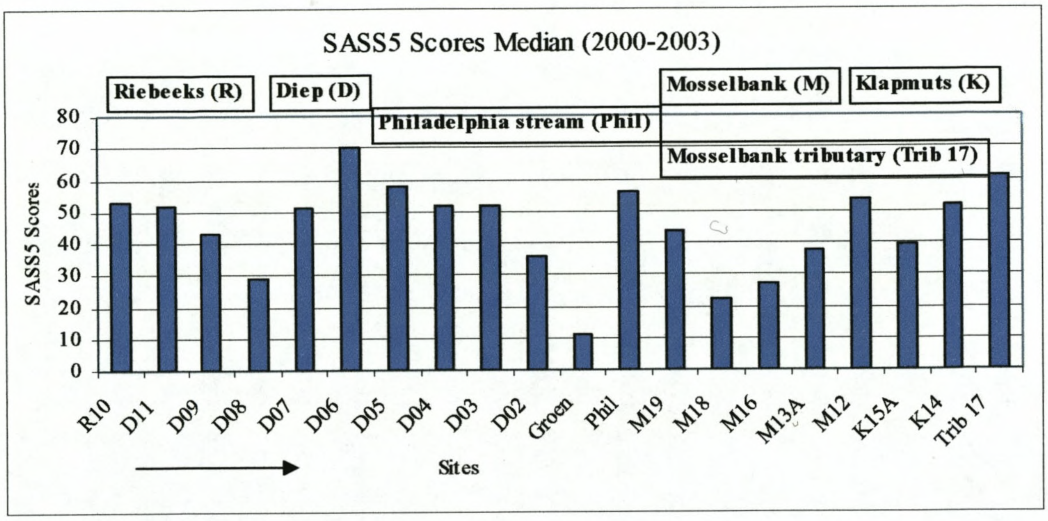


Figure 4.12 Median SASS Scores (2000-2003, n = 4) in the Diep River and its tributaries (R10 – reference site, → downstream direction).

Figure 4.12, Median SASS Scores (2000-2003) indicates the same pattern as seasonal SASS Score, a decrease of SASS Score as the river flows downstream and the improvement after the long reach after the Malmesbury WWTW and the Kraaifontein WWTW in-flow points.

4.2.2 Number of Taxa

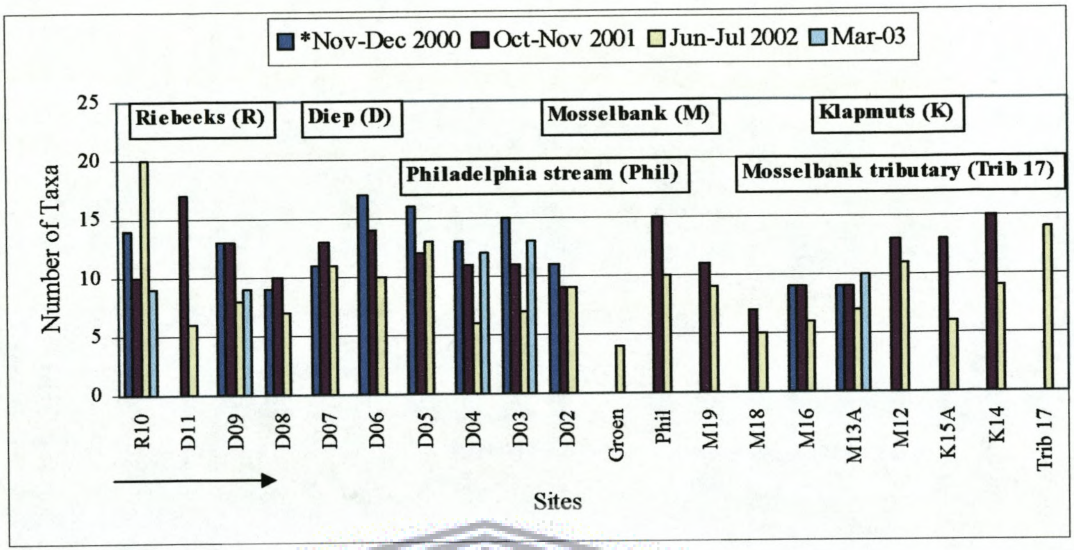


Figure 4.13 Distribution of the Number of Taxa found in the Diep River and its tributaries (R10 – reference site, *SASS4 data, ⟶ downstream direction). Note that not all the sites were sampled all the time (sampling dates) due to lack of flow (Table 3.2).

The pattern of Taxa follows that of SASS Scores in all sites of the Diep River system. The highest number of taxa recorded was 20 (sampled at R10 during winter), and followed by 17 at D11 in spring, and 17 at D06 and 16 at D05 during summer. The lowest number of taxa recorded was four in the Groen River; sampled during winter 2002. Over 15 taxa were recorded at R10, D11, DO6, and D05 during spring, summer and winter.

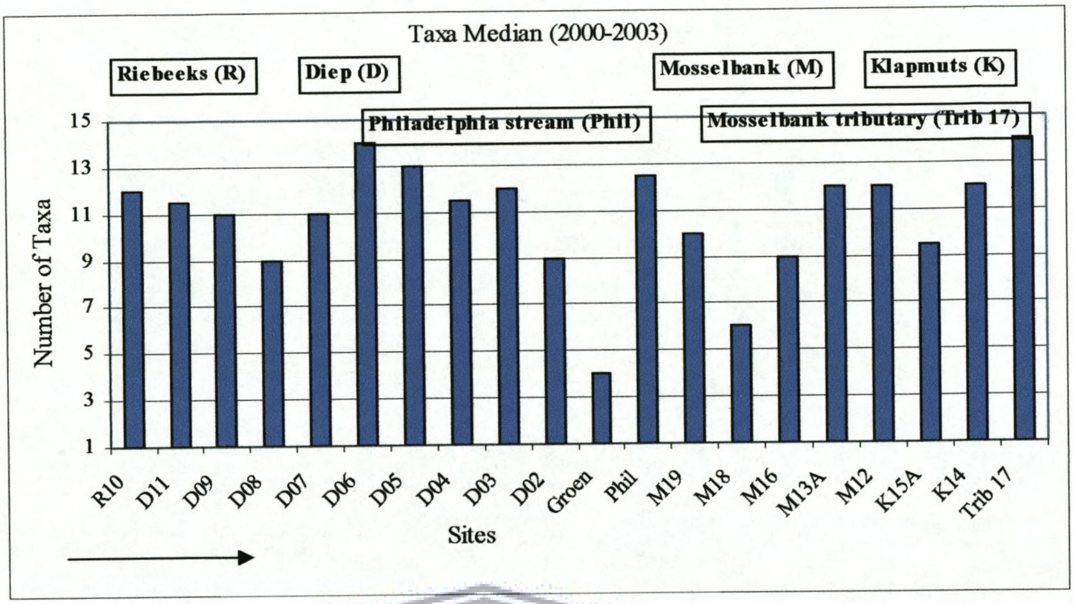


Figure 4.14 Median Number of Taxa (2000-2003, n = 4) found in Diep River and its tributaries (R10 – reference site, → downstream direction).

The Number of Taxa Median values show similar pattern to the number of taxa graphed.

4.2.3 Average Score Per Taxon (ASPTs)

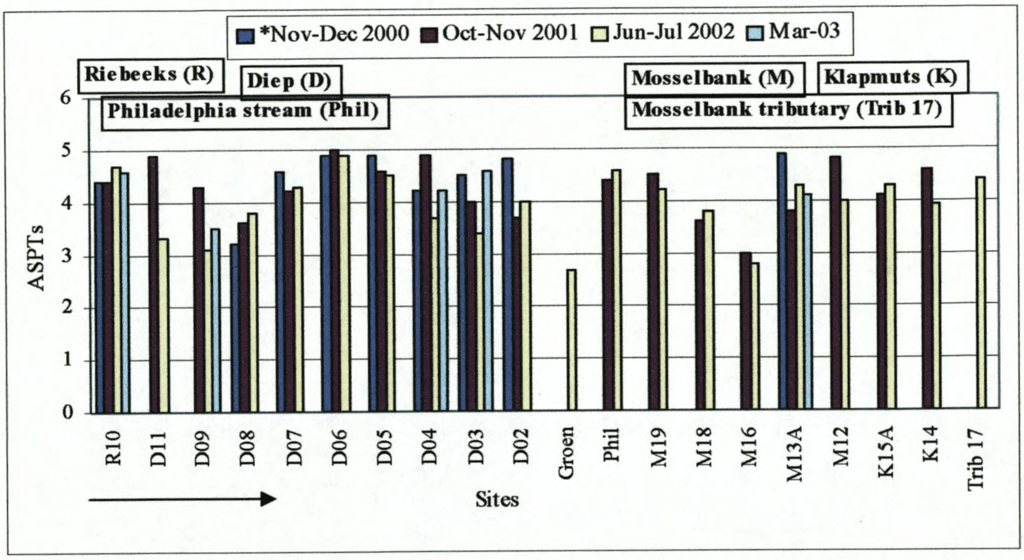


Figure 4.15 Distribution of ASPTs found in the Diep River and its tributaries (R10 – reference site, *SASS4 data, ⟶ downstream direction). Note that not all the sites were sampled all the time (sampling dates) due to lack of flow (Table 3.2).

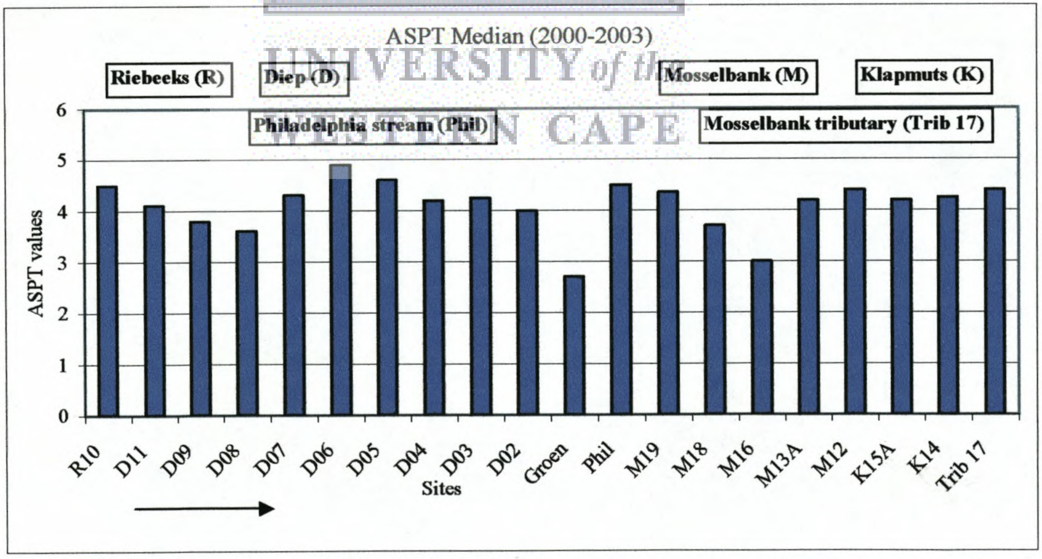


Figure 4.16 Median ASPTs (2000-2003, n = 4) of the Diep River and its tributaries (R10 – reference site, ⟶ downstream direction).

All ASPTs in the Diep River system are less than five, but at the Groen and M16 sites are less than three.

Median ASPT values have a similar pattern to the Median Number of Taxa and SASS Scores except for site D04; which is slightly high, and similarly K15A and M13A.

4.2.4 *Invertebrate Habitat Assessment System (IHAS)*

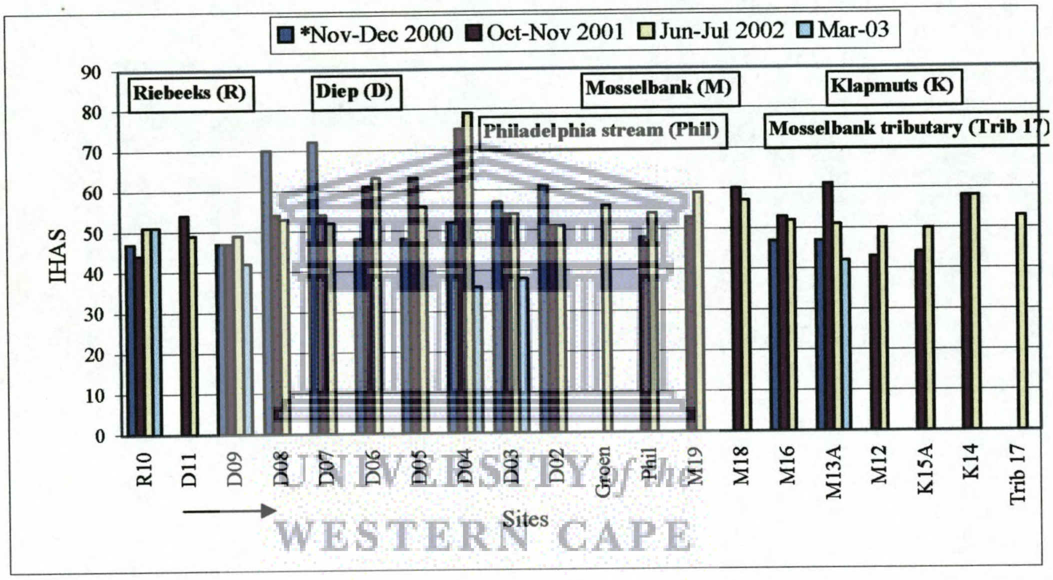


Figure 4.17 Distribution of IHAS found in the Diep River and its tributaries during sampling (R10 – reference site, *SASS4 data, ⟶ downstream direction). Note that not all the sites were sampled all the time (sampling dates) due to lack of flow (Table 3.2).

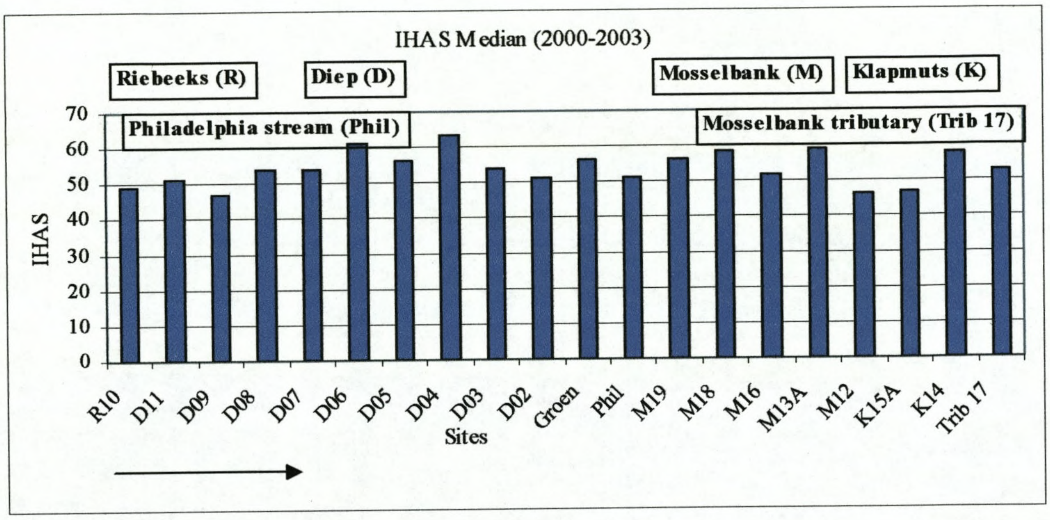


Figure 4.18 Median IHAS (2000-2003, n = 4) of Diep River and its tributaries during sampling (R10 – reference site, → downstream direction).

In Figure 4.17 and 4.18, the D04 and Groen sites have a very high IHAS, especially in winter; yet they have a relatively low SASS Scores and ASPT. These might be because winter rainfall, with supplementary flows from the Philadelphia stream and Mosselbank tributaries, expand the vegetation types available for sampling.

4.3 Flow

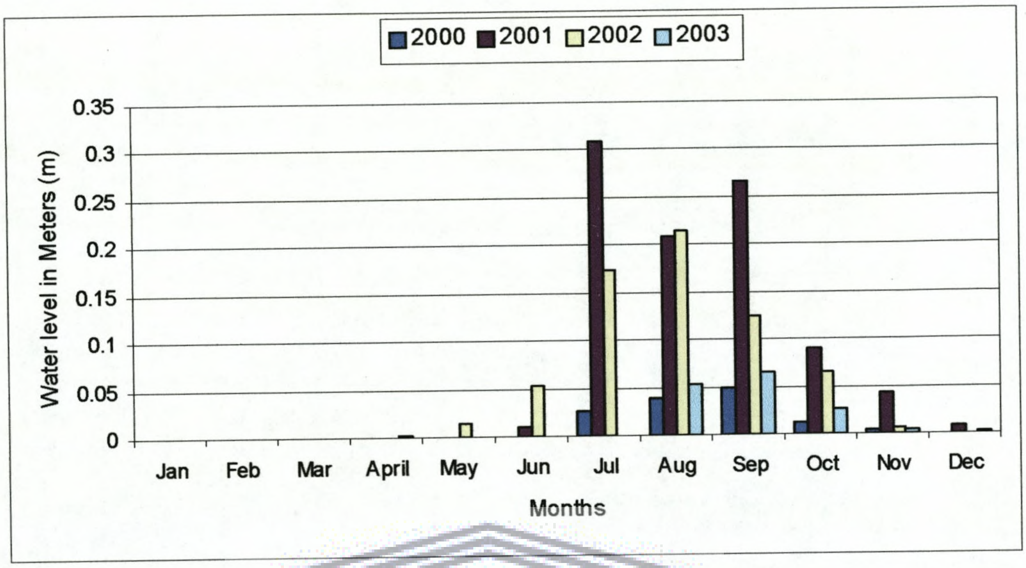


Figure 4.19 The maximum water levels in meters (2000-2003) of the Diep River at the hydrology station G2H012.

The water level in the Diep River at the Malmesbury hydrology station G2H012, basically indicates the flow and/or water availability throughout the year in upstream sites of Diep River. During winter (June to July) all sites were sampled due to the availability of water, as indicated in figure 4.19. Number of sites sampled was reduced in spring (October to November) with two sites not sampled, followed by summer (November to December) with nine sites not sampled, and then autumn (March) with only five out of twenty sites sampled due to lack of flow and/or water availability (Figure 4.11).

4.4 Primer results

4.4.1 Cluster Analysis / Classification and Multi-dimensional scaling (MDS)

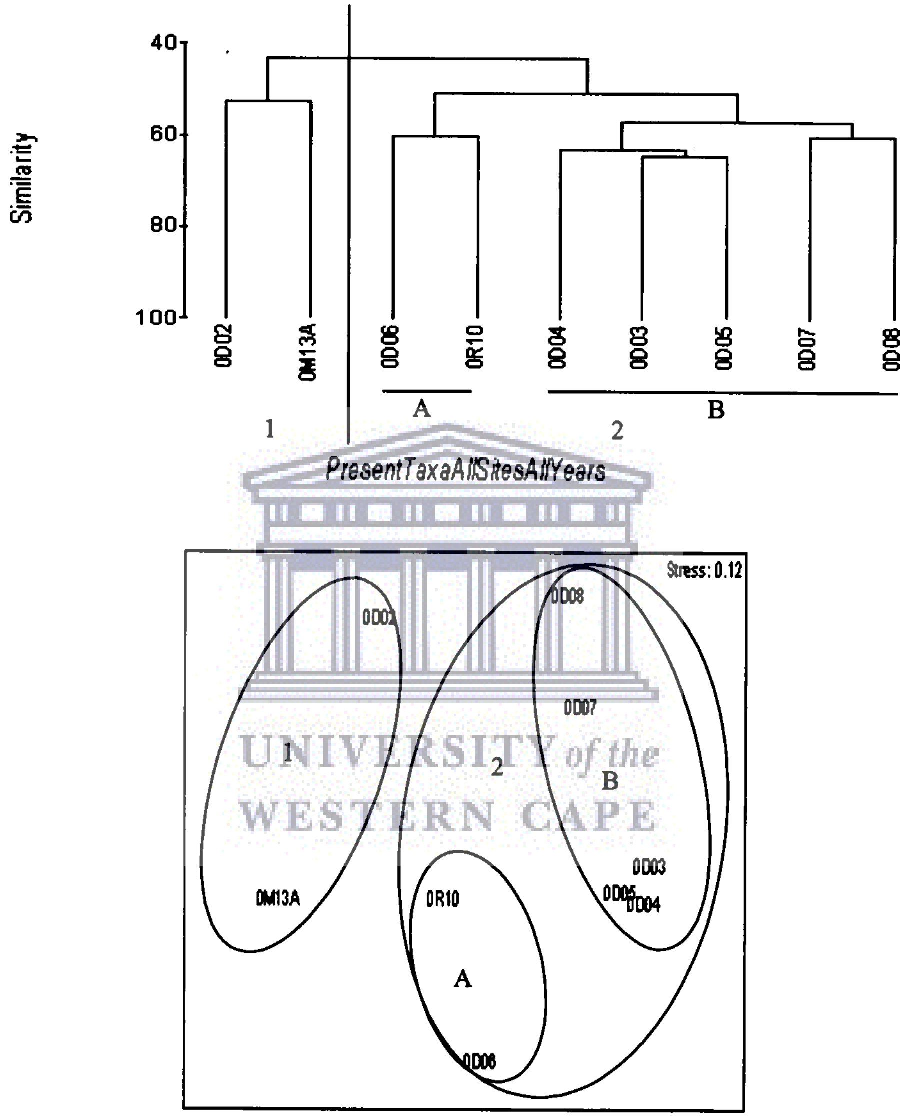


Figure 4.20 SASS Taxa 2000, (indicated by 0 before site code) summer Dendrogram and MDS ordination showing the classification of sites in the Diep River System using group average clustering from Bray-Curtis similarities.

In Figure 4.20, two groups (Groups 1 and 2) split at 43% similarity, and at 51% similarity levels, Group 2 split again into further two subgroups comprising of A and B. Group 1 splits further into two subgroups of D02 and M13A sites at 53% similarity. The stress value in MDS ordination is 0.12.

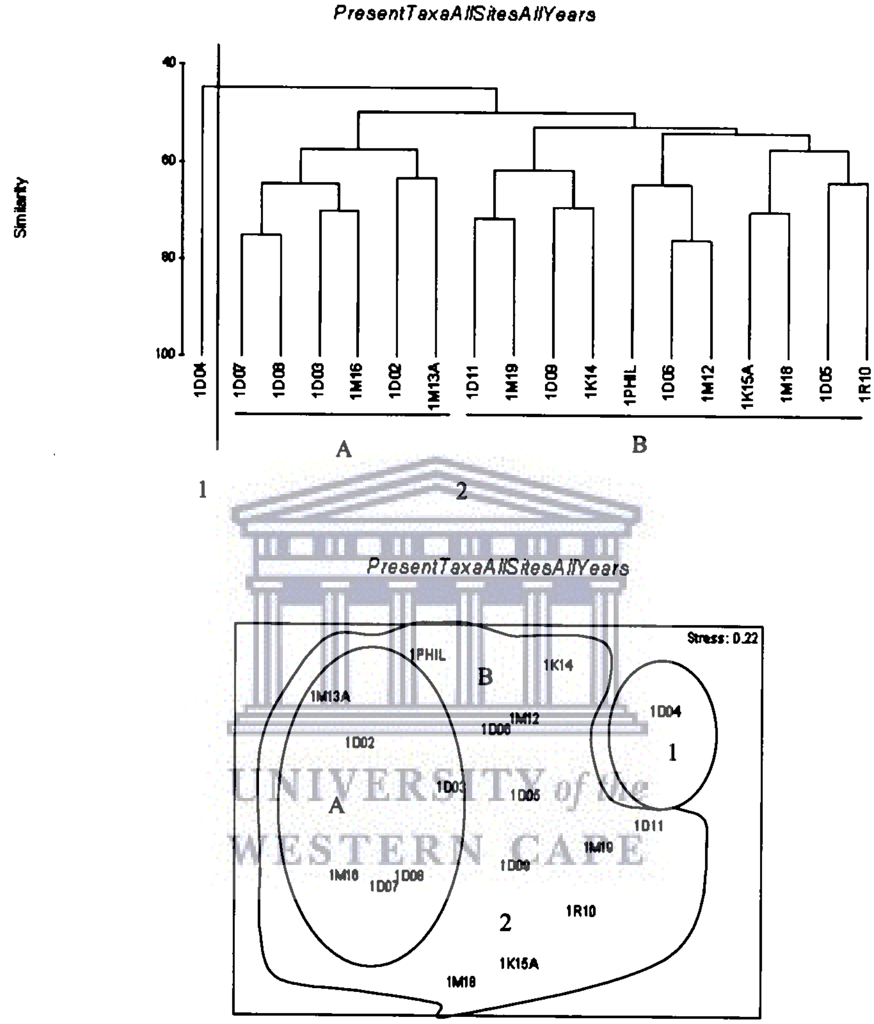


Figure 4.21 SASS Taxa 2001 (indicated by 1 before site code) spring Dendrogram and MDS ordination showing the classification of sites in the Diep River System using group average clustering from Bray-Curtis similarities.

Groups 1 and 2 in Figure 4.21 split out at 45% similarity. Group 2 then split further into two subgroups, which are A and B at 50% similarity levels.

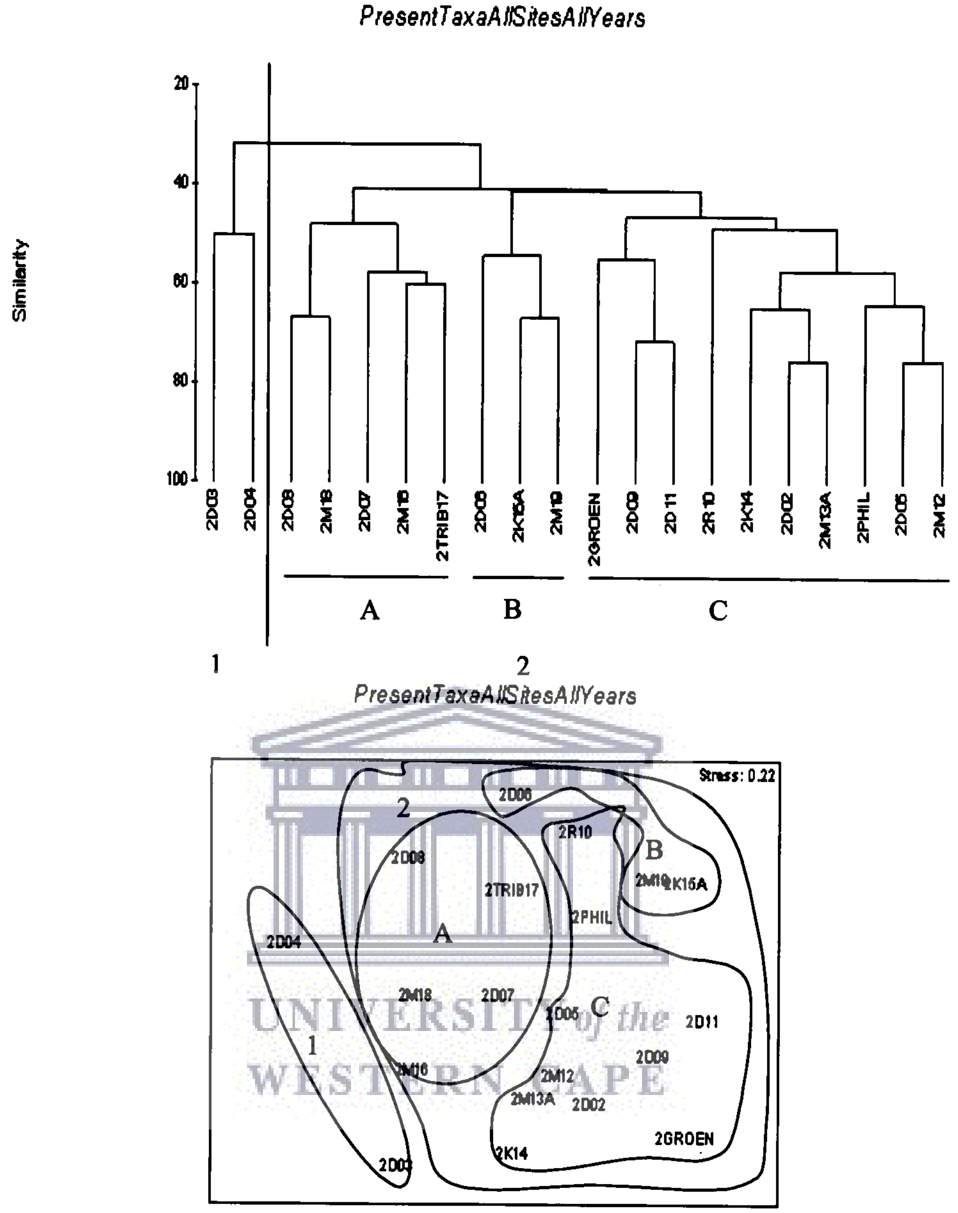


Figure 4.22 SASS Taxa 2002 (indicated by 2 before site code) winter Dendrogram and MDS ordination showing the classification of sites in the Diep River System using group average clustering from Bray-Curtis similarities.

SASS 2002 in Figure 4.22 indicates groups 1 and 2 split out at 32% similarity. Group 2 then splits into 3 subgroups (A, B and C) at 41% similarity levels, whereas Group 1 further splits into site D03 and D04 at 50% similarity level. MDS ordination stress value is 0.22.

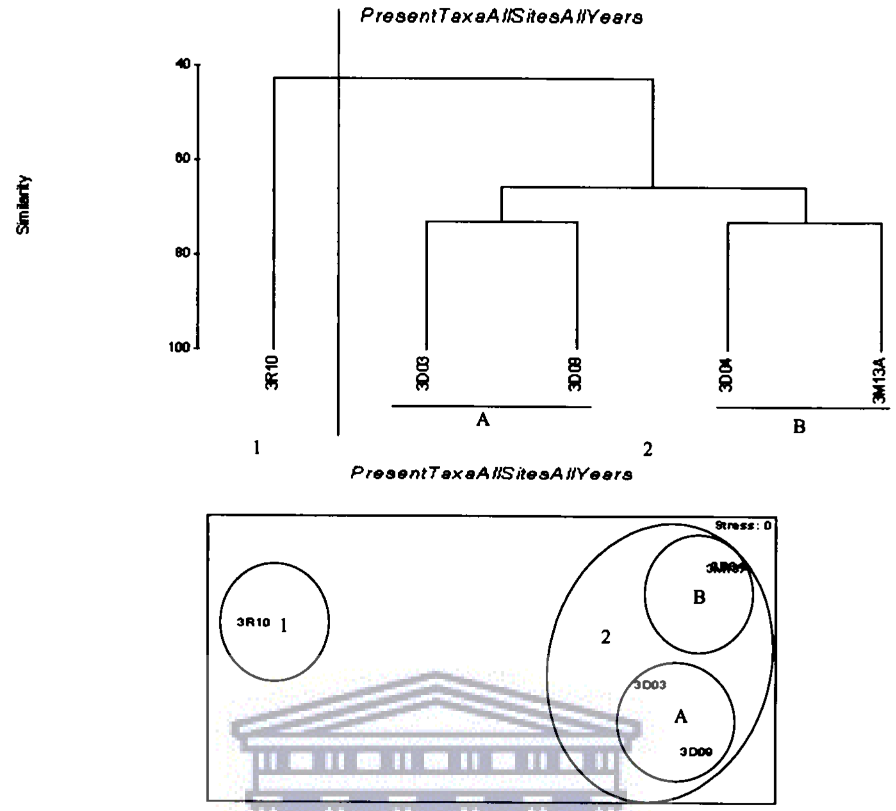


Figure 4.23 SASS Taxa 2003 (indicated by 3 before site code) autumn Dendrogram and MDS ordination showing the classification of sites in the Diep River System using group average clustering from Bray-Curtis similarities.

SASS 2003 in Figure 4.23, Groups 1 and 2 split out at 43% similarity, and at 66% similarity levels, Group 2 split again into two subgroups comprising of

A and B. MDS ordination indicated stress value of 0.

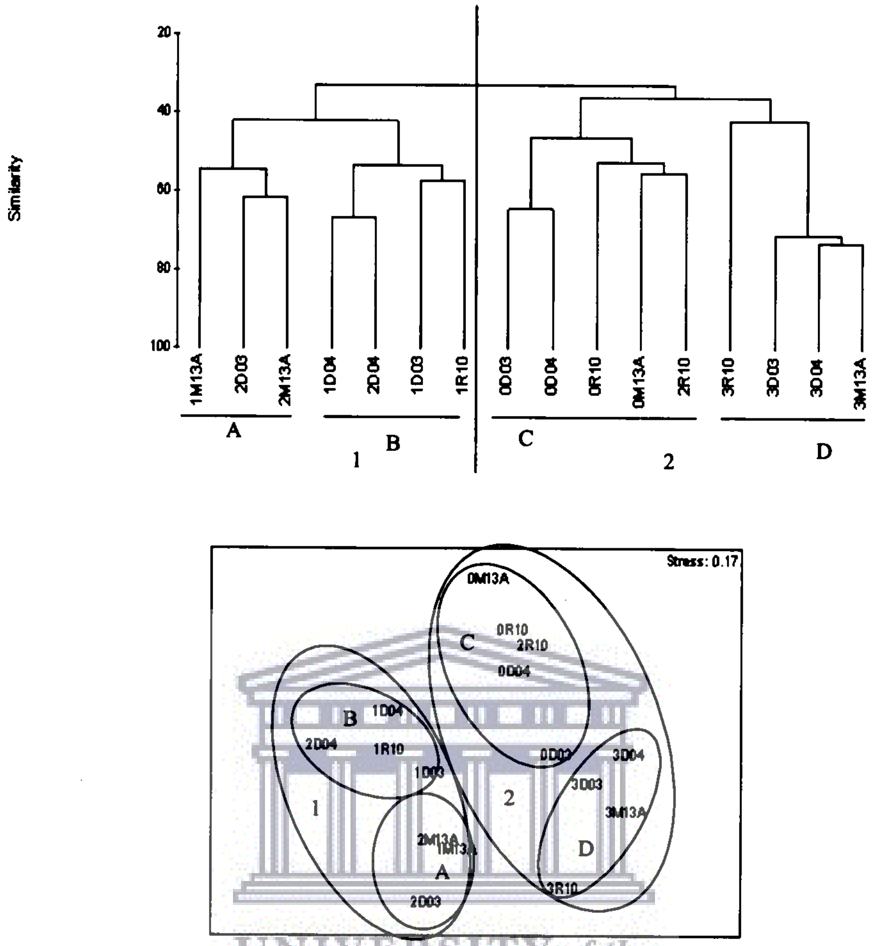


Figure 4.24 SASS Taxa (SASS data sampled all four times, 2000-2003) Dendrogram and MDS ordination showing the classification of sites in the Diep River System using group average clustering from Bray-Curtis similarities.

The Diep River System macroinvertebrates assemblages in Figure 4.24 formed two groups (Group 1 and 2), splitting at 34% similarity. Group 1 further splits into subgroup A and B at 42% similarity levels. Group 2 also splits again into two subgroups C and D at 34% similarity levels. MDS ordination indicated stress value of 0.17.

CHAPTER 5: DISCUSSION

In this chapter, the results of the data findings are discussed in relation to the General and Special limit of the wastewater (effluent) guidelines, South African Water Quality Guideline: Aquatic Ecosystems, historical data, reference conditions and other river systems in the region. Chemical and biological assessment, primer results as well as the relationship between the Diep River system and other river systems in Western Cape are discussed in this chapter.

5.1 Chemical assessment (water chemistry)

5.1.1 Ammonia (NH_3-N)

Ammonia concentration trend (Figure 4.1) corresponds with the number of taxa trend, thus the fewer taxa in the D08 and M18 sites, where the ammonia values exceeded the AEV of 0.1 mg/l for aquatic ecosystem (DWAF 1996); the values are even more than a General Limit of 3 mg/l for waste water discharge (effluent standards) and is probably caused by non-complying effluent discharge from the Malmesbury and Kraaifontein WWTWs and the runoff from extensive stock farming and dense informal settlements along the Mosselbank River.

5.1.2 Chemical Oxygen Demand (COD)

Chemical Oxygen Demand (COD) is measured as a potential for organic wastes to deplete oxygen (DWAF 1996a). High points in D03 and M18 sites (Figure 4.2) were probably influenced by contributions from the tributaries and the urban encroachment in the catchment, and the WWTW upstream of M18. The General Limit for COD in the water resource is 75, with 30 being the Special Limit; only 7 sites out of 20 comply with the General Limit and none complied with the Special Limit. A discharge of effluents rich in organic matter downstream of site D06 and M19 increased COD levels, which then increased low oxygen tolerant macroinvertebrates like dipterans larvae and worms (e.g. oligochaetes) in the Diep River system (Dallas and Day 1993; Allanson 1995).

5.1.3 Electrical Conductivity (EC)

The water in the Diep River catchment is naturally saline (generally above 300 mS/m) due to the main underlying geology which is the Malmesbury shales (70-300 mS/m in Diep River above Philadelphia and 300-1 000 mS/m at Diep River below D04 site (Figure 2.2). The natural salinity is however elevated due to disturbances of the land surface mainly by agriculture. The influence of the estuary in D02 site is seen only in late summer when freshwater input from the river is low. According to Madikizela *et al.* (2001), no Ephemeroptera were recorded when the EC was raised to 325 mS/m. Only one type of Baetidae spp. was found in the Diep River system.

Electrical conductivity concentration values indicated that D03, Phil, D02 and K14 sites exceeded 300 mS/m (Figure 4.3; 4.4) and did not comply with the Aquatic Ecosystem TWQR of 70-300 mS/m specific for the upstream sites of the Diep River system, but complied with the TWQR of 300-1 000 mS/m specified for downstream sites of Diep River (below D04 site) due to the geology of the area. Diep River system did not comply with the Effluent General Limit range of 70-150 mS/m (DWAF 1999a) either, with highest points of 319 at D03 and 514 at Phil.

According to Scherman *et al.* (2003) high salinities are said to have lethal or sub-lethal effects. *Daphnia pulex* has been indicated to be more sensitive to salts than most freshwater invertebrates, but *Daphnia* spp. were found in D02 site (where EC is up to 200 mS/m) in 2001. According to a Salinity Guideline (Scherman *et al.* 2003): Health Classes A-F for upper Olifants River (Gauteng, Mpumalanga), by Palmer (1999), more than 155 mS/m is the Class F, which would result in biotic degradation after a short exposure of at least four days. A Health Class allocation table for EC, based on toxicity data, indicates more than 200 mS/m as E/F class (Palmer and Scherman 1999).

Generally, many species appear to be able to survive at relatively high salinities, it is often the rate of change that is most critical. A critical level of salinity of about 5000-8000 mg/l is the upper limit of most salinity tolerant freshwater animals (Dallas 1994). Insects (hemiptera), dipterans, molluscs and crustaceans are the more saline tolerant macroinvertebrates and hypo-osmotic regulators, with crustaceans and dipterans being the most tolerant. Flatworms, segmented worms, and coleoptera are salt sensitive macroinvertebrates (which cannot tolerate a toxic effects of more than 1000 mg/l), with gastropods, insects (mayflies, dragonflies, stoneflies and caddisflies) being the most salt sensitive. Mayflies and stoneflies abundance is generally high in lower salinities; ranging from 28-460 mg/l (Hart *et al.* 1990 in Palmer *et al.* 1996).

5.1.4 Nitrates (NO_3-N)

Upstream sites of Diep, Mosselbank, and Klapmuts rivers and recovering downstream sites are the only sites complying with mesotrophic conditions of NO_3-N concentration (Figure 4.5), which are the supporting species diversity and less nuisance growth. Downstream sites of Mosselbank River and Groen River falls under eutrophic condition of aquatic system had low levels of species diversity and high nuisance growth of *Azolla filiculoi*des at Groen site noticed during winter 2002 sampling. Trib 17 site falls under hypertrophic conditions with low species diversity, and the presence of *Azolla filiculoi*des bloom noticed during winter 2002 sampling.

Nitrate concentrations at all sites in the Diep River system were all below 15 mg/l (Figure 4.5), which is the General Effluent Limit for wastewater disposed into the water resource according to General Authorization (DWAF 1999a).

Several sites complied with Special Limits of 1.5 mg/l for wastewater into a water resource.

Other than natural concentrations caused by mineral salts in the soil and rocks, sources of nitrates in the Diep River Catchment are basically from agricultural runoff and stock farming (DWAF 1996a).

Nitrate concentration corresponds with the taxa pattern indicating fewer taxa in the D08 and Groen sites where nitrate values are high, but the Trib 17 site has high taxa due to flow supplement.

5.1.5 Phosphates (PO4-P)

There is a drastic increase in the phosphorus levels downstream of the Malmesbury WWTW, the Kraaifontein WWTW, the Fisantekraal (urban fringe and informal dense settlement) and Mellish (agriculture) According to the Aquatic Ecosystem guideline (DWAF 1996b), only upstream sites (R10, D11 to D09) and the Groen site comply with the eutrophic conditions limit of 0.3 mg/l (Figure 4.6); and the rest of the sites are hypertrophic with a lot of algae and possibility of algal blooms in future in similar conditions (Figure 4.6). Palmer (1996) and Zokufa *et al.* (2001) indicated that WWTWs add nutrients and increases phosphate levels, which determines eutrophication levels in the water bodies.

There was an abundance of gastropods (Physidae, Thiaridae and Ancilidae) in the Diep River system (Appendices A-D), which agrees with (Dallas and Day 1993) by indicating that the massive growth of algae in eutrophic waters may result in a population explosion of snails and the loss of mayfly and stonefly nymphs.

Phosphates (PO4-P) and NO_3-N concentrations are linked when discussing nutrients loads in the water, and are mostly in low concentration in nonimpacted aquatic systems. Cultivation and livestock are the land-use activities that mostly increase PO4-P concentrations in aquatic systems. Plants need nutrients for growth and this decreases PO4-P concentration further downstream of the discharge point as a result of river self purification especially in slow flowing river systems (Madikizela *et al.* 2001; Malan and Day 2002), as in the Diep River System (Figure 4.6 - in the Groen River tributary; which is regarded as a non-perennial stream, flowing only in winter).

5.1.6 pH

A pH median (Figure 4.7) indicated a fluctuation within a range of 7.4 to 8.1, which is an indication that the alkaline waters of Diep River System are within the Target Water Quality Range (TWQR) of 6-8 for well-buffered Aquatic Ecosystems (DWAF 1996b); and an allowable General Limit of 5.5-9.5 for wastewater.

Extreme rates of photosynthesis are said to result in high pH values in standing water. For all aquatic ecosystems, pH values must not exceed 5 % of the allowable limit for a specific site. Macroinvertebrates are site specific in terms of acidity or alkalinity; there are acid-tolerant and less-tolerant organisms. (Chutter 1998; Dallas *et al.* 1998). Certain invertebrates such as amphipods are tolerant of pH values approximately 2.4 (Dallas *et al.* 1998), as indicated by the absence of amphipods in the Diep River system (Appendices A-D).

5.1.7 Suspended Solids (SS)

Natural riverbanks in the Diep River system is dominated by easily eroded soils of Malmesbury shales, all these lead to an increase value of SS. The Diep River has become increasingly silted in the past few centuries as agricultural activities have increased and extensive erosion has taken place, particularly in the Swartland and Sandveld (IWQS 2001). Extensive silt deposition due to erosion in the catchment has resulted in the lower part of the Diep River being muddy (for example, in D02 and D03 sites), as seen during sampling. Malan and Day (2002) and Zokufa *et al.* (2001) indicated that the turbidity in the southwestern Cape Rivers is highest in the first flush of rainy season and during storm events. Turbidity is generally low during low flows. The Geological formation in Diep River is predominantly Malmesbury Formation, from which clay type of soil is derived, which is a source of clay minerals in sediments (IWQS 2001).

There are a number of sand and stone quarries upstream of D03-D02 together with sedimentation inflow from agricultural fields, brick and pottery factories along Mosselbank River, and natural riverbank erosion around the Klapmuts River. The Diep River system does not comply with the TWQR of less than 10 mg/l SS concentration of Aquatic Ecosystem guidelines, except at R10, Groen and Phil sites.

High silt loads in rivers reduce and contributed to the variation of diversity of taxa (Chutter 1998; Peeters *et al.* 2004), for example urban stormwater flow was said to have resulted in increased SS and decreased DO which lead to a decrease in macroinvertebrates species diversity in Provo River, United States of America (Gray 2004). High SS concentration generally leads to loss of ephemeropterans (mayfly) and increase in chironomids (Dallas and Day 1993). Sensitive species may be eliminated and replaced by organisms that burrow in soft sediment if the SS problem persists (DWAF 1996b).

5.1.8 Temperature (Temp)

Table 5.1 TWQR for water temperatures in the Diep River system as determined by the set RQOs in this study (Table 6.2-6.9) as follows:

Seasons	Actual Temp. (°C)	RQOs Temp. Range (°C)	TWQR
Spring	18-23	16-20	Not to vary by >2 °C
Summer	21-27	22-26	Not to vary by >2 °C
Autumn	23-33	17-22	Not to vary by >2 °C
Winter	11-16	12-16	Not to vary by >2 °C

Diep River system comply with the Temperature Range determined by the set RQOs in this study (Table 6.2-6.9) and the TWQR of Aquatic Ecosystems at all the seasons but Autumn samples ranging from 23-33°C instead of 17 to 22°C (Table 5.1). Increased temperature up to 33°C at R10 site in March 2003 (Figure 4.9) was due to reduced flows and climate such as warm air temperature and slow wind speed, as supported by Myburgh (2003), that water temperature may be influenced by seasonal shifts.

Optimal water temperature for maximum macroinvertebrate abundance ranges from 9 to 29°C (Palmer 1997). Human induced changed water temperature does affect the organism behavior and distribution. Generally in South Africa the temperature of inland water ranges from 5-30°C. Palmer (1997) indicated that blackflies (simulids) were abundant during cold conditions and caddisflies during warm conditions in the Orange River system, and these supports the absence of blackflies (simulids) at site R10 during warm Autumn 2003 samples. SASS Scores were lower at temperatures less than 15°C compared to warmer temperatures

Very low temperatures normally inhibit macroinvertebrates activities, just like *S. chutteri* is known not to pupate at temperatures below 10°C (Palmer 1997).

Increased temperatures increase metabolic rates and hence oxygen demand of aquatic organisms, leading to oxygen depletion in the river system. A slight temperature change, maintained for a long period of time, may alter the distribution of aquatic organisms. Severe changes in water temperature may have a lethal effect (DWAF 1996b; Myburgh 2002).

5.2 Biological Assessment

Table 5.2 Preliminary guidelines for the interpretation of SASS data in the Western Cape, separated on the basis of sub-regions (H.F. Dallas)

Sub-region	SASS4 Score	ASPT	Comment
Mountain Stream and Foothills cobble bed	>140	>8	Water quality natural and biotope diversity high
	<140	>8	Water quality natural, biotope diversity reduced
	>140	<8	Borderline case between natural and some deterioration in water quality, interpretation should be based on extent by which SASS4 results exceed 140 and ASPT is less than 8
	100-140	6-8	Some deterioration in water quality
	<100	<6	Major deterioration in water quality
Foothills	>110	>7	Water quality natural, (gravel bed) and biotope diversity high
	<110	>7	Water quality natural, biotope diversity reduced
Lowland Floodplains	>110	<7	Borderline case between water quality natural and some deterioration in water quality, interpretation should be based on extent by which SASS4 results exceed 110 and ASPT is less than7
	70-110	5-7	Some deterioration in water quality
	<70	<5	Major deterioration in water quality

Table 5.3 Summary of the Ecological classes assigned on the basis of SASS Scores, "WQ" indicates water quality

Sites & Dates	SASS Scores	ASPT	Ecological class	Comments
R10				
Nov-Dec 2000	62	4.4		
Oct-Nov 2001	44	4.4	D (Fair)	Some deterioration in WQ
Jun-Jul 2002	94	4.7		
Mar 2003	41	4.6		
D11				
Oct-Nov 2001	84	4.9	D (Fair)	Some deterioration in WQ
Jun-Jul 2002	20	3.3		Major deterioration in WQ
D09				
Nov-Dec 2000	54	4.1		Some deterioration in WQ
Oct-Nov 2001	56	4.3	D-E (Fair-Poor)	
Jun-Jul 2002	25	3.1		Major deterioration in WQ
Mar 2003	32	3.5		
D08				
Nov-Dec 2000	29	3.2		
Oct-Nov 2001	36	3.6	E/F (Poor)	Major deterioration in WQ
Jun-Jul 2002	27	3.8		
D07				
Nov-Dec 2000	51	4.6		Some deterioration in WQ
Oct-Nov 2001	55	4.2	D-E (Fair)	
Jun-Jul 2002	47	4.3		Major deterioration in WQ
D06				
Nov-Dec 2000	83	4.9		Some deterioration in WQ
Oct-Nov 2001	70	5.0	D (Fair)	
Jun-Jul 2002	49	4.9		
D05				
Nov-Dec 2000	78	4.9		Some deterioration in WQ
Oct-Nov 2001	55	4.6	D (Fair)	
Jun-Jul 2002	58	4.5		
D04				
Nov-Dec 2000	55	4.2		Major deterioration in WQ
Oct-Nov 2001	54	4.9	D-E (Fair-Poor)	
Jun-Jul 2002	22	3.7		
Mar 2003	50	4.2		
D03				
Nov-Dec 2000	68	4.5		
Oct-Nov 2001	44	4.0		Major deterioration in WQ
Jun-Jul 2002	24	3.4	E/F (Poor)	
Mar 2003	60	4.6		
D02				
Nov-Dec 2000	53	4.8		Major deterioration in WQ
Oct-Nov 2001	33	3.7	E/F (Poor)	
Jun-Jul 2002	36	4.0		
GROEN				
Jun-Jul 2002	11	2.7	E/F (Poor)	Major deterioration in WQ
M19				
Oct-Nov 2001	50	4.5	D-E (Fair-Poor)	Major deterioration in WQ
Jun-Jul 2002	38	4.2		

Table 5.3 continued

Sites and Dates	SASS Scores	ASPT	Ecological class	Comments
M18				
Oct-Nov 2001	25	3.6	E/F (Poor)	Major deterioration in WQ
Jun-Jul 2002	19	3.8		
Trib17				
Jun-Jul 2002	61	4.4	E/F (Poor)	Major deterioration in WQ
M16				
Nov-Dec 2000	44	4.9		
Oct-Nov 2001	27	3.0	E/F (Poor)	Major deterioration in WQ
Jun-Jul 2002	17	2.8		
K14				
Oct-Nov 2001	69	4.6	D-E (Fair-Poor)	Deterioration in WQ
Jun-Jul 2002	35	3.9		
K15A				Major deterioration in WQ
Oct-Nov 2001	53	4.1	E/F (Poor)	
Jun-Jul 2002	26	4.3		
M13A				
Nov-Dec 2000	44	4.9		
Oct-Nov 2001	34	3.8	D-E (Fair-Poor)	Deterioration in WQ
Jun-Jul 2002	30	4.3		
Mar 2003	41	4.1		
M12				
Oct-Nov 2001	63	4.8	D-E (Fair-Poor)	Deterioration in WQ
Jun-Jul 2002	44	4.0		
PHIL				
Oct-Nov 2001	66	4.4	D-E (Fair-Poor)	Deterioration in WQ
Jun-Jul 2002	46	4.6		

5.2.1 South African Scoring System (SASS) Scores

Madikizela *et al.* 2001 indicated that municipal treatment plants discharge causes modification of invertebrate community structures. Nutrients loads discharged from Malmesbury and Kraaifontein WWTWs decreased SASS scores and altered macroinvertebrates communities to *Poor* Ecological classes (Figure 4.11-4.12, Table 5.3 and Appendices A-D) in the Diep River system. The sudden decrease in SASS Scores in Abbotsdale might be due to the stormwater runoff from the agricultural and stock farming (cattle and pigs), and legal and illegal Solid Waste Disposal Sites in that part of the catchment.

WWTWs supplement flow by discharging a certain amount of treated wastewater into the system. An improvement of water quality and ecological health of the river system occurs over a distance below the discharge point, for example, improvement of site D07-D05 in Table 5.3. Water quality improves as the river system recovers (Hynes 1963). In the Diep River system, which is now made non-perennial/ephemeral due to over-abstraction, Malmesbury and Kraaifontein WWTWs decreases water quality close to the effluent input points and improves it as it flows further from the input point (at a long reach) (Figure 4.11 and 4.12). Reduced flow changes macroinvertebrates community composition or diversity, for example *Daphnia* and diatoms flourish during low flow (Madikizela *et al.* 2001). The Groen River SASS score is the lowest of all the sites, which confirms Chutter (1998)'s findings that low scores can be expected in non-perennial streams and that natural hazards such as drought and floods can place limits on the successful use of invertebrates in water quality monitoring. This indicates that SASS is not suitable for non-perennial rivers, but is designed for perennial rivers or non-perennial rivers when they flow.

The highest SASS Score recorded was 94, in the Riebeeks River (R10 site), upstream tributary of the Diep River, in the winter sample 2002. The reason for this high score might be because all the available biotopes were available for sampling. Site R10 was chosen as a reference site due to minimal human activities upstream of the site and less impact found up to date compared to the other sites. The highest SASS Score corresponds with historical data indicating that the highest SASS4 Score and ASPT ever found in the Diep River was 98 and 7.5, in mountain stream in November 1997 (Dallas 1997a). These results indicated that the site falls under ecological class D (Fair) (SASS Score of 70 to 100), indicating some deterioration in water quality (Table 5.3). The lowest historical SASS score recorded in the Diep River system was 11 at M16 and 14 at D03 in 1998, indicating poor state of health (Dallas 1997a; Day 1998); the system had not improved because the lowest SASS Score recorded during this study was 11 in the Groen and 17 in M16. These low scores fall under ecological class E/F (Poor) (SASS Score of less than 70), indicating major deterioration in water quality (Table 5.2). Non-perennial state of the river for example Groen site in Groen River also influenced low scores. Regulated flow decrease macroinvertebrates abundances (Munn *et al.* 1991).

5.2.2 Number of Taxa

In the Diep River System, taxa over 15 were recorded in winter, spring, and summer on sites R10, D11, D06 and D05 respectively. Dallas (2002) indicated that in other Western Cape Rivers sampled, more taxa were recorded in autumn than in spring and high-scoring taxa were recorded in spring. Fewer taxa were recorded in winter compared to summer in other Western Cape Rivers (Dallas 2002), similar trend as recorded in the Diep River System. The lowest number of taxa recorded in the Diep River System was 4 in the Groen, 5 in M18, 6 in M16 and 7 in D18 that correspond with historical taxa as low as 4 in D03, M12, M16 and 6 in D08 and M18 recorded in 1997 indicating no improvement of ecological integrity (Dallas 1997a; Day 1998). Number of taxa indicated fair to poor macroinvertebrates diversity in the Diep River system. Regulated flows in river systems reduce taxa richness (Munn *et al.* 1991).

5.2.3 Average Score Per Taxon (ASPT)

The lowest ASPT recorded in the Diep River system was 2.7 in M16 sampled September 1998 (Dallas 1997a; Day 1998), which corresponds with 2.7 in the Groen and 2.8 in M16 site recorded in winter 2002 which might be an indication of poor water quality in terms of macroinvertebrates. ASPTs in the Diep River system follow the same pattern as the SASS Scores. In D04 site, ASPT is better than expected. K15A should have been much lower due to many openings from the stormwater channels. Chutter (1998) stated that the absence of certain habitats (biotopes) decrease SASS Scores to the level of water quality deterioration rather than the ASPT, which remain on the level of no impact, only when water quality is good. Significantly higher ASPT values are recorded in winter and spring compared to summer and autumn in Western Cape Rivers (Dallas 2002). The ASPT values in the Diep River system are high in spring and summer, followed by winter. The ASPT values of less than 5 in the Diep River system indicate ecological class E/F (Poor) meaning major deterioration in water quality (Table 5.2), but due to SASS Scores over 70, R10, D11, D06 and D05 may qualify to be class D (Fair) instead of E/F.

5.2.4 SASS discussion

The SASS Scores were generally higher in summer and spring, compared to other seasons, because all biotopes at a site were sampled with ease. The South African Scoring System Scores in winter were generally low due to the heavy flows during the winter rainy period, with the exception of the upstream site R10 and Trib 17; which happened to be the highest scores respectively. Macroinvertebrates are likely to be washed down during rainy period. Not all biotopes were sampled because of the winter high flows, and this may be the other reason why winter SASS Scores were low. The SASS Scores in autumn were higher than in winter even though there was lack of flow in many sites (Figure 4.19); this is the reason why only few sites were sampled in this season.

Seasonal variation patterns for the number of taxa and SASS Scores are similar. The seasonal ASPT scores (Figure 4.15) were between 3 and 5, except for Groen and M16 in winter and spring, and are possibly influenced much by flow.

5.2.5 Invertebrate Habitat Assessment (IHAS)

Table 5.4 Habitat Evaluation Table (Thirion *et al.* 1995)

Habitat Value	Comments
> 80	Natural
60-80	Good
40-60	Fair
< 40	Poor

The Habitat Scoring index shows how to evaluate habitat; adopted from SASS4 Manual (Thirion *et al.* 1995). All sites displayed poor habitat qualities except D08, D07, D06, D05, D04 and the M13 sites; which are within good (Table 5.4), and this is due to flow supplement from the WWTW. Very poor habitat (<40) was indicated in autumn at D04 and D03 because of low or no flows, which excludes some of the vegetation from the instream (Figure 4.17).

The IHAS is directly proportional to the flow/quantity in the river and slightly influenced by the physical state of the water (e.g. turbidity and algae). The higher the flow the more the marginal vegetation is immersed in the water and becomes accessible for sampling and scoring on the IHAS sheet. During floods accessibility becomes a problem and not all the habitats are available. The Groen River has low SASS Score and ASPT but fair IHAS score (over 50) (Figure 4.18). Low ASPT and high habitat scores is mostly indicative of biological impairment, as demonstrated by the Selati River in Mpumalanga

(Palmer *et al.* 1996). D04 and Groen sites (Figure 4.17 and 4.18) have a very high IHAS and yet SASS Scores and ASPT are low. These are indication of poor water quality as Chutter (1998) has indicated that in poor water quality, where tolerant taxa remain, habitat availability is not a factor influencing SASS Score. Unlike habitat index SASS Scores, ASPTs, and Number of taxa reflects changes in macroinvertebrates community structure (Vos *et al.* 2002). In the case of the Groen River, flow is another factor, other than water quality, influencing low scores.

The South African Scoring System (SASS) Scores, Taxa and ASPT (Figure 4.11, 4.13 and 4.15) were comparable. The dissimilarity between winter and the other three seasons can be related to the fact that some invertebrates were probably washed down the river. Though summer and autumn has high SASS Scores, winter has high IHAS scores, mainly above 50; and is the one set having the lowest ASPT of below 3 (Figure. 4.15 and 4.17).

5.2.6 Reference conditions

The highest SASS4 Score ever found in the Diep River System was 98, the number of taxa was 13, and the ASPT was 7.5. The sample was taken upstream of Paardeberg (D11), in the mountain subregion (Dallas, 1997), and it served as a reference site for the Diep River System. In this study, Riebeeks River site R10 was used as a reference site because is the least impacted of all the sites in the Diep River system and falls within the same subregions of Foothill-gravel and Lowland. Even though Paardeberg (D11) had SASS scores higher than that of Riebeeks River, the site is not used as a reference site because it falls under a mountain subregion which is different from that of other Diep River system sites. The best attainable scores for foothill-gravel bed and lowland subregions were a SASS4 Score of 182 and an ASPT of 9.6. Lowland SASS4 Scores of more than 85 and ASPT more than 6.5 were always found to be lower than that of Mountain and Foothill-cobble-bed (Dallas *et al.* 1998).

Acidic (pH <6) un-impacted mountain streams of southern and western Cape have higher SASS Scores than the rest of the country. The highest ASPT of 11.6 was recorded in the upper catchment of the Berg River, while the highest SASS4 Score of 231 on the Elandspad River. The Eerste River upstream of Jonkershoek had SASS4 Score of 213 and ASPT of 10 (Chutter 1998).

5.2.7 The difference between the Diep River System and other rivers in Western Cape

The Diep River system is divided into three subregions, Mountain stream (not extensive), Foothill-gravel, and Lowland subregions. The headwaters are not distinct and the river system is not fed by an extensive mountain catchment. Much of the catchment is situated on a fairly gentle gradient from top to bottom. Only VEG and GSM invertebrate habitats are present in this river, whereas other rivers in Western Cape are divided into more than three subregions, which include either/or the following: Mountain Stream, Gorge, Foothill-cobble-bed, Rejuvenation, Foothill-gravel-bed and Lowland floodplains.

The Diep River system is a renosterveld river with pH Median range between 7.4 to 8.1, whereas most of the rivers in Western Cape, especially in mountain subregions are fynbos rivers with pH values ranges from 5.0 to 6.5 due to organic materials from the fynbos plants in the river systems. It is therefore unlikely that the SASS and ASPT scores for the Diep River would have reached the high scores of other fynbos rivers of the Western Cape. Much of the catchment is situated in nutrient rich shales, which are likely to increase pH values and chance of eutrophication.

5.3 Primer

The Diep River system dendrograms reflect sample groupings and patterns, wherein the groups split at the percentage similarity value (Figure 4.20 to 4.24) (King *et al.* 1988; Dallas 2002; Vos *et al.* 2002).

The sites within Group 1 (Figure 4.20) indicated similar macroinvertebrates assemblages and this might be because the sites are both downstream sites of the Diep and Mosselbank Rivers and were equally impacted. The stress value of 0.12 indicates a good ordination for interpretation.

Sites in subgroup A (Figure 4.21) are mostly low scoring, downstream of the major impacts (for example WWTW) and downstream of the Diep and Mosselbank Rivers with extensive stock farming. Sites in subgroup B mostly comprised of upstream sites of the Diep and Mosselbank River and least impacted sites of the other tributaries of the Diep. The stress value of 0.22 indicates an unreliable representation of data or not that good ordination.

The stress value of 0.22 in Figure 4.22 indicates not a good ordination without a complementary technique. In Figure 4.23, Group 1 comprised of a reference site (R10), which stands out to be dissimilar to other sites in Group 2 by 23%. The stress value of 0 in Figure 4.23 gives an excellent and/or perfect reliable representation.

In Figure 4.24, subgroups A and B comprised a combination of spring (2001) and winter (2002) samples. Subgroup C comprised of the summer (2000) downstream sites samples and winter (2002) reference site R10. Subgroup D comprised of the autumn (2003) samples only, which splited at 42% similarity level into subgroups comprised of upstream and reference site (R10) and downstream sites of the Diep (D03 and D04) and Mosselbank Rivers (M13A) maybe due to availability of flow most of the year. The stress value of 0.17 does not give a good ordination without a complementary technique.

Generally, the Dendrograms and MDSs for the Diep River showed the lower sites of the Diep and Mosselbank rivers to be similar (D02, D03, D04 and M13A), while the site R10 on the Riebeeck was dissimilar to all of the other sites. Sites D09, D11 and the Groen, all currently non-perennially flowing rivers also showed similarity. Streams with similar ecological functioning have similar faunal distribution (King *et al.* 1988).

5.4 Links between flow and macroinvertebrates communities

5.4.1 Seasonal changes

Temporal changes in flow (natural or human induced), floods or drought, are major factors affecting invertebrate community contribution. Permanent presence of water influences water temperature and therefore the composition of aquatic macroinvertebrate assemblages (Collinson 1995; Matonickin, *et al.* 2001). Seasonal changes mostly affect SASS Scores and not ASPTs (Dallas *et al.* 1994). Seasonal distribution of invertebrates in the Diep River is indicated in SASS scores (Figure 4.11) and taxa (Figure 4.13). Summer samples have the highest SASS Scores and Number of taxa in many sites, followed by autumn and spring; with winter being the least except R10 site, which is the least impacted. Similar to the Diep River system, the Eerste River also in Western Cape Province had low macroinvertebrates abundance and biomass through winter and peaked in spring (King 1983; King *et al.* 1988). Vaal River had a density of the invertebrate community in its highest in dry, early summer months when the water is not turbid and organic material is low (Allanson 1995).

5.4.2 Low flow

The abundance of individuals for each species can be correlated with water quality and quantity variations (Ocon and Capitulo 2004; Shieh *et al.* 1999). Chironomidae, mollusca, collectors, gatherers, and scrapers are in abundance and dominant in nutrient enriched part of the rivers and regulated flow (Camargo *et al.*; King 1983, King *et al.* 1988; Munn *et al.* 1991; Vivas and Casas 2002; Shieh *et al.* 1999). Figure 4.19 indicates flow in the Diep River with the highest level of 0.3 m in July 2001 (mid winter), which supports the availability of lotic macroinvertebrates found in other seasons. Trichopterans were not found in the Diep River system because of low flow. Few Baetids in terms of abundance and species diversity were found in the Diep River system (Appendices A-D) probably due to pollution because some Ephemeropterans are known to be sensitive to pollution (Palmer *et al.* 1996). Filter-feeding taxa like midges (chironomids) and blackflies (simulids) are mostly associated with very low flows (<16m^3 /s), and mayflies (baetids) and blackflies (simulids) are associated with low flows (16-19m^3 /s) (Palmer 1997), and were in abundance in the Diep River system.

According to Pollard (1996) low flow causes a decrease in both taxa and SASS Scores. The high number of crustaceans indicated the change of habitat from lentic to lotic and deteriorating water quality (Collinson 1995; King 1983). Few Ephemeroptera, baetids, and caenids, which are flow-dependent, were present due to the lack of riffle habitat or low flow. Corixids increased during early stages of drought, but decreased as drought intensified. Generally, drought causes change in community structure, with some species disappearing while others flourish. SASS Scores at Sabie River decreased drastically during winter, when flow was at its lowest level. SASS Scores and ASPT in Twenty Four Rivers in Western Cape decreased due to minimal flow (Chutter 1998).

5.4.3 *Moderate flow*

An abundance of ephemeroptera, baetids, corixids, and caenids were present during wet winter season in the Diep River system (only those flows considered moderate and not floods). Taxa typically associated with moderate flows (60-142 m^3 /s) were found to be caddisflies (trichoptera) and blackflies (simulids). The highest ASPT was recorded at moderate flow. Fluctuating flows increased the abundance, and not the diversity of taxa like leeches, some baetids, leptocerids and simulids. The abundance of several taxa responded to variations on flow. Turbellaria, notonemourids, simulids and chironomids abundance increased when the flow was stable or constant (Palmer 1997; Myburgh 2002).

5.4.4 *Flushing*

Very high flows (floods) at more than 70m^3 /s, had a negative impact on the abundance and species composition. SASS Scores and number of Taxa decreased after flood flushing (chironomids, sensitive baetids and leptocerids disappear after flood events) and recovered after the event, especially the number of chironomidae (in sand habitats), Trichoptera and Ephemeroptera (in VEG habitat) indicating improved habitat and water quality (Pollard 1996; Palmer 1997). In Figure 4.11, June-July 2002 sample, SASS Scores are low in winter in almost all the sites except the R10, which serves as a reference site. The reason for such a decrease may be because the increased flows sweep away the macroinvertebrates following winter rains (Figure 4.19). To support this, in the Eerste River, macroinvertebrates abundance and biomass were low at the beginning of winter when floods scoured the river bed (King 1983). Palmer (1997) indicated that in the Orange River system, four months after a flood, lower SASS Scores and ASPTs were recorded. Chutter (1998) indicated that heavy rains inundate riverbeds, make some biotopes inaccessible for sampling and may sweep the invertebrates away or cause them to hide on the bottom material of the pools.

Lillehammer & Saltveit 1984 in Pollard (1996) indicated a similar trend as the Diep River system, in Suldalslagen, a Norwegian river, in which 33-37% of the total invertebrates disappear and at the same time chironomidae and a change in dominant *Beatids* spp. increase due to an increase in winter flow and reduced summer flow.

5.5 Biotope (Habitat)

Certain taxa are more commonly found in one biotope than another (Dallas *et al.* 1999).

5.5.1 Sandy biotope

Sandy habitat is known to have less macroinvertebrates diversity (Pollard 1996) and therefore did not prove to be the good refuge for many species in Diep River system (Appendices A-D; Table 4.1). Families such as oligochaetes, dipterans (Chironomidae, Simulidae, Muscidae), Caenidae and gastropods (Ancylidae, Lymnaeidae and Physidae) were in abundance in GSM biotope in the Diep River system. Leeches were also in abundance in sandy habitat of a degraded water quality sites, especially a site immediately below Malmesbury WWTW. One of the distinguishing taxa for the GSM biotope was caenids (Dallas 2002) and the biotope is the most variable in terms of SASS Score and the Number of taxa (Dickens and Graham 2002).

5.5.2 Vegetation biotope

Taxa associated with VEG in the Western Cape Rivers were Gyrinidae, Gerridae and Vellidae; to add on that are Culicidae, Naucoridae, Coenagrionidae and Zygoptera juveniles. Vegetation habitat decreased due to loss of flow by drought, which influenced loss of habitat for sampling (Pollard 1996). In VEG habitat, Chironomidae, gastropods and Leeches increased as drought conditions deteriorated (Dallas 2002), this condition is similar to the Diep River system during summer and autumn seasons (Appendices A-D). Important factors affecting the survival of flow-dependant invertebrates are water quantity, dependant on durability and availability of vegetation habitat and not water quality as a deciding factor. Vegetation biotope in the Diep River system contributed a lot in the provision for the abundance of Ephemeroptera and odonata types of macroinvertebrates. Marginal Vegetation in flowing water provides a different environment to aquatic organisms than in standing water (Dallas 2002).

5.5.3 Riffle and Bedrock biotope

There are few SIC/SOOC and Bedrock habitat in the Diep River system (M18, K14, M13A, M12, D09, D07, D06, D04, D03) (Table 4.1). The system constitutes Foothill-gravel-bed and Lowland subregions where riffle and rapids are few if not available (Figure 2.3). The Diep River system is noted for its low numbers of invertebrate species due to limited SIC and SOOC biotopes. Taxa found in this river system are opportunists, for example, the scrapers like midges, and is likely to be grouped under severely impacted sites because of the unavailability of SIC biotope like Palmiet River system within the same area (Dallas 2002). SIC/SOOC biotope has high percentage of high scoring taxa than sandy biotope (GSM) (Dallas 1997a; 2002). Sampling of SIC/SOOC alone would ensure approx. 67% of the taxa compared to VEG and GSM (Dallas 2002). The limited number of SIC/SOOC in the Diep River system seems to have no significant impact on the low SASS Scores and ASPT because even in VEG habitat, SASS Scores decreased at certain points along the river, and the reason is that the water quality deterioration has an impact and the fact that scores in this system are lower than other Western Cape Rivers.

CHAPTER 6: RESOURCE DIRECTED MEASURES (RDM)

Reserve Determination (Quantity and Quality) is one of the components of RDM. Currently, in the absence of a Classification Systems as defined in the NWA, 1998 (Act 36 of 1998), all the Reserves done will be Preliminary. Desktop Reserve requirements were done for water quantity/flow for each river unit (Table 6.1). In terms of the Quality Reserve, Diep River has a low ecological importance and sensitivity, and therefore is not a driver in determining water quality requirements. Water user requirements were mainly used to establish the RQOs (Table 6.2-6.9).

6.1 Classification of River Reaches/Management Units

For classification purposes the catchment has been divided into the following management units based on the points of impact:

River Unit 1: Riebeeks River
River Unit 2: Diep River from Paardeberg to Malmesbury Town
River Unit 3: Diep River from Malmesbury Town to Kalbaskraal
River Unit 4: Diep River from Kalbaskraal to Philadelphia
River Unit 5: Groen River
River Unit 6: Klapmuts River up to Mikpunt
River Unit 7: Mosselbank River up to Goedontmoeting
River Unit 8: Diep River from N7 bridge downstream

River Health Categories below are colour coded for water quality and SASS icons references (Chapter 1, section 1.4 (Resource Protection) and 1.4.1 (RDM) (DWAF 1999b; 2002b; Roux *et al.* 1999; SoR report 2001, Roux, pers.comm.).

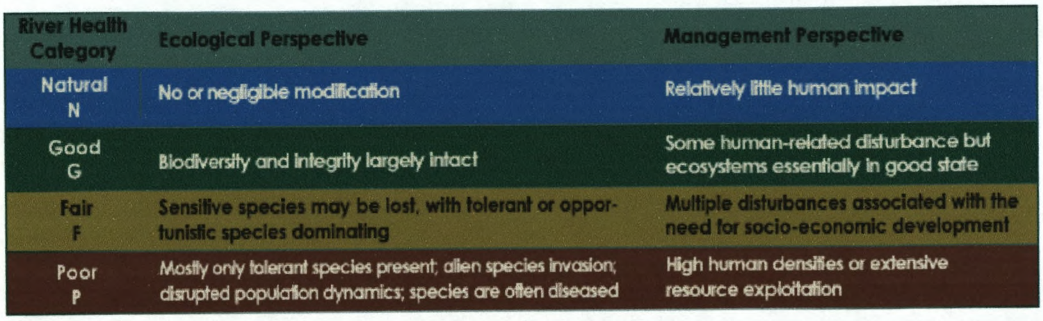
The **present health** of a river is a measure of the present ecological state of the river during the time of the survey and is presented in terms of the river health categories given below.

The **desired health (Dh:)** of a river is an indication of the envisioned future ecological state of the river and is based on ecological considerations, the need for sustainable development and management actions.

The availability of quantitative information on the reference and current biological integrity of a river system will influence the setting of realistic and ecologically sound resource management goals. Desired Health is an indication of the management goals and no indicator group should deteriorate from its current integrity category given the social, economic and biophysical importance of the river (Roux *et al.* 1999).

Currently, in the absence of a Classification Systems as defined in the NWA, 1998 (Act 36 of 1998), water resources are classed according to their ecological state. For rivers, much of this is based in the River Health Categories.

Water Quality icon in Figure 6.1 is the indication of the suitability of water quality for aquatic ecosystems based on South African Water Quality Guidelines for Aquatic Ecosystems (DWAF 1996b). SASS icon (Figure 6.1) is the indication of the ecological health of the river system using macroinvertebrates as a tool, based on their availability in the river system (Chutter 1994; Roux *et al.* 1999; Dickens and Graham 2002). River Health Categories have been colour coded according to different levels of water resource classification (DWAF 2002b). Matching the colour of the icons with the River Health Categories indicates the present health state together with the desired health state of the river unit.



River Health Category	Ecological Perspective	Management Perspective
Natural N	No or negligible modification	Relatively little human impact
Good G	Biodiversity and integrity largely intact	Some human-related disturbance but ecosystems essentially in good state
Fair F	Sensitive species may be lost, with tolerant or opportunistic species dominating	Multiple disturbances associated with the need for socio-economic development
Poor P	Mostly only tolerant species present; alien species invasion; disrupted population dynamics; species are often diseased	High human densities or extensive resource exploitation

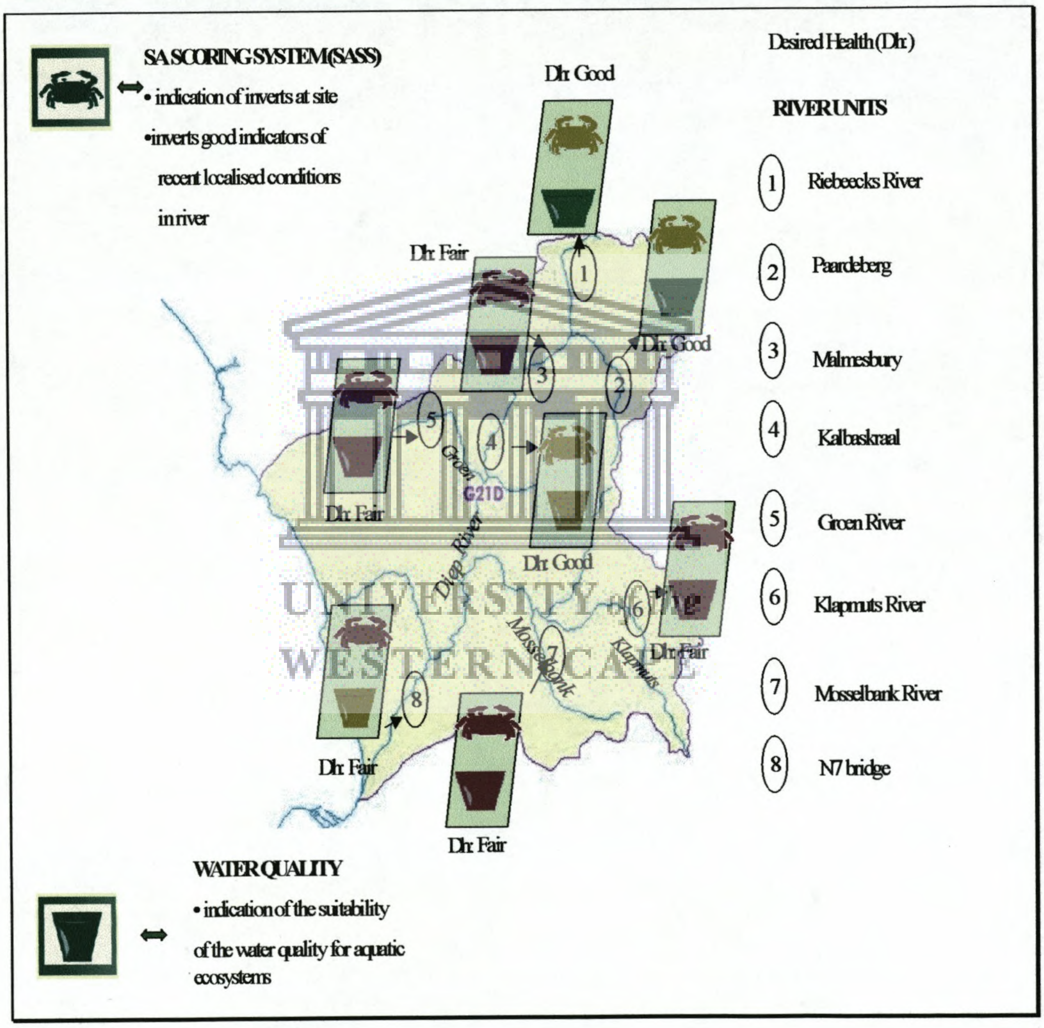


Figure 6.1 Summary map of SASS and water quality icons of the Diep River System biomonitoring sites. G21D is a quaternary catchment at the point.

6.2 Water Quantity (Flow) Reserve

Desktop Flow Reserve (Table 1.1; DWAF 1999c) in Diep River system was determined (Table 6.1) by running the Hydrology Model for Present Ecological Status (PES) using DWAF data. The results of the Model are Flow Ecological Category, Total Instream Flow Requirements (IFR), Lowflow and Highflow maintenance requirements on each unit. The IFR, Lowflow and Highflow maintenance are presented as Mean Annual Runoff (MAR) percentage and monthly distributions in Mill. m^3. per million (MCM a^{-1}).

Table 6.1 Summary table of Desktop Flow Reserve and SASS and Water Quality icons's Present and Desired states. Monthly Distributions in MCM a^{-1} (Mill. m^3. per million)

River Units	Present state	Desired State (Dh:)	Ecological Category	Total IFR	Maintenance Lowflow
1 Riebeeks	Fair	Good	Good (B/C)	1.983 (25.6% MAR)	1.074 (13.9%MAR)
2 Paardeberg	Fair	Good	Good (C)	1.494 (20.5% MAR)	0.725 (9.96%MAR)
3 Malmesbury	Poor	Fair	Fair (D)	2.027 (13.4% MAR)	0.680 (4.48%MAR)
4 Kalbaskraal	Fair	Good	Good (C)	3.577 (19.7% MAR)	1.562 (8.60%MAR)
5 Groen	Poor	Fair	Fair (D)	0.664 (13.5% MAR)	0.232 4.71% MAR)
6 Klapmuts	Poor	Fair	Fair (D)	0.778 (13.42%MAR)	0.266 (4.58%MAR)
7 Mosselbank	Poor	Fair	Fair (D)	4.084 (13.4% MAR)	1.394 (4.58%MAR)
8 N7 bridge	Poor	Fair	Fair (D)	1.115 (12.9% MAR)	0.321 (3.71%MAR)

Table 6.1 continued

River Units	Maintenance Lowflow	Drought Lowflow	Maintenance Highflow
1 Riebeeks	1.074 (13.9%MAR)	0.302 (3.91% MAR)	0.909 (11.7% MAR)
2 Paardeberg	0.725 (9.96%MAR)	0.285 (3.91% MAR)	0.768 (10.5% MAR)
3 Malmesbury	0.680 (4.48%MAR)	0.593 (3.91% MAR)	1.348 (8.88% MAR)
4 Kalbaskraal	1.562 (8.60%MAR)	0.529 (2.91% MAR)	2.015 (11.1% MAR)
5 Groen	0.232 4.71% MAR)	0.208 (4.22% MAR)	0.432 (8.78% MAR)
6 Klapmuts	0.266 (4.58%MAR)	0.233 (4.03 % MAR)	0.512 (8.84 % MAR)
7 Mosselbank	1.394 (4.58%MAR)	1.226 (4.03%MAR)	2.690 (8.84%MAR)
8 N7 bridge	0.321 (3.71%MAR)	0.268 (3.10% MAR)	0.795 (9.19% MAR)

6.3 Resource Quality Objectives (RQOs)

Water Quality Guidelines: Aquatic Ecosystems (DWAF 1996b) were used when setting RQOs for each river unit of the Diep River system. The default benchmark category boundaries used are Natural, Good, Fair and Poor, which are physiological boundaries that should remain unchanged. The benchmark category boundaries used for Diep River units are according to their monthly desired health categories for aquatic systems (Table 6.2-6.9). Other requirements of RQOs like irrigation, livestock watering and recreation, which are the main water uses in the Diep River Catchment, were assessed referring to specific Water Quality Guidelines for each water uses (DWAF 1996a). The Ecological specifications are made at low confidence assessment because the Reserve is Desktop which is done within 2 days with limited amount of information (DWAF 1999c).

Preliminary IFR Results indicated monthly distribution of flow in % MAR at each River Unit (Figure 6.2 – 6.9). Total Natural flow, Baseflow, Mean Flow

Requirements MFRLow and MFRhigh, Difference MFR curves are indicated in each unit.

6.3.1 Environmental Water Quantity (Flow) and Quality Requirements

Table 6.2 River Unit 1: Riebeeks River

Month	Flow (l/s)	DO (mg/l) Good	NO_3-N + NH_3-N (mg/l) Good	PO_4^+ (mg/l) Good	pH Natural	Temp (°C)
October	76	> 6mg/l @ 25°C	0.251-1.0	0.0051-0.025	6.5-8.0	<17
November	47	> 6mg/l @ 25°C	0.251-1.0	0.0051-0.025	6.5-8.0	<20
December	21	> 6mg/l @ 25°C	0.251-1.0	0.0051-0.025	6.5-8.0	<22
January	7	> 6mg/l @ 25°C	0.251-1.0	0.0051-0.025	6.5-8.0	<26
February	4	> 6mg/l @ 25°C	0.251-1.0	0.0051-0.025	6.5-8.0	<24
March	3	> 6mg/l @ 25°C	0.251-1.0	0.0051-0.025	6.5-8.0	<22
April	6	> 6mg/l @ 25°C	0.251-1.0	0.0051-0.025	6.5-8.0	<20
May	53	> 6mg/l @ 25°C	0.251-1.0	0.0051-0.025	6.5-8.0	<17
June	122	> 6mg/l @ 25°C	0.251-1.0	0.0051-0.025	6.5-8.0	<14
July	98	> 6mg/l @ 25°C	0.251-1.0	0.0051-0.025	6.5-8.0	<12
August	210	> 6mg/l @ 25°C	0.251-1.0	0.0051-0.025	6.5-8.0	<13
September	103	> 6mg/l @ 25°C	0.251-1.0	0.0051-0.025	6.5-8.0	<16

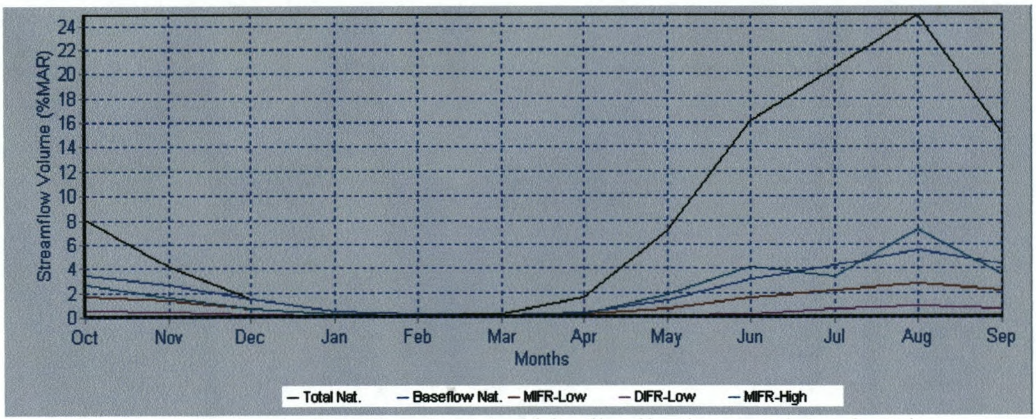


Figure 6.2 Preliminary IFR Results-Monthly distribution at Riebeeks River.

Table 6.3 River Unit 2: Diep at Paardeberg

Month	Flow (l/s)	DO (mg/l) Good	NO_3N + NH_3N (mg/l) Good	PO_4^+ (mg/l) Fair	pH Natural	Temp (°C)
October	56	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<17
November	33	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<20
December	15	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<22.25
January	5	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<26
February	3	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<24
March	2	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<22
April	4	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<20
May	42	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<17
June	96	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<14
July	72	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<12
August	164	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<13
September	75	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<16

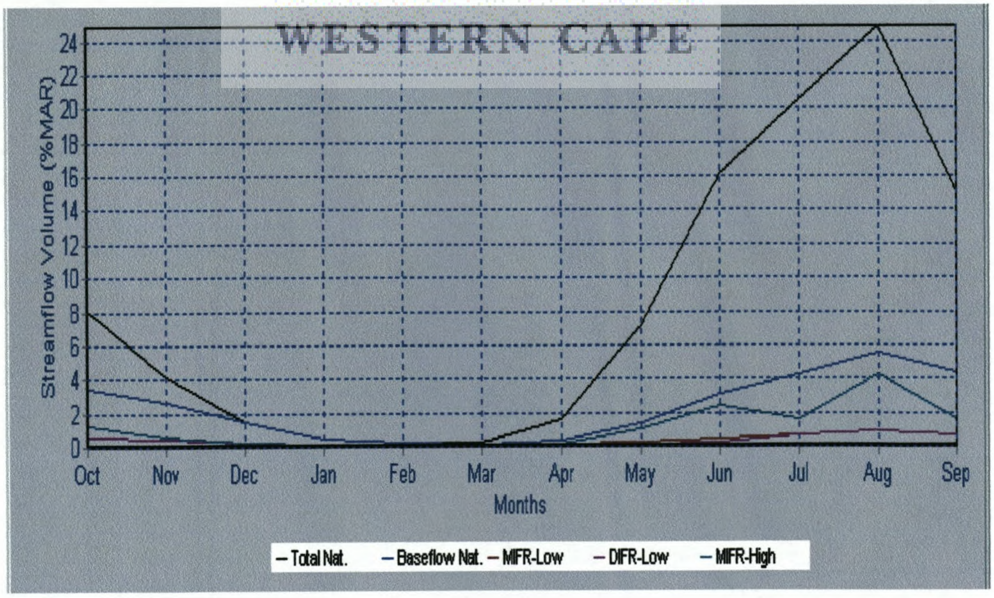


Figure 6.3 Preliminary IFR Results-Monthly distribution at Paardeberg.

Table 6.4 River Unit 3: Diep at Malmesbury

Month	Flow (l/s)	DO (mg/l) **Good**	NO_3-N + NH_3-N (mg/l) **Natural**	PO_4^+ (mg/l) Good	pH **Natural**	Temp (°C)
October	70	> 6mg/l @ 25°C	<=0.25	0.0051-0.025	6.5-8.0	<17
November	37	> 6mg/l @ 25°C	<=0.25	0.0051-0.025	6.5-8.0	<20
December	14	> 6mg/l @ 25°C	<=0.25	0.0051-0.025	6.5-8.0	<22.25
January	5	> 6mg/l @ 25°C	<=0.25	0.0051-0.025	6.5-8.0	<26
February	3	> 6mg/l @ 25°C	<=0.25	0.0051-0.025	6.5-8.0	<24
March	2	> 6mg/l @ 25°C	<=0.25	0.0051-0.025	6.5-8.0	<22
April	4	> 6mg/l @ 25°C	<=0.25	0.0051-0.025	6.5-8.0	<20
May	62	> 6mg/l @ 25°C	<=0.25	0.0051-0.025	6.5-8.0	<17
June	142	> 6mg/l @ 25°C	<=0.25	0.0051-0.025	6.5-8.0	<14
July	92	> 6mg/l @ 25°C	<=0.25	0.0051-0.025	6.5-8.0	<12
August	243	> 6mg/l @ 25°C	<=0.25	0.0051-0.025	6.5-8.0	<13
September	96	> 6mg/l @ 25°C	<=0.25	0.0051-0.025	6.5-8.0	<16

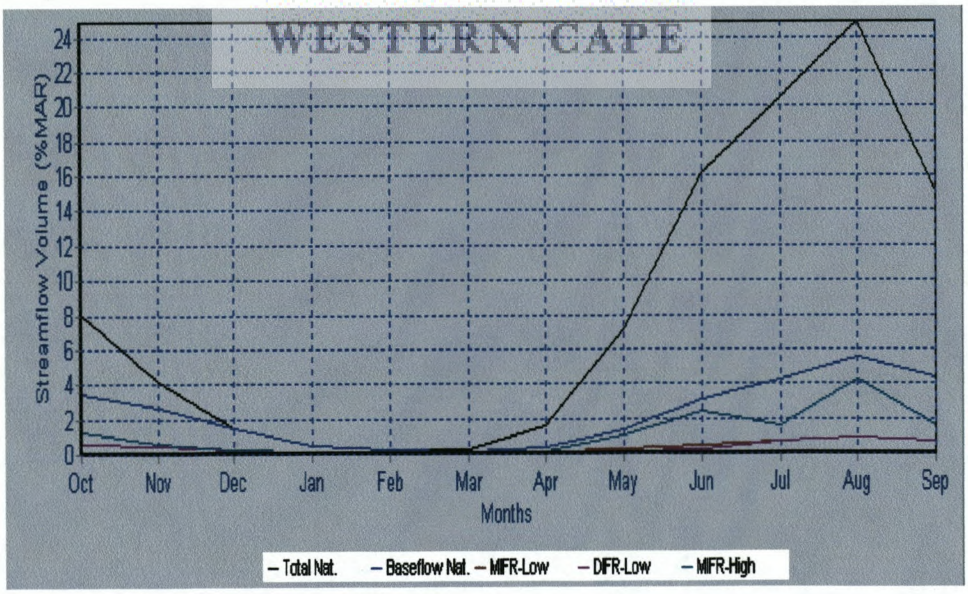


Figure 6.4 Preliminary IFR Results-Monthly distribution at Malmesbury Town.

Table 6.5 River Unit 4: Diep at Kalbaskraal

Month	Flow (l/s)	DO (mg/l) Good	NO_3N + NH_3N (mg/l) Good	PO_4^+ (mg/l) Fair	pH Natural	Temp (°C)
October	141	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<17
November	81	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<20
December	33	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<22.25
January	8	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<26
February	2	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<24
March	1	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<22
April	6	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<20
May	99	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<17
June	236	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<14
July	169	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<12
August	395	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<13
September	179	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<16

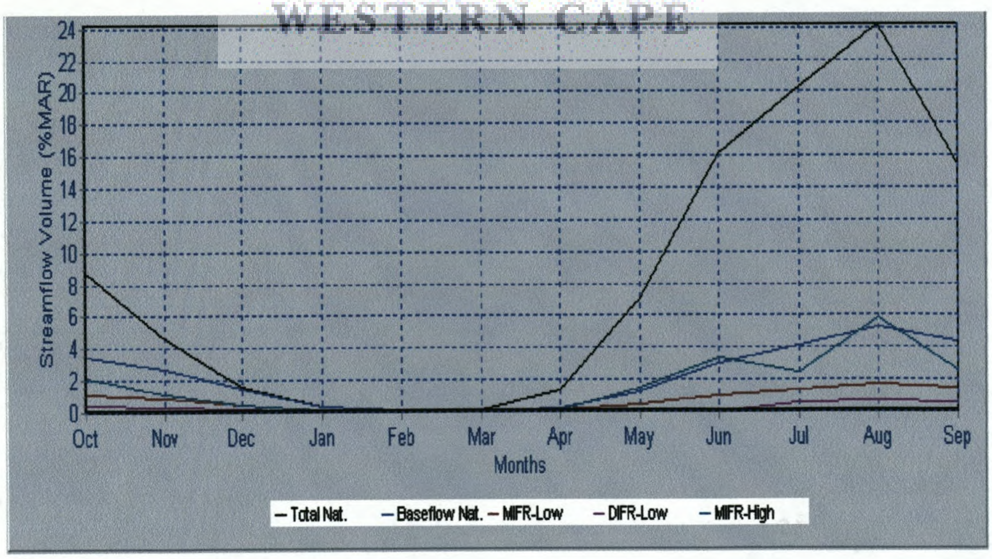


Figure 6.5 Preliminary IFR Results-Monthly distribution at Kalbaskraal.

Table 6.6 River Unit 5: Groen River

Month	Flow (l/s)	DO (mg/l) Good	NO_3-N + NH_3-N (mg/l) Fair	PO_4^+ (mg/l) Fair	pH Natural	Temp (°C)
October	26	> 6mg/l @ 25°C	1.01-4.0	0.0251-0.125	6.5-8.0	<17
November	14	> 6mg/l @ 25°C	1.01-4.0	0.0251-0.125	6.5-8.0	<20
December	5	> 6mg/l @ 25°C	1.01-4.0	0.0251-0.125	6.5-8.0	<22.25
January	2	> 6mg/l @ 25°C	1.01-4.0	0.0251-0.125	6.5-8.0	<26
February	1	> 6mg/l @ 25°C	1.01-4.0	0.0251-0.125	6.5-8.0	<24
March	1	> 6mg/l @ 25°C	1.01-4.0	0.0251-0.125	6.5-8.0	<22
April	1	> 6mg/l @ 25°C	1.01-4.0	0.0251-0.125	6.5-8.0	<20
May	19	> 6mg/l @ 25°C	1.01-4.0	0.0251-0.125	6.5-8.0	<17
June	46	> 6mg/l @ 25°C	1.01-4.0	0.0251-0.125	6.5-8.0	<14
July	30	> 6mg/l @ 25°C	1.01-4.0	0.0251-0.125	6.5-8.0	<12
August	75	> 6mg/l @ 25°C	1.01-4.0	0.0251-0.125	6.5-8.0	<13
September	31	> 6mg/l @ 25°C	1.01-4.0	0.0251-0.125	6.5-8.0	<16

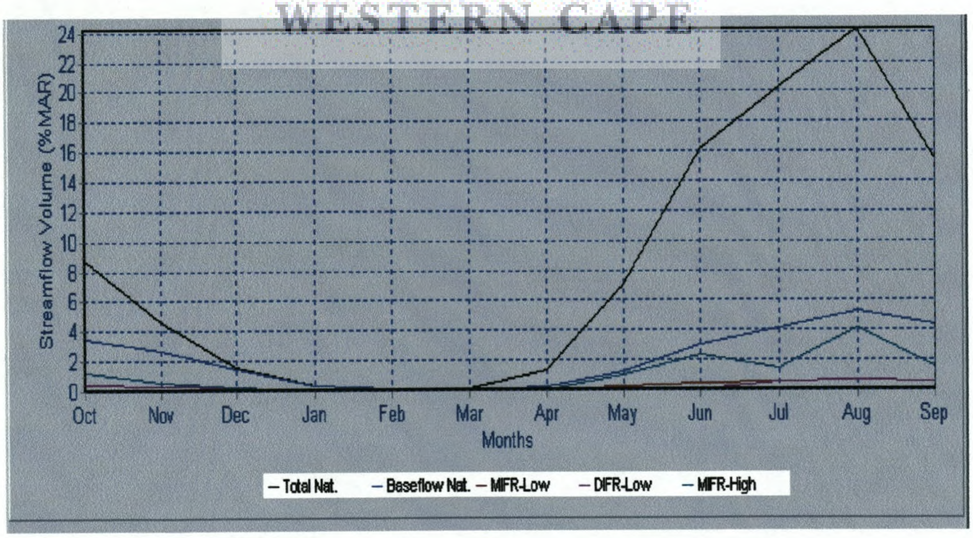


Figure 6.6 Preliminary IFR Results-Monthly distribution at Groen River.

Table 6.7 River Unit 6: Klapmuts River at Mikpunt

Month	Flow (l/s)	DO (mg/l) Good	NO_3-N + NH_3-N (mg/l) Good	PO_4^+ (mg/l) Fair	pH Natural	Temp (°C)
October	26	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<17
November	14	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<20
December	5	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<22.25
January	2	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<26
February	1	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<24
March	1	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<22
April	2	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<20
May	23	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<17
June	52	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<14
July	35	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<12
August	96	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<13
September	37	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<16

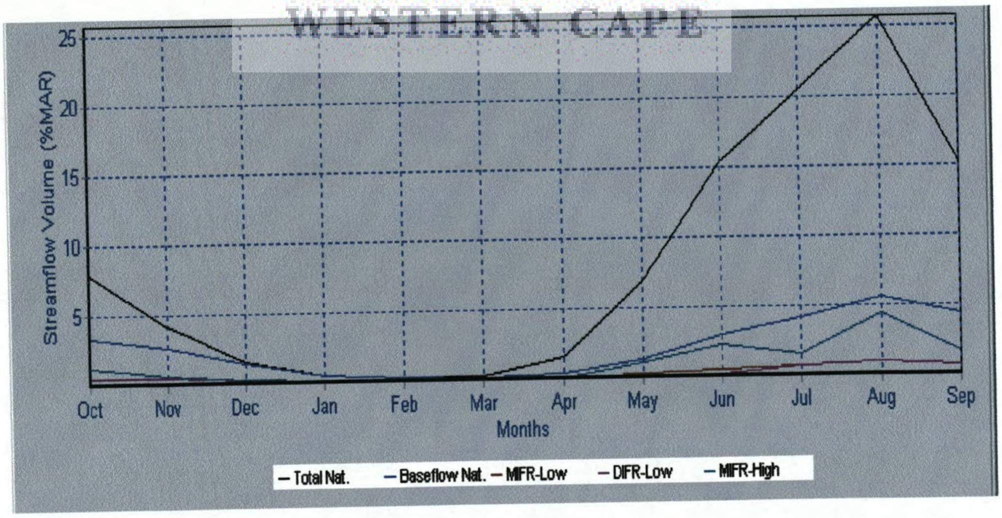


Figure 6.7 Preliminary IFR Results-Monthly distribution at Klapmuts River.

Table 6.8 River Unit 7: Mosselbank at Goedontmoeting

Month	Flow (l/s)	DO (mg/l) Good	NO_3N + NH_3N (mg/l) Good	PO_4^+ (mg/l) Fair	pH Natural	Temp (°C)
October	166	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<17
November	87	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<20
December	34	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<22.25
January	12	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<26
February	7	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<24
March	5	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<22
April	10	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<20
May	141	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<17
June	323	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<14
July	220	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<12
August	598	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<13
September	232	> 6mg/l @ 25°C	0.251-1.0	0.0251-0.125	6.5-8.0	<16

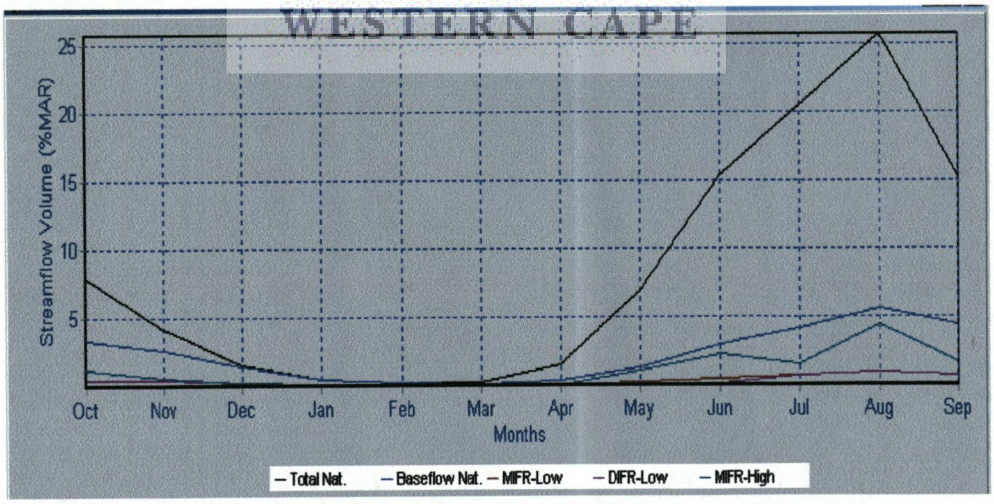


Figure 6.8 Preliminary IFR Results-Monthly distribution at Mosselbank River.

Table 6.9 River Unit 8: Diep at N7 bridge

Month	Flow (l/s)	DO (mg/l) Good	NO_3-N + NH_3-N (mg/l) Natural	PO_4^+ (mg/l) Fair	pH Natural	Temp (°C)
October	398	> 6mg/l @ 25°C	<=0.25	0.0251-0.125	6.5-8.0	<17
November	197	> 6mg/l @ 25°C	<=0.25	0.0251-0.125	6.5-8.0	<20
December	67	> 6mg/l @ 25°C	<=0.25	0.0251-0.125	6.5-8.0	<22.25
January	19	> 6mg/l @ 25°C	<=0.25	0.0251-0.125	6.5-8.0	<26
February	7	> 6mg/l @ 25°C	<=0.25	0.0251-0.125	6.5-8.0	<24
March	4	> 6mg/l @ 25°C	<=0.25	0.0251-0.125	6.5-8.0	<22
April	14	> 6mg/l @ 25°C	<=0.25	0.0251-0.125	6.5-8.0	<20
May	331	> 6mg/l @ 25°C	<=0.25	0.0251-0.125	6.5-8.0	<17
June	781	> 6mg/l @ 25°C	<=0.25	0.0251-0.125	6.5-8.0	<14
July	496	> 6mg/l @ 25°C	<=0.25	0.0251-0.125	6.5-8.0	<12
August	1377	> 6mg/l @ 25°C	<=0.25	0.0251-0.125	6.5-8.0	<13
September	524	> 6mg/l @ 25°C	<=0.25	0.0251-0.125	6.5-8.0	<16

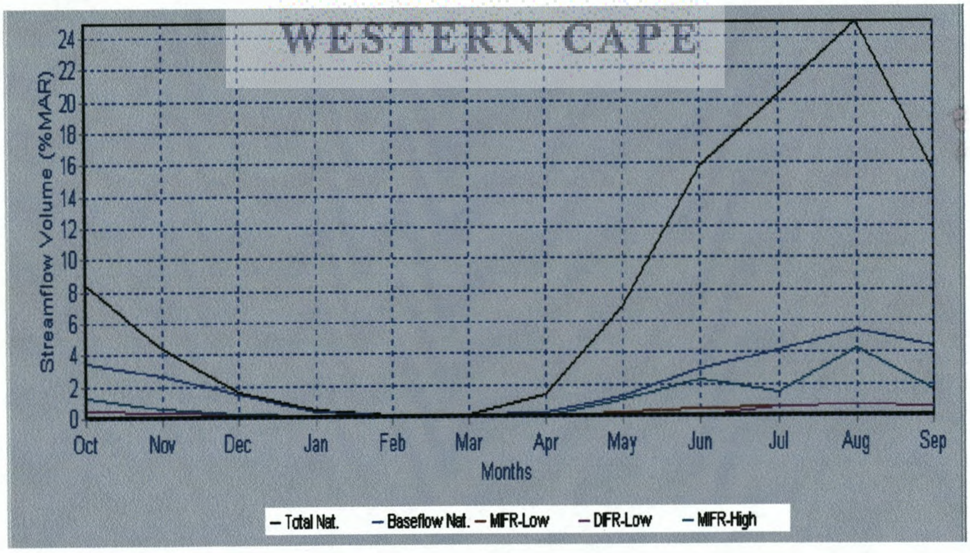


Figure 6.9 Preliminary IFR Results-Monthly distribution at N7 Bridge.

The default benchmark category boundaries for Dissolved Oxygen (DO) used is Good – 6mg/l @ 25°C which is a physiological boundary that should remain unchanged (Table 6.2-6.9). The Ecological specifications are made at low confidence assessment.

The Ecological specification of Natural (6.5-8.0) default benchmark category boundaries for pH is used because the available data fall within the "Natural" boundary values (Table 6.2-6.9). The median pH values for Diep River system ranges between 7.2-8.1 with 7.9 in site R10 (Reference site).

The WQG:AE (DWAF 1996a) suggested a target water temperature range of 2°C or 10% deviation from natural (Table 6.2-6.9). Ecological specifications use for temperature is Upper Natural boundary for each calendar month as a benchmark.

Nitrates (NO_3.N) and Ammonia (NH_3.N) default benchmark category ranges from *Natural* to *Poor*. Diep River in Malmesbury Town (D09) and at N7 bridge (D03) falls within *Natural* benchmark category for NO_3.N and remain unchanged for the ecological sensitivity or importance of the river (Table 6.4; 6.9). Riebeeks River (R10) and Diep River at Paardeberg (D11) fall within *Good* benchmark category and the management categories remain unchanged taking in consideration the reference conditions of the river system (Table 6.2; 6.3, 6.5; 6.7; 6.8). Mosselbank River at Goedontmoeting (M12) and Klapmuts River at Mikpunt (K14) falls within *Fair* benchmark category and was improved to *Good* Management categories (Table 6.6). Groen River falls within *Poor* benchmark category and is managed for *Fair* category (Table 6.6). Both Fair and Poor categories were raised a level for sustainable level of use and maintenance in relation to the land-use activities upstream of the river system.

The default benchmark category boundaries for median phosphate (PO_4^+) concentrations used are *Good* and *Fair*. *Good* category benchmark range of 0.0051-0.025 mg/l is used as a Management category for sites in Riebeeks River

(R10) and Diep River in Malmesbury Town (D09) which are in *Fair* Ecological category (Table 6.2; 6.4). The rest of the sites in each Management units are in *Poor* Ecological category and need to be improved and managed for *Fair* category benchmark range of 0.0251-0.125 mg/l for sustainable level of use and consideration of ecological importance and reference conditions (Table 6.3; 6.5; 6.6; 6.7; 6.8; 6.9). The assessment was done for a medium to high confidence determination.

6.3.2 Other User Requirements

For water quality purposes, the major users of the system are irrigators of vineyards and pastures for grazing, recreation (fishing) as well as livestock watering. Domestic use of surface water only occurs in the upper catchment and not in the Diep River itself.

Additional water quality objectives to the environment water quality requirements are:

1. Electrical Conductivity (EC) for irrigation of vineyards and pastures for grazing, for example, in River Units 1, 2 and 3
2. Faecal coliforms and or *Eschericia coli* (*E. coli*) for livestock watering in units 1 to 8
3. Faecal coliforms and or *Eschericia coli* (*E. coli*) for contact and non-contact recreational purposes in units 1 to 8.

Water quality requirements for irrigation are salts (EC/TDS). Grapes are moderately sensitive than wheat (fodder) which is mostly moderately tolerant. Grapes are used to set water quality requirements for irrigation in Diep River system, which are EC (40-90 mS/m), Boron (0.5-1.0 mg/l), Chloride (less or equal to 175 mg/l), and Sodium adsorption ratio (less or equal to 2 mmol/l) (DWAF 1996a).

The target water quality requirements for the key water quality constituents for livestock watering are EC/TDS (in mg/l) which are chlorides (0-1500 for non-ruminants and 0-3000 for ruminants), Nitrate (0-100 for non-ruminants and 0-200 for ruminants), Sodium (0-2000), and faecal coliforms (0-1000 counts/100ml) (DWAF 1996c).

The water quality requirements for recreation in freshwater are given for most sensitive users, for example swimming. The constituent is faecal coliforms (in counts/100ml) with a target range of 0-130, slight risk/acceptance range of 130-600, moderate risk range of 600-2000, and increasing risk/severe of more than 2000 (DWAF 1996d).

6.3.3 Biological indicator of water quality

The Reserve procedure relies on ASPT, as it is the least variable of the scores (Dallas 2000; Dickens and Graham 2002). ASPT provides the most reliable measure of a Natural category whereas the other two scores can be used to aid interpretation.

The SASS Score provides a good indicator of the diversity of habitat availability in the river at a site (Dickens and Graham 2002).

SASS Score and ASPT in sites D08, D07, D03, D02, M19, M18, M16, M13A, M12 and Groen are in *Poor* category, and must remain above 50 and 5 respectively at all times to ensure that the river is managed at an acceptable level of at least *Fair* management category. Sites R10, D11, D09, D06, D05, D04, K15, K14, Phil and Trib 17 are in *Fair* category and must be managed or maintained to remain in *Good* management category by maintaining SASS Score and ASPT of above 80 and 6 respectively. The Ecological specifications are made at medium confidence assessment (Table 6.1).

6.3.4 Habitat

Based on the requirements of the NWA, I would recommend 1:100 year floodline to be maintained between the river system and any land-use activities in order to prevent overflow and/or spillage of contaminants into the river system; and to protect the riparian vegetation from damage. Any land-use that takes place below the 1:100 year floodline must apply for a licence to DWAF and must be such that it will not cause contamination of the river system by complying with the specified conditions on the issued licence.

To provide habitat for the macroinvertebrates, sections of the river reaches should be maintained as shallow runs with vegetated banks. A diversity of habitat should be maintained to provide for a diversity of macroinvertebrates.

6.3.5 Monitoring Requirements

Monitoring requirements for the Diep River system chemical determinants would be to stick to the DWAF monitoring routine of monitoring each site once every after six weeks and update the data as soon as possible and let it be available for all water users.

Biomonitoring requirements for the Diep River system using SASS would be monitoring each site four times per year, that is once each and every season in order to determine the trend in ecological changes as well as seasonal changes trend.

CHAPTER 7: SUMMARY AND RECOMMENDATIONS

7.1 Summary

7.1.1 Water Chemistry

High turbidity is one of the negative factors affecting water quality in the lower Diep River System. The presents of reed-invaded banks and beds along Diep River system, thus in Malmesbury town, N7 bridge, and Goedeontmoeting is an evidence of a poor water quality.

The overall concentration of the nutrients in the Diep River Catchment proved to be high and did not comply with the Water Quality guidelines, though pH values did comply with the General Limits. The Chemical Trend in the Diep River Catchment is influenced by the human impacts along the catchment. The Chemical Trend in the Sabie River indicated the lower zone of the river (mostly sand and mud) mostly having low DO, high loads of nutrients and minerals (Zokufa *et al.* 2001). Dominant invertebrates in these river zones are collectors (Dallas and Day 1993; Allanson 1995). High concentrations of ammonia, phosphorus, nitrates, COD and SS indicated the impact of the land-use activities like WWTW, runoff from urban areas and agricultural activities (stock farming, fertilizers, insecticides) and quarries and are usually high during first flush or peak flow. The impact of WWTW is supported by Day (1998) by indicating that below Malmesbury WWTW, water quality remained low and that some improvement with distance downstream of Malmesbury was observed. The River Health Category of water quality in the Diep River system indicates a good health category in Riebeecks tributary and upstream sites of the Diep River, above Malmesbury, which indicates minimum human disturbances. River Health Categories immediately below Malmesbury and downstream of the Mosselbank river were poor as an indication of high human impacts on water quality. Water quality recovery to fair category, indicating multiple human impacts, was reflected in Kalbaskraal down to Abbotsdale and at the N7 bridge.

7.1.2 Major impacts in the Diep River Catchment

- High level of water abstraction (surface and groundwater resources).
- Effluent disposal from industries, wineries, abattoirs and WWTWs
- Solid waste dumping (Waste disposal sites and illegal dumping within 1:100 year floodline)
- Stormwater runoff from urban areas, quarries, crop and stock farming.
- Overgrazing and tramping of the animals on the riparian zone

7.2 Recommendations

7.2.1 Management Actions in the Diep River Catchment

South African Scoring System (SASS) ideally should only be used in perennial systems, however, in a river such as the Diep, it should be perennial (under natural conditions) but due to excess abstraction it no longer flows all year. In terms of the allocation of water for the ecological part of the "Reserve", the recommendation would be to ensure that water (according to the identified Environmental water requirement) is released from dams to allow for ecological functioning. The increasing number of water storage dams in the Diep River Catchment should be minimized or avoided. This study showed that very low flow as well as an extended low flow period occurred due to water abstraction. This in turn reduced invertebrate diversity and the ability of the system to assimilate water quality impacts.

Land-use practices (e.g. cultivation and stock farming) need to be improved to reduce sedimentation and water quality problems. Any land-use practices within 1:100 year floodline must not be approved at all (DWAF 2004).

A riparian zone along the river banks should be maintained in order to improve the protection of the indigenous plants.

Pollution is a problem, and monitoring of effluent needs to take place so that problematic effluent can be improved.

Monitoring and management of stormwater runoff from urban and agricultural areas should be improved. Stormwater channels in industries must be separated from the effluent systems. The use of environmentally friendly insecticides and fertilizers must be encouraged and well practiced.

Monitoring requirements for the assessment of the Diep River system RQOs set recommended would be SASS sampling for four times per year each season and chemical sampling at least once every six weeks.

7.2.2 Recommendations for future studies

Reference condition (SASS Scores and a list of expected taxa) need to be developed based on foothill-gravel-bed and lowland rivers where SIC/SOOC is absent or limited in order to get a clear idea of the situation in the Diep River system relative to other Western Cape Lowland Rivers.

CONCLUSIONS

Major land-use impacts highlighted in the Diep River Catchment are water abstraction, effluent disposal and dumping of waste. These impacts had altered the ecological integrity of the river system. Land use practices such as wineries, crop farming, stock farming, abattoirs, quarries, waste sites and wastewater treatment works are believed to have resulted in a significant deterioration in the ecological state of the Diep River Catchment.

There is extensive groundwater abstraction in the Diep River Catchment for domestic purposes; for example, Riverlands and Chatsworth are supplied from groundwater. More than 70% of the farms in this catchment have one or more boreholes for domestic and agricultural purposes. Currently there are a lot of applications in DWAF for authorization of subdivisions, rezoning, consent use, and licenses in the catchment, and the activities mostly applied for are wineries and abattoirs, which need water for processing and washing. All the subdivided portions may each need to sink a borehole or build a dam for water supply. There is currently a concern about ground water exploitation in Diep River Catchment and DWAF would like to see the "Reserve" done in order to determine whether more water can be abstracted from the river system and the groundwater resources in the catchment.

The Diep River is not operated specifically to manage for any user water quantity requirements (for example, there are no releases made into the system for irrigation purposes). Therefore the flow objectives for the system will be those required for the Ecological Reserve.

The South African Scoring System has proved to be a useful tool for the assessment of water quality impairment, and ecological integrity or the health of riverine ecosystems. SASS appears to be effective in assessing site differences in terms of different land-use activities within a catchment impacting on water quality. SASS enables the identification of places where there is biological evidence of water quality deterioration, and therefore proved to be useful in water quality monitoring and guiding water quality managers.

Generally, in southwestern Cape Rivers, the severely impacted sites had low SASS Scores and ASPT, while unimpacted sites had a high SASS Score and ASPT (Dallas 1997b). In the Diep River system, both SASS Scores, number of taxa and ASPT demonstrated differences as a result of water quality between sites; for example, the trend indicated in Figure 4.1 to 4.6, especially a decrease in scores downstream Malmesbury and Kraaifontein WWTW. Upstream sites in the Diep River system indicated some deterioration in water quality, which is an ecological category D (*fair*). The impacted sites immediately downstream of the source of impacts indicated major deterioration in water quality and an ecological category E/F (*poor*). In terms of management perspectives, *Fair* category needs to be managed for desired health: *Good*, and *Poor* category for desired health: *Fair*.

The major part of the Diep River system is mostly lowlands and floodplains, which are wide mature zones of the other river systems, with low flow rates. In the floodplains sedimentation increases, the river bottom becomes muddy, and dissolved oxygen levels depleted because the impact of effluent discharges become obvious and severe.

The Diep River system assessments indicated that during the sampling period, the biological integrity of the aquatic system was low and impacted by poor water quality from wineries, industries and WWTWs, over-abstraction and runoff from stock farming, crop farming, vineyards, solid waste sites and dumping, and quarries. Over-abstraction of water in the system renders the system non-perennial and unhealthy for the ecological integrity and could not meet the requirements for the "Ecological Reserve".

REFERENCES

AGNEW, C. and ANDERSON, E. 1992. Water Resources in the Arid Realm. Routledge. London.

ALLANSON, B.R. 1995. An introduction to the Management of Inland Water Ecosystems in South Africa.Water Research Commission Report TT 72/95.

BLACK, W.B. and MUNN, M.D. 2003. Using macroinvertebrates to identify biota-land cover optima and multiple scales in the Pacific Northwest, USA. *Journal of the North American Benthological Society*. 23(2): 340-362.

BROWN, C.A., EEKHOUT, S. and KING, J.M. 1996. National Biomonitoring Programme for Riverine Ecosystem: Proceedings of Spatial Framework Workshop. NBP Report series No. 2, Institute for Water Quality Studies, Department of Water Affairs and Forestry, Pretoria.

CAMARGO, J.A., ALONSO, A. and DE LA PUENTE, M. 2004. Multimetric Assessment of Nutrient Enrichment in Impounded Rivers Base Benthic Macroinvertebrates. *Environmental Monitoring and Assessment*. 96(1-3): 233-249.

CAPE METROPOLITAN COUNCIL, 1998. Kuils River Catchment Forum: Annual Report 1998.

CAPE METROPOLITAN COUNCIL, 2001. Backyard to Bay: Steps you can take to improve the health of rivers and their catchments. Cape Town.

CHUTTER, F.M. 1995. The role of aquatic organisms in the management of river basins for sustainable utilization. *Water Science and Technology* 32(5-6): 283-291.

CHUTTER, F.M. 1998. Research on the Rapid Biological Assessment of Water Quality Impacts in Streams and Rivers. Water Research Commission Report No. 422/1/98.

CLARKE, K.R. and WARWICK, R.M. 1994. Change in marine communities: An approach to Statistical Analysis and Interpretation. Plymouth Marine Laboratory. UK

COLLINSON, N.H., BIGGS, J., CORFIELD, A., HODSON, M.J., WALKER, D., WHITFIELD, M. and WILLIAMS, P.J. 1995. Temporary and permanent ponds: An assessment of the effects of drying out on the conservation value of aquatic macroinvertebrate communities. *Biological Conservation.*74: 125-133.

CSIR, 1999. Handboek of Groundwater Quality Protection for farmers, Water Research Commission Report TT116/00.

DALLAS, H.F. and DAY, J.A. 1993. The effect of Water Quality Variables on Riverine Ecosystems: A review. Freshwater Research Unit. University of Cape Town. Water Research Commission TT 61/93.

DALLAS, H.F., DAY, J.A. and REYNOLDS, E.G. 1994. The effects of Water Quality Variables on Riverine Biotas. Water Research Commission Report No. 351/1/94.

DALLAS, H.F. 1997a. An assessment of the current status of aquatic macroinvertebrate communities of the Diep River system, south-western Cape, using SASS4. Institute of Water Quality Studies, Department of Water Affairs and Forestry.

DALLAS, H.F. 1997b. A preliminary evaluation of aspects of SASS (South African Scoring System) for the rapid bioassessment of water quality in rivers, with particular reference to the incorporation of SASS in a National Biomonitoring Programme. *Sth. Afr. J. aquat. Sci.* 23 (1): 79-94.

DALLAS, H.F., DAY, J.A., MUSIBONO, D.E. and DAY, E.G. 1998. Water Quality for Aquatic Ecosystems: Tools for Evaluating Regional Guidelines. Water Research Commission Report No. 626/1/98.

DALLAS, H.F., JANSSENS, M.P. and DAY, J.A. 1999. An aquatic macroinvertebrate and chemical database for riverine ecosystems. *Water SA*.25(1): 1-8.

DALLAS, H.F. 2002. Spatial and temporal heterogeneity in lotic systems: Implications for defining reference conditions for macroinvertebrates. Water Research Commission Report No. KV 138/02.

DAY, E. 1998. An assessment of the current status of aquatic macroinvertebrate communities of the Diep River system, south-western Cape, using SASS4. University of Cape Town.South Africa.

DAVIES, B.R. and DAY, J.A. 1986. The biology and conservation of South Africa's vanishing waters. University of Cape Town Press. Cape Town. South Africa.

DAVIES, B. and DAY, J. 1998. Vanishing Waters. University of Cape Town Press. Cape Town. South Africa.

DEMING, H.G. 1975. Water: The fountain of opportunity. Oxford University Press. New York.

DEPARTMENT OF WATER AFFAIRS, 1986. Management of the Water Resources of the Republic of South Africa. Pretoria. South Africa.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY, 1990. Water for the Western Cape. Pretoria. South Africa.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY, 1996a. Agricultural Water Use: Irrigation. South African Water Quality Guidelines. Volume 4. Second Edition.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY, 1996b. Aquatic Ecosystems. South African Water Quality Guidelines. Volume 7: First Edition.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY, 1996c. Agricultural Use: Livestock Watering. South African Water Quality Guidelines. Volume 5. Second Edition.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY, 1996d. Recreational Use: South African Water Quality Guidelines. Volume 2. Second Edition.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY, 1997. White Paper on a National Water Policy for South Africa. Pretoria. South Africa.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY, 1998. Quality of Domestic Water Supplies. Volume 1: Assessment Guide. Water Research Commission Report No. TT 101/98.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY, 1999a. Government Gazette No. 20526. General Authorisations in terms of Section 39 of the National Water Act, 1998 (Act 36 of 1998).

DEPARTMENT OF WATER AFFAIRS AND FORESTRY, 1999b. Resource Directed Measures for Protection of Water Resources. Volume 2: Integrated Manual Version 1.0. Pretoria, South Africa.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY, 1999c. Resource Directed Measures for Protection of Water Resources. Volume 3: River Ecosystems Version 1.0. Pretoria, South Africa.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY, 2000a. Terms of Reference for the Determination of a Comprehensive Reserve for the Olifants/Doring Catchment. Pretoria, South Africa.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY, 2000b. Profile on water management in the Berg, Breede, Gouritz and Olifants/Doring Water Management Areas: The utilization and availability of water. Western Cape.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY, 2001. White Paper on Basic Household Sanitation. Pretoria. South Africa.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY, 2002a. Profile on water management in the Berg, Breede, Gouritz and Olifants/Doring Water Management Areas: The utilization and availability of water. Western Cape.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY, 2002b. National Water Resource Strategy. Proposed First Edition. Pretoria. South Africa.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY, 2004. General Authorisation in terms of section 39 of the National Water Act, 1998 (Act No. 36 of 1998).

DICKENS, C.W.S and GRAHAM, P.M. 2002. The South African Scoring System (SASS) Version 5 Rapid Bioassessment Method for Rivers. *Afr. J. Aqua. Sci.* 27(1): 1-10.

GERBER, A. and GABRIEL M.J.M. not dated (nd). Aquatic Invertebrates of South African Rivers. Illustrations. Institute of Water Quality Studies. Department of Water Affairs and Forestry.

GERBER, A. and GARRIEL, M.J.M. 2002a. Aquatic Invertebrates of South African Rivers. Illustrations. Institute of Water Quality Studies. Department of Water Affairs and Forestry.

GERBER A and GABRIEL MJM. 2002b. Aquatic Invertebrates of South African Rivers. Field Guide. Institute of Water Quality Studies. Department of Water Affairs and Forestry.

GRAY, L. 2004. Changes in Water Quality and macroinvertebrates communities resulting from urban stormwater flows in the Provo River, Utah, U.S.A. *Hydrobiologia*. 518(1-3): 33-46.

HAMMER, M.J. and MICKICHAN, K.A. 1981. Hydrology and quality of water resources. John Wiley and Sons.

HOSE,G., TURAK, E. and WADDELL, N. 2002. Reproducibility of Australian River Assessment System rapid bioassessments using macroinvertebrates. *Journal of the North American Benthological Society*. 23(1): 126-139.

HYNES, H.B.N. 1963. The biology of polluted rivers. Liverpool University Press. Liverpool.

INSTITUTE FOR WATER QUALITY STUDIES, 1999. Terms of reference: A situation assessment towards the development of a Water Resources Management Plan for the Diep River. Department of Water Affairs and Forestry. Pretoria. South Africa.

INSTITUTE FOR WATER QUALITY STUDIES, 2000. Diep River situation assessment. Draft 1. Pretoria, South Africa.

KEFFORD B.J., DALTON, A., PALMER, C.G. and NUGEGODA, D. 2004. The salinity tolerance of eggs and hatchlings of selected aquatic macroinvertebrates in south-east Australia and South Africa. *Hydrobiologia*. 517(1-3): 179-192.

KEMPER, N.P. 2000. Riparian Vegetation Index. Institute for Water Research, Environmental, Final Report.

KING, J.M. 1983. Abundance, biomass and diversity of benthic macroinvertebrates in a Western Cape River, South Africa. *Trans. Roy. Soc. S. Afr.* 45 (1): 11-29.

KING, J.M., DAY, J.A., HURLY, P.R., HENSHALL-HOWARD, M-P. and DAVIES, B.R. 1988. Macroinvertebrate Communities and Environment in a Southern African Mountain Stream. *Can. J. Fish. Aquat. Sci.* 45: 2168-2181

KLEYNHANS, C.J. and HILL, L. 1999. Preliminary ecoregion classification system for South Africa. Department of Water Affairs and Forestry. Pretoria

MADIKIZELA, B.R., DYE, A.H. and O'KEEFFE, J.H. 2001. Water quality and faunal studies in the Umzimvubu catchment, Eastern Cape, with particular emphasis on species as indicators of environmental change. Water Research Commission Report No. 716/1/01.

MALAN, H.L. and DAY, J.A. 2002. Linking discharge, water quality and biotic response in rivers: A literature review. Water Research Commission Report No. 956/2/02.

MATONICKIN, R., HABDIJA, I and PRIMC-HABDIJA, B. 2001. The effects of season and food availability on macroinvertebrate colonization in a woodland stream. *Arch. Hydrobiol.* 153(1):55-74.

MAYBURG, 2003. Diep River. Pretoria, South Africa.

McMILLAN, P.H., 1998. An Integrated Habitat Assessment System Version 2 for the Rapid Biological Assessment of Rivers and Streams, CSIR Research Report No. ENV-P-1 98132. Council for Scientific and Industrial Research, Pretoria.

MILLARD, N.A.H. and SCOTT, K.M.F, 1955. The ecology of South African estuaries. Part VI: Milnerton Estuary and the Diep River, Cape. *Transactions of the Royal Society of South Africa*. 34(2): 279-324

MUNN, M.D. and BRUSVEN, M.A. 1991. Benthic macroinvertebrate communities in nonregulated and regulated waters of the Clearwater River, Idaho, USA. *Regulated Rivers: Research and Management*. 6: 1-11.

MYBURG, W.J. 2000. River Ecosystems: Researchers assesses the riparian vegetation of the Olifants River. Water Research Commission, Report No. 663/1/99. *SA Waterbulletin*. 26(4):12-19.

MYBURGH, E. 2002. Factors that influence adult blackfly (Diptera: Simuliidae) survival along the lower Orange River, South African. Water Research Commission Report No. 1019/1/03.

NATIONAL WATER ACT, 1998 (Act 36 of 1998).

OCON, C.S and CAPITULO, A.R. 2004. Presence and abundance of Ephemeroptera and other sensitive macroinvertebrates in relation with habitat conditions in pampean stream, Buenos Aires, Argentina. *Archiv fur Hydrobiologie*. 159(4): 473-487.

PALMER, C.G., GOETSCH, P.A. and O'KEEFFE, J.H. 1996. Development of a Recirculating Artificial Stream System to investigate the use of macroinvertebrates as Water Quality Indicators. Water Research Commission Report No. 475/1/96.

PALMER, R.W. 1997. Changes in the abundance of invertebrates in the stones-in-current biotope in the middle Orange River over five years. Water Research Commission Report No KV130/00.

PALMER, C.G. 1999. Application of ecological research to the development of a new South African Water Law. *J.N. Am. Benthol. Soc.* 18(1): 132 – 142.

PEARCE, M.W and SCHUMANN, E.H. 2001. The impact of irrigation return flow on aspects of the water quality of the upper Gamtoos estuary, South Africa. *Water SA*. 27(3): 367-372.

PEETERS, E.T.H.M., GYLSTRA, R. and VOS, J.H. 2004. Benthic macroinvertebrate community structure in relation to food and environmental variables. *Hydrobiologia*. 519(1-3): 103-115.

POLLARD, S.R., WEEKS, D.C. and FOURIE, A. 1996. A pre-impoundment study of the Sabie-Sand River System, Mpumalanga with special reference to predicted impacts on the Kruger National Park: Effects of the 1992 drought on the fish and macroinvertebrate fauna. Volume two. Water Research Commission Report No 294/2/96.

REPUBLIC OF SOUTH AFRICA, 1997. Council for Geoscience. Pretoria

RIVER HEALTH PROGRAMME, 2003. State of Rivers Report: Diep, Hout Bay, Lourens and Palmiet River Systems. Department of Water Affairs and Forestry. Pretoria.

ROGERS, J.J.W. and FEISS, P.G. 1998. People and the earth: Basic issues in the sustainability of resources and environment. Cambridge University Press. United States of America.

ROUX, D.J., KLEYNHANS, C.J. and THIRION, C. 1999. Biological Monitoring and Assessment of Rivers as a basis for identification of rivers as a basis for identifying and prioritizing river management options. *Wat. Sci. Tech.* 39(10-11): 207-210.

ROWNTREE, K.M., WADESON, R.A and O'KEEFFE, J. 2000. The development of a geomorphological classification system for the Longitudinal zonation of South African rivers. *South African Geographical Journal* 82(5): 163-172

SCHERMAN, P.A., PALMER, C.G. and MULLER, W.J. 2003. Use of indigenous riverine invertebrates in applied toxicology and water resources-quality management. Water Research Commission Report No. 955/1/03.

SHIEH, S.-H., KONDRATIEFF, B.C., WARD, J.V. and RICE D.A. 1999. The relationship of macroinvertebrate assemblages to water chemistry in a polluted Colorado plains stream. *Arch. Hydrobiol.* 145(4): 405-432.

STATE OF RIVERS REPORT, 2001. Roux, D. Pers.comm.

STEPHENS, A. and BREDENKAMP, D.B. 2002. Institutional arrangements for groundwater management in dolomitic terrains: Situation analysis. Water Research Commission Report No. KV140/02.

THIRION, A.; MOCKE, A. WOEST, R. 1995. Biological Monitoring of Streams and Rivers Using SASS4: A user Manual. Final Report. 1995.

TRZYNA, T.C. 1995. A sustainable world: Defining and measuring sustainable development. UCN. Claremont.

VIVAS, S. and CASAS, J.J. 2002. Macroinvertebrates colonizing leaf litter of contrasting quality in a travertine Mediterranean stream. *Arch. Hydrobiol.* 154(2): 225-238.

VOS, P., WEPENER, V. and CYRUS, D.P. 2002. SASS4 on the Mhlathuze River, Efficiency of the SASS4 rapid bioassessment protocol in determining river health: A case study on the Mhlathuze River, KwaZulu-Natal, South Africa. *Water SA*. 28(1): 13-22.

WORLD RESOURCES, 2001. People and Ecosystems: The vrying web of life. World Resources Institute. Washington DC.

ZOKUFA, W.T.S, SCHERMAN, P.A. and PALMER, C.G. 2001. Tolerance of selected riverine indigenous macroinvertebrates from the Sabie River (Mpumalanga), and Buffalo River (Eastern Cape), to complex saline kraft and textile effluents. Grahamstown. Water Research Commission Report No. 783/1/01.

WORLD SUMMIT, 2002. WaterDome. Johannesburg World Summit. South Africa.

Appendix A Summer (Nov-Dec 2000) macro-invertebrates community (SASS4) data in the Diep River Catchment

ORDER	SITE FAMILY	R10	D08	D07	D06	D05	D04	D03	D02	M16
Tubellaria	Planaria	-	-	-	-	-	-	-	-	-
Annelida	Oligochaeta	X	X	-	-	-	-	-	-	-
Hirudinea	Leeches	-	-	-	-	-	-	-	X	X
Crustacea	Amphipoda	-	-	-	-	-	-	-	-	-
	Crabs	-	X	X	-	X	-	X	-	-
	Decapoda	-	-	-	-	-	-	-	-	-
Hydracarina	Hydrachnellae	X	-	-	X	X	-	-	X	X
Plecoptera	Notonemouridae	-	-	-	-	-	-	-	-	-
	Perlidae	-	-	-	-	-	-	-	-	-
Ephemeroptera	Baetidae 1 species	-	-	-	X	-	-	X	-	-
	2 species	-	X	X	-	X	X	-	X	-
	> 2 species	X	-	-	-	-	-	-	-	-
	Leptophlebidae	-	-	-	-	-	-	-	-	-
	Ephemerellidae	-	-	-	-	-	-	-	-	-
	Heptagenidae	-	-	-	-	-	-	-	-	-
	Caenidae	-	-	-	-	X	-	-	-	-
Odonata	Chlorolestidae	X	-	X	X	X	-	X	-	-
	Coenagriidae	X	-	X	X	X	X	-	X	X
	Calopterygidae	-	-	-	-	-	-	-	-	-
	Zygoptera juv	-	-	-	-	-	-	-	-	-
	Gomphidae	-	-	-	-	-	-	-	-	-
	Aeshnidae	-	-	-	-	X	-	X	X	-
	Corduliidae	-	-	-	-	-	-	-	-	-
	Libellulidae	X	-	-	X	-	-	-	-	-
Hemiptera	Notonectidae	X	X	X	X	X	X	X	X	X
	Pleidae	X	-	-	X	-	-	-	-	-
	Naucoridae	-	-	-	-	X	X	X	-	-
	Belostomatidae	-	-	X	-	-	-	-	-	-
	Corixidae	-	X	X	-	X	-	X	X	-
	Gerridae	-	-	-	X	X	X	X	-	-
	Veliidae	X	-	X	X	-	X	X	-	-
	Nepidae	X	-	-	-	-	-	X	-	-
Megaloptera	Corydalidae	-	-	-	-	-	-	-	-	-
Trichoptera	Hydropsychidae	-	-	-	-	-	-	-	-	-
	Philopotamidae	-	-	-	-	-	-	-	-	-
	Psychomyiidae	-	-	-	-	-	-	-	-	-
	Hydroptilidae	-	-	-	-	X	-	-	-	-
	Ecnomidae	-	-	-	-	-	-	-	-	-
	Cased larvae	-	-	-	-	-	-	-	-	-
	1sp									
	2sp									
	3sp									
	4sp									
	5sp									
	>5sp									

Appendix A Continued

ORDER	SITE FAMILY	R10	D08	D07	D06	D05	D04	D03	D02	M16
Coleoptera	Dytiscidae	X	X	X	X	X	X	X	-	X
	Elmidae	-	-	-	-	-	-	-	-	X
	Gyrinidae	-	-	-	-	-	-	-	-	-
	Helodidae	-	-	-	-	-	-	-	-	-
	Hydraenidae	-	-	-	-	-	-	-	-	-
	Hydrophilidae	-	-	-	-	-	-	-	-	-
	Limnichidae	-	-	-	-	-	-	-	-	-
Diptera	Tipulidae	-	-	-	-	-	-	-	-	-
	Culicidae	-	X	-	X	X	X	X	-	-
	Dixidae	-	-	-	-	-	-	-	-	-
	Simuliidae	X	X	X	-	-	X	X	X	X
	Chironomidae	X	X	-	-	X	X	X	X	-
	Ceratopogononidae	X	-	-	X	-	-	-	-	X
	Athericidae	-	-	-	-	-	-	-	-	-
	Mucidae	-	-	-	-	-	-	-	-	-
Gastropoda	Lymnaeidae	-	-	-	X	X	X	-	-	X
	Melanidae	-	-	-	-	-	X	-	-	-
	Physidae	-	-	-	X	-	-	-	X	-
	Planorbidae	-	-	-	-	-	-	-	-	-
	Ancylidae	-	-	X	X	-	X	X	-	-
	Hydrobiidae	-	-	-	-	-	-	-	-	-
SASS4 SCORE		62	29	51	83	78	55	68	53	44
NO. OF TAXA		14	9	11	17	16	13	15	11	9
ASPT		4.4	3.2	4.6	4.9	4.9	4.2	4.5	4.8	4.9
IHAS (%)		47	70	72	48	48	52	57	61	47

Appendix B Spring (Oct-Nov 2001) macro-invertebrates community (SASS5) data in the Diep River Catchment

ORDER	SITE FAMILY	R10	D11	D09	D08	D07	D06	D05	D04	D03
Tubellaria	Planaria	-	-	-	-	X	-	-	-	-
Annelida	Oligochaeta	X	X	X	X	X	-	-	-	-
Hirudinea	Leeches	-	-	X	-	X	-	-	-	X
Crustacea	Amphipoda	-	-	-	-	-	-	-	-	-
	Potamonautidae	-	-	-	X	X	X	-	X	-
	Decapoda	-	-	-	-	-	-	-	-	-
Hydracarina	Hydrachnellae	X	X	X	X	X	X	X	X	X
Plecoptera	Notonemouridae	-	-	-	-	-	-	-	-	-
	Perlidae	-	-	-	-	-	-	-	-	-
Ephemeroptera	Baetidae 1 species	-	-	-	X	X	-	-	-	-
	2 species	X	-	-	-	-	-	X	-	-
	> 2 species	-	X	X	-	-	X	-	X	-
	Leptophlebidae	-	-	-	-	-	-	-	-	-
	Ephemerellidae	-	-	-	-	-	-	-	-	-
	Heptagenidae	-	-	-	-	-	-	-	-	-
	Caenidae	-	-	-	-	-	-	-	-	-
Odonata	Chlorolestidae	-	-	-	-	-	-	-	-	-
	Coenagriidae	-	-	-	-	X	X	X	-	-
	Calopterygidae	-	-	-	-	-	-	-	-	-
	Zygoptera juv	-	-	-	-	-	1	-	-	-
	Gomphidae	-	-	-	-	-	-	-	-	-
	Aeshnidae	-	-	-	-	-	-	-	-	-
	Corduliidae	-	-	-	-	-	X	-	-	-
	Libellulidae	-	-	-	-	-	-	-	-	-
Hemiptera	Notonectidae	-	X	X	-	-	-	X	-	-
	Pleidae	-	X	X	-	-	-	-	-	-
	Naucoridae	-	-	-	-	-	-	-	X	-
	Belostomatidae	-	-	-	-	-	-	-	-	-
	Corixidae	X	X	X	X	X	X	X	-	X
	Gerridae	-	-	X	-	-	-	X	-	-
	Veliidae	-	-	-	-	-	X	-	-	-
	Hydromertidae	-	-	-	-	-	-	-	-	-
	Nepidae	-	-	-	-	-	-	-	-	-
Megaloptera	Corydalidae	-	-	-	-	-	-	-	-	-
Trichoptera	Hydropsychidae 1sp	-	-	-	-	-	-	-	-	-
	Hydropsychidae 2sp	-	-	-	-	-	-	-	-	-
	Hydropsychidae >2sp	-	-	-	-	-	-	-	-	-
	Philopotamidae	-	-	-	-	-	-	-	-	-
	Psychomyiidae	-	-	-	-	-	-	-	-	-
	Hydroptilidae	-	-	-	-	-	-	-	-	-
	Ecnomidae	-	-	-	-	-	-	-	-	-
Cased larvae	Babrachthonidae	-	-	-	-	-	-	-	-	-
	Calamoceratidae	-	-	-	-	-	-	-	-	-
	Glossosomatidae	-	-	-	-	-	-	-	-	-
	Hydoptilidae	-	-	-	-	-	-	-	-	-
	Hdrosalpingidae	-	-	-	-	-	-	-	-	-
	Lepidostomatidae	-	-	-	-	-	-	-	-	-
	Leptoceridae	-	-	-	-	-	-	-	-	-
	Petrothrincidae	-	-	-	-	-	-	-	-	-

Appendix B Continued

ORDER	SITE FAMILY	R10	D11	D09	D08	D07	D06	D05	D04	D03
	Pisullidae	-	-	-	-	-	-	-	-	-
	Sericostomatidae	-	-	-	-	-	-	-	-	-
Coleoptera	Dytiscidae	X	X	X	X	X	X	X	X	X
	Elmidae	-	X	-	-	-	-	-	-	-
	Gyrinidae	X	X	-	-	-	X	X	X	X
	Helodidae	-	-	-	-	-	-	-	-	-
	Hydraenidae	X	X	-	-	X	-	-	-	-
	Hydrophilidae	-	-	A	-	-	-	-	-	-
	Limnichidae	-	-	-	-	-	-	-	-	-
Diptera	Tipulidae	-	-	-	-	-	-	-	-	-
	Culicidae	-	-	-	X	-	X	-	-	X
	Dixidae	-	-	-	-	-	-	-	-	-
	Simuliidae	-	X	-	X	X	X	X	X	X
	Chironomidae	X	X	X	X	X	X	X	X	X
	Ceratopogononidae	-	-	-	-	X	-	-	-	-
	Athericidae	-	X	-	-	-	-	-	-	-
	Ephydridae	-	X	X	-	-	-	-	-	-
	Muscidae	X	X	-	-	-	-	-	X	-
Gastropoda	Lymnaeidae	-	X	-	-	-	-	X	X	X
	Melanidae	-	-	-	-	-	-	-	-	-
	Physidae	-	X	X	-	-	X	-	-	-
	Planorbidae	-	-	-	-	-	-	-	-	-
	Ancylidae	X	-	X	X	X	X	X	-	X
	Thiaridae	-	-	-	-	-	-	-	X	X
	Hydrobiidae	-	-	-	-	-	-	-	-	-
SASS4 SCORE		44	84	56	36	55	70	55	54	44
NO. OF TAXA		10	17	13	10	13	14	12	11	11
ASPT		4.4	4.9	4.3	3.6	4.2	5.0	4.6	4.9	4.0
IHAS (%)		40	54	47	54	54	58	63	75	54

Appendix B Continued

ORDER	SITE FAMILY	D02	M19	M18	M16	K14	K15A	M13A	M12	Phil
Tubellaria	Planaria	-	-	X	-	-	-	-	-	-
Annelida	Oligochaeta	-	X	-	X	-	X	-	-	-
Hirudinea	Leeches	X	-	-	X	X	-	X	-	-
Crustacea	Amphipoda	-	-	-	-	-	-	-	-	-
	Potamonautidae	-	-	-	-	-	-	-	-	-
	Decapoda	-	-	-	-	-	-	-	-	-
Hydracarina	Hydrachnellae	-	X	X	-	-	X	-	X	-
Plecoptera	Notonemouridae	-	-	-	-	-	-	-	-	-
	Perlidae	-	-	-	-	-	-	-	-	-
Ephemeroptera	Baetidae 1 species	-	-	-	X	-	-	-	-	-
	2 species	-	-	-	-	-	X	-	-	X
	> 2 species	-	X	-	-	X	-	X	X	-
	Leptophlebidae	-	-	-	-	-	-	-	-	-
	Ephemerellidae	-	-	-	-	-	-	-	-	-
	Heptagenidae	-	-	-	-	-	-	-	-	-
	Caenidae	-	-	-	-	X	-	-	-	X
Odonata	Chlorolestidae	-	-	-	-	-	-	-	-	-
	Coenagriidae	X	-	-	-	-	X	-	-	X
	Calopterygidae	-	-	-	-	-	-	-	-	-
	Zygoptera juv	-	-	-	-	-	-	-	-	-
	Gomphidae	-	-	-	-	-	-	-	-	-
	Aeshnidae	-	-	-	-	-	-	-	-	X
	Corduliidae	-	-	-	-	-	X	-	-	-
	Libellulidae	-	-	-	-	-	-	-	-	-
Hemiptera	Notonectidae	X	X	-	-	X	X	-	X	-
	Pleidae	-	-	-	-	-	X	-	-	X
	Naucoridae	-	-	-	-	X	-	-	X	-
	Belostomatidae	-	-	-	-	-	X	-	-	-
	Corixidae	X	X	X	X	X	X	X	X	X
	Gerridae	-	-	X	-	X	X	-	-	X
	Veliidae	-	X	-	-	-	-	-	X	-
	Hydromertidae	-	-	-	-	-	-	-	-	-
	Nepidae	-	-	-	-	-	-	-	-	-
Megaloptera	Corydalidae	-	-	-	-	-	-	-	-	-
Trichoptera	Hydropsychidae 1sp	-	-	-	-	-	-	-	-	-
	Hydropsychidae 2sp	-	-	-	-	-	-	-	-	-
	Hydropsychidae >2sp	-	-	-	-	-	-	-	-	-
	Philopotamidae	-	-	-	-	-	-	-	-	-
	Psychomyiidae	-	-	-	-	-	-	-	-	-
	Hydroptilidae	-	-	-	-	-	-	-	-	-
	Ecnomidae	-	-	-	-	-	-	-	-	-
Cased larvae	Babrachthonidae	-	-	-	-	-	-	-	-	-
	Calamoceratidae	-	-	-	-	-	-	-	-	-
	Glossosomatidae	-	-	-	-	-	-	-	-	-
	Hydoptilidae	-	-	-	-	-	-	-	-	-
	Hdrosalpingidae	-	-	-	-	-	-	-	-	-
	Lepidostomatidae	-	-	-	-	-	-	-	-	-
	Leptoceridae	-	-	-	-	-	-	-	-	-

Appendix B Continued

ORDER	SITE FAMILY	D02	M19	M18	M16	K14	K15A	M13	M12	Phil
	Petrothrincidae	-	-	-	-	-	-	-	-	-
	Pisullidae	-	-	-	-	-	-	-	-	-
	Sericostomatidae	-	-	-	-	-	-	-	-	-
Coleoptera	Dytiscidae	X	X	X	X	X	X	-	X	X
	Elmidae	-	-	-	-	-	-	-	-	-
	Gyrinidae	-	-	-	-	X	X	-	-	-
	Helodidae	-	-	-	-	-	-	-	-	-
	Hydraenidae	-	-	-	-	-	-	-	-	-
	Hydrophilidae	-	-	-	-	-	-	-	-	X
	Limnichidae	-	-	-	-	-	-	-	-	-
Diptera	Tipulidae	-	-	-	-	-	-	-	-	-
	Culicidae	-	-	X	X	-	X	-	X	X
	Dixidae	-	-	-	-	-	-	-	-	-
	Simuliidae	-	X	-	X	X	-	X	X	X
	Chironomidae	X	X	X	X	X	X	X	X	X
	Ceratopogononidae	-	-	-	-	-	-	X	-	-
	Athericidae	-	-	-	-	-	-	-	-	-
	Ephydridae	-	X	-	-	X	-	-	-	-
	Muscidae	-	-	-	-	X	-	-	-	-
Gastropoda	Lymnaeidae	-	X	-	X	-	-	-	-	-
	Melanidae	-	-	-	-	-	-	-	-	-
	Physidae	X	-	-	-	X	-	X	X	X
	Planorbidae	-	-	-	-	-	-	-	-	-
	Ancylidae	X	-	-	-	X	-	X	X	X
	Thiaridae	-	-	-	-	-	-	-	X	X
	Hydrobiidae	-	-	-	-	-	-	-	-	-
SASS4 SCORE		33	50	25	27	69	53	34	63	66
NO. OF TAXA		9	11	7	9	15	13	9	13	15
ASPT		3.7	4.5	3.6	3.0	4.6	4.1	3.8	4.8	4.4
IHAS (%)		51	48	60	53	58	44	61	43	48

Appendix C Winter (Jun-Jul 2002) macro-invertebrates community (SASS5) data in the Diep River Catchment

ORDER	SITE FAMILY	R10	D11	D09	D08	D07	D06	D05	D04	D03
Tubellaria	Planaria	B	-	-	-	-	-	-	-	-
Annelida	Oligochaeta	-	A	1	A	A	-	-	-	-
Hirudinea	Leeches	-	-	-	A	A	-	-	-	-
Crustacea	Amphipoda	-	-	-	-	-	-	-	-	-
	Potamonautidae	-	-	-	-	-	-	-	-	A
	Decapoda	-	-	-	-	-	-	-	-	-
Hydracarina	Hydrachnellae	B	-	-	A	-	A	A	-	-
Plecoptera	Notonemouridae	-	-	-	-	-	-	-	-	-
	Perlidae	-	-	-	-	-	-	-	-	-
Ephemeroptera	Baetidae 1 species	1	-	1	-	A	-	A	-	-
	2 species	-	-	-	-	-	-	-	A	-
	> 2 species	-	-	-	-	-	A	-	-	-
	Leptophlebidae	-	-	-	-	-	-	-	-	-
	Ephemerellidae	-	-	-	-	-	-	-	-	-
	Heptagenidae	-	-	-	-	-	-	-	-	-
	Caenidae	A	-	B	-	-	-	-	-	-
Odonata	Chlorolestidae	-	-	-	-	-	-	-	-	-
	Coenagriidae	1	-	-	-	B	B	A	-	-
	Calopterygidae	-	-	-	-	-	-	-	-	-
	Zygoptera juv	1	-	-	-	-	-	-	-	-
	Gomphidae	-	-	-	-	-	-	-	-	-
	Aeshnidae	1	-	-	-	-	-	-	-	-
	Corduliidae	-	-	-	-	-	-	-	-	-
	Libellulidae	A	-	-	-	-	A	-	-	-
Hemiptera	Notonectidae	1	1	A	-	-	-	A	-	-
	Pleidae	-	-	-	-	A	A	-	-	-
	Naucoridae	A	-	-	-	-	-	A	-	-
	Belostomatidae	-	-	-	-	-	-	-	-	-
	Corixidae	-	-	A	-	A	-	C	-	A
	Gerridae	1	-	-	A	-	-	A	-	-
	Veliidae	-	-	-	-	-	-	-	-	-
	Hydromertidae	-	-	-	-	-	-	-	-	-
	Nepidae	-	-	-	-	-	-	-	-	-
Megaloptera	Corydalidae	-	-	-	-	-	-	-	-	-
Trichoptera	Hydropsychidae 1sp	-	-	-	-	-	-	-	-	-
	Hydropsychidae 2sp	-	-	-	-	-	-	-	-	-
	Hydropsychidae >2sp	-	-	-	-	-	-	-	-	-
	Philopotamidae	-	-	-	-	-	-	-	-	-
	Psychomyiidae	-	-	-	-	-	-	-	-	-
	Hydroptilidae	-	-	-	-	-	-	-	-	-
	Ecnomidae	-	-	-	-	-	-	-	-	-
Cased larvae	Babrachthonidae	-	-	-	-	-	-	-	-	-
	Calamoceratidae	-	-	-	-	-	-	-	-	-
	Glossosomatidae	-	-	-	-	-	-	-	-	-
	Hydoptilidae	-	-	-	-	-	-	-	-	-
	Hdrosalpingidae	-	-	-	-	-	-	-	-	-
	Lepidostomatidae	-	-	-	-	-	-	-	-	-
	Leptoceridae	-	-	-	-	-	-	-	-	-

Appendix C Continued

ORDER	SITE FAMILY	R10	D11	D09	D08	D07	D06	D05	D04	D03
	Petrothrincidae	-	-	-	-	-	-	-	-	-
	Pisullidae	-	-	-	-	-	-	-	-	-
	Sericostomatidae	-	-	-	-	-	-	-	-	-
Coleoptera	Dytiscidae	A	B	A	-	A	-	A	-	-
	Elmidae	1	-	-	-	-	-	-	-	-
	Gyrinidae	-	-	-	-	-	-	-	B	-
	Helodidae	-	-	-	-	-	-	-	-	-
	Hydraenidae	A	1	-	-	-	-	A	-	-
	Hydrophilidae	-	-	-	-	-	-	-	-	A
	Limnichidae	-	-	-	-	-	-	-	-	-
Diptera	Tipulidae	-	-	-	-	-	-	-	-	-
	Culicidae	A	1	A	-	-	A	A	-	-
	Dixidae	-	-	-	-	A	-	-	-	-
	Simuliidae	A	-	-	A	A	C	A	B	A
	Chironomidae	B	B	B	A	A	A	B	B	A
	Ceratopogononidae	1	-	-	-	-	-	-	-	-
	Athericidae	-	-	-	-	-	-	-	-	-
	Ephydridae	-	-	-	-	-	-	-	-	-
	Muscidae	1	-	-	-	-	-	-	A	-
Gastropoda	Lymnaeidae	1	-	-	A	-	B	-	-	-
	Melanidae	-	-	-	-	-	-	-	-	A
	Physidae	-	-	-	-	-	-	-	-	-
	Planorbidae	-	-	-	-	-	-	-	-	-
	Ancylidae	-	-	-	-	A	A	-	-	-
	Thiaridae	-	-	-	-	-	-	B	B	B
	Hydrobiidae	-	-	-	-	-	-	-	-	-
SASS4 SCORE		94	20	25	27	47	49	58	22	24
NO. OF TAXA		20	6	8	7	11	10	13	6	7
ASPT		4.7	3.3	3.1	3.8	4.3	4.9	4.5	3.7	3.4
IHAS (%)		48	46	49	53	51	63	56	79	56

Appendix C Continued

ORDER	SITE FAMILY	D02	Groen	M19	M18	Trib 17	M16	K14	K15A	M13A
Tubellaria	Planaria	-	-	-	-	-	-	-	-	-
Annelida	Oligochaeta	-	-	A	A	A	A	-	-	-
Hirudinea	Leeches	-	-	-	-	1	A	-	A	-
Crustacea	Amphipoda	-	-	-	-	-	-	-	-	-
	Potamonautidae	-	-	-	-	1	-	-	-	-
	Decapoda	-	-	-	-	-	-	-	-	-
Hydracarina	Hydrachnellae	A	-	A	A	1	-	-	1	A
Plecoptera	Notonemouridae	-	-	-	-	-	-	-	-	-
	Perlidae	-	-	-	-	-	-	-	-	-
Ephemeroptera	Baetidae 1 species	A	-	-	-	-	-	-	-	-
	2 species	-	-	A	-	B	-	-	-	1
	> 2 species	-	-	-	-	-	-	-	-	-
	Leptophlebidae	-	-	-	-	-	-	-	-	-
	Ephemerellidae	-	-	-	-	-	-	-	-	-
	Heptagenidae	-	-	-	-	-	-	-	-	-
	Caenidae	-	-	-	-	-	-	-	-	-
Odonata	Chlorolestidae	-	-	-	-	-	-	-	-	-
	Coenagriidae	A	-	-	-	B	-	1	-	-
	Calopterygidae	-	-	-	-	-	-	-	-	-
	Zygoptera juv	-	-	-	-	-	-	-	-	-
	Gomphidae	-	-	-	-	-	-	-	-	-
	Aeshnidae	-	-	-	-	1	-	-	-	-
	Corduliidae	-	-	-	-	-	-	-	-	-
	Libellulidae	-	-	-	-	-	-	-	1	-
Hemiptera	Notonectidae	A	-	-	-	1	1	1	-	-
	Pleidae	A	-	1	-	-	-	-	A	-
	Naucoridae	-	-	-	-	-	-	-	-	-
	Belostomatidae	-	-	-	-	-	-	-	-	-
	Corixidae	A	-	-	-	A	A	1	-	A
	Gerridae	-	-	-	-	-	-	1	-	-
	Veliidae	-	-	-	-	-	-	-	-	-
	Hydromertidae	-	-	-	-	-	-	-	-	-
	Nepidae	-	-	-	-	-	-	-	-	-
Megaloptera	Corydalidae	-	-	-	-	-	-	-	-	-
Trichoptera	Hydropsychidae 1sp	-	-	-	-	-	-	-	-	-
	Hydropsychidae 2sp	-	-	-	-	-	-	-	-	-
	Hydropsychidae >2sp	-	-	-	-	-	-	-	-	-
	Philopotamidae	-	-	-	-	-	-	-	-	-
	Psychomyiidae	-	-	-	-	-	-	-	-	-
	Hydroptilidae	-	-	-	-	-	-	-	-	-
	Ecnomidae	-	-	-	-	-	-	-	-	-
Cased larvae	Babrachthonidae	-	-	-	-	-	-	-	-	-
	Calamoceratidae	-	-	-	-	-	-	-	-	-
	Glossosomatidae	-	-	-	-	-	-	-	-	-
	Hydoptilidae	-	-	-	-	-	-	-	-	-
	Hdrosalpingidae	-	-	-	-	-	-	-	-	-
	Lepidostomatidae	-	-	-	-	-	-	-	-	-
	Leptoceridae	-	-	-	-	-	-	-	-	-
	Petrothrincidae	-	-	-	-	-	-	-	-	-

Appendix C Continued

ORDER	SITE FAMILY	D02	Groen	M19	M18	Trib 17	M16	K14	K15A	M13A
	Pisullidae	-	-	-	-	-	-	-	-	-
	Sericostomatidae	-	-	-	-	-	-	-	-	-
Coleoptera	Dytiscidae	A	B	B	-	-	-	B	B	1
	Elmidae	-	-	1	-	1	-	-	-	-
	Gyrinidae	-	-	-	-	-	-	-	-	-
	Helodidae	-	-	-	-	-	-	-	-	-
	Hydraenidae	-	-	-	-	-	-	-	-	-
	Hydrophilidae	-	-	-	-	-	-	1	-	-
	Limnichidae	-	-	-	-	-	-	-	-	-
Diptera	Tipulidae	-	-	-	-	-	-	-	-	-
	Culicidae	-	A	1	-	1	-	-	-	-
	Dixidae	-	-	-	-	-	-	-	-	-
	Simuliidae	-	-	-	A	A	1	A	-	B
	Chironomidae	A	B	B	B	B	A	B	B	B
	Ceratopogononidae	-	-	-	-	-	-	-	-	-
	Athericidae	-	-	-	-	-	-	-	-	-
	Ephydridae	-	-	-	-	-	-	-	-	-
	Muscidae	-	-	-	-	-	-	-	-	-
Gastropoda	Lymnaeidae	-	-	-	-	-	-	-	-	-
	Melanidae	-	-	-	-	-	-	-	-	-
	Physidae	A	A	-	1	-	-	A	-	-
	Planorbidae	-	-	1	-	-	-	-	-	B
	Ancylidae	-	-	-	-	-	-	-	-	-
	Thiaridae	-	-	-	-	-	-	-	-	-
	Hydrobiidae	-	-	-	-	-	-	-	-	-
SASS4 SCORE		36	11	38	19	61	17	35	26	30
NO. OF TAXA		9	4	9	5	14	6	9	6	7
ASPT		4.0	2.7	4.2	3.8	4.4	2.8	3.9	4.3	4.3
IHAS (%)		51	56	59	57	53	52	68	50	51

Appendix C Continued

	SITE	M12	Phil
ORDER	FAMILY		
Tubellaria	Planaria	-	-
Annelida	Oligochaeta	-	-
Hirudinea	Leeches	-	-
Crustacea	Amphipoda	-	-
	Potamonautidae	-	-
	Decapoda	-	-
Hydracarina	Hydrachnellae	-	A
Plecoptera	Notonemouridae	-	-
	Perlidae	-	-
Ephemeroptera	Baetidae 1 species	A	-
	2 species	-	-
	> 2 species	-	-
	Leptophlebidae	-	-
	Ephemerellidae	-	-
	Heptagenidae	-	-
	Caenidae	A	A
Odonata	Chlorolestidae	-	-
	Coenagriidae	A	1
	Calopterygidae	-	-
	Zygoptera juv	-	-
	Gomphidae	-	-
	Aeshnidae	1	-
	Corduliidae	-	-
	Libellulidae	-	-
Hemiptera	Notonectidae	-	-
	Pleidae	-	A
	Naucoridae	-	-
	Belostomatidae	-	-
	Corixidae	A	-
	Gerridae	-	-
	Veliidae	-	-
	Hydromertidae	-	-
	Nepidae	-	-
Megaloptera	Corydalidae	-	-
Trichoptera	Hydropsychidae 1sp	-	-
	Hydropsychidae 2sp	-	-
	Hydropsychidae >2sp	-	-
	Philopotamidae	-	-
	Psychomyiidae	-	-
	Hydroptilidae	-	-
	Ecnomidae	-	-
Cased larvae	Babrachthonidae	-	-
	Calamoceratidae	-	-
	Glossosomatidae	-	-
	Hydoptilidae	-	-
	Hdrosalpingidae	-	-
	Lepidostomatidae	-	-
	Leptoceridae	-	-
	Petrothrincidae	-	-

Appendix C Continued

	SITE	M12	Phil
ORDER	FAMILY		
	Pisullidae	-	-
	Sericostomatidae	-	-
Coleoptera	Dytiscidae	B	B
	Elmidae	-	1
	Gyrinidae	-	-
	Helodidae	-	-
	Hydraenidae	A	-
	Hydrophilidae	-	-
	Limnichidae	-	-
Diptera	Tipulidae	-	-
	Culicidae	A	1
	Dixidae	-	-
	Simuliidae	A	A
	Chironomidae	B	B
	Ceratopogononidae	-	-
	Athericidae	-	-
	Ephydridae	-	-
	Muscidae	-	-
Gastropoda	Lymnaeidae	-	-
	Melanidae	-	-
	Physidae	A	-
	Planorbidae	-	-
	Ancylidae	-	-
	Thiaridae	B	B
	Hydrobiidae	-	-
SASS4 SCORE		44	46
NO. OF TAXA		11	10
ASPT		4.4	4.6
IHAS (%)		49	54

Estimate Abundances: 1=1, A =2-10, B =10-100, C =100-1000, D =>1000

Appendix D Autumn (Mar 2003) macro-invertebrates community (SASS5) data in the Diep River Catchment

ORDER	SITE FAMILY	R10	D09	D04	D03	M13A
Tubellaria	Planaria	-	-	-	-	-
Annelida	Oligochaeta	1	-	-	-	-
Hirudinea	Leeches	-	-	-	-	-
Crustacea	Amphipoda	-	-	-	-	-
	Crabs	A	A	A	1	A
	Decapoda	-	-	-	-	-
Hydracarina	Hydrachnellae	-	-	-	1	-
Plecoptera	Notonemouridae	-	-	-	-	-
	Perlidae	-	-	-	-	-
Ephemeroptera	Baetidae 1 species	-	A	-	1	1
	2 species	-	-	-	-	-
	> 2 species	B	-	-	-	-
	Leptophlebidae	-	-	-	-	-
	Ephemerellidae	-	-	-	-	-
	Heptagenidae	-	-	-	-	-
	Caenidae	-	-	-	-	-
Odonata	Chlorolestidae	-	-	-	-	-
	Coenagriidae	-	-	1	-	-
	Calopterygidae	-	-	-	-	-
	Zygoptera juv	1	-	A	-	1
	Gomphidae	-	-	-	-	-
	Aeshnidae	A	-	-	-	-
	Corduliidae	-	-	-	-	-
	Libellulidae	-	-	-	-	-
Hemiptera	Notonectidae	-	A	B	B	1
	Pleidae	-	-	A	-	A
	Naucoridae	-	1	-	-	-
	Belostomatidae	-	-	-	-	-
	Corixidae	B	A	B	B	A
	Gerridae	-	1	A	1	-
	Veliidae	-	-	A	B	A
	Hydromertidae	-	-	-	1	-
	Nepidae	-	-	-	-	-
Megaloptera	Corydalidae	-	-	-	-	-
Trichoptera	Hydropsychidae 1sp	-	-	-	-	-
	Hydropsychidae 2sp	-	-	-	-	-
	Hydropsychidae >2sp	-	-	-	-	-
	Philopotamidae	-	-	-	-	-
	Psychomyiidae	-	-	-	-	-
	Hydroptilidae	-	-	-	-	-
	Ecnomidae	-	-	-	-	-
Cased larvae	Babrachthonidae	-	-	-	-	-
	Calamoceratidae	-	-	-	-	-
	Glossosomatidae	-	-	-	-	-
	Hydoptilidae	-	-	-	-	-
	Hdrosalpingidae	-	-	-	-	-
	Lepidostomatidae	-	-	-	-	-
	Leptoceridae	-	-	-	-	-

Appendix D Continued

ORDER	SITE FAMILY	R10	D09	D04	D03	M13A
	Petrothrincidae	-	-	-	-	-
	Pisullidae	-	-	-	-	-
	Sericostomatidae	-	-	-	-	-
Coleoptera	Dytiscidae	B	1	-	-	-
	Elmidae	-	-	-	-	-
	Gyrinidae	-	-	B	-	-
	Helodidae	-	-	-	-	-
	Hydraenidae	-	-	-	-	-
	Hydrophilidae	-	A	1	-	A
	Limnichidae	-	-	-	-	-
Diptera	Tipulidae	-	-	-	-	-
	Culicidae	1	-	-	-	-
	Dixidae	-	-	-	-	-
	Simuliidae	-	-	-	-	-
	Chironomidae	C	A	1	A	A
	Ceratopogononidae	-	-	1	-	-
	Athericidae	-	-	-	-	-
	Mucidae	-	-	-	-	-
Gastropoda	Lymnaeidae	-	-	-	-	-
	Melanidae	-	-	-	-	-
	Physidae	-	-	-	-	-
	Planorbidae	-	-	-	-	1
	Ancylidae	-	-	-	-	-
	Hydrobiidae	-	-	-	-	-
SASS4 SCORE		41	32	50	60	41
NO. OF TAXA		9	9	12	13	10
ASPT		4.6	3.5	4.2	4.6	4.1
IHAS (%)		51	42	36	38	42

Estimate Abundances: 1=1, A =2-10, B =10-100, C =100-1000, D =>1000

APPENDIX E Summary of Descriptive Statistical Analysis for NH_3-N data (1997-2002) per sites in the Diep River system

NH_3-N Sites	Actual Median values	Mean values	Ranges	Standard Deviations	Minimum values	Maximum values
R10	0.15	0.260952	1.37	0.351382	0.13	1.5
D11	0.15	0.343333	1.35	0.452717	0.15	1.5
D09	0.15	0.175926	0.25	0.06559	0.15	0.4
D08	3.85	8.433333	42.05	10.56852	0.15	42.2
D07	0.6	3.252083	37.25	6.798803	0.15	37.4
D06	0.15	0.457143	4.65	0.91845	0.15	4.8
D05	0.15	0.174074	0.25	0.071213	0.15	0.4
D04	0.15	0.234483	1.35	0.264947	0.15	1.5
D03	0.15	0.204167	1.25	0.21293	0.15	1.4
D02	0.15	1.292671	8.385	1.885396	0.015	8.4
Groen	0.15	0.209375	0.55	0.14857	0.15	0.7
Phil	0.15	0.75	4.35	1.30499	0.15	4.5
M19	0.15	0.911429	7.95	1.873346	0.15	8.1
M18	1.95	8.259211	59.25	13.91052	0.15	59.4
M16	0.75	2.702679	37.25	5.749572	0.15	37.4
M13A	0.15	0.471429	3.35	0.724209	0.15	3.5
M12	0.15	0.322727	3.95	0.620714	0.15	4.1
K15A	0.3	3.523684	31.25	7.776788	0.15	31.4
k14	0.15	0.61875	6.55	1.546732	0.15	6.7
Trib17	0.8	1.730556	16.15	3.020409	0.15	16.3

APPENDIX F Summary of Descriptive Statistical Analysis for COD data (1996-2002) per site in the Diep River system

COD Sites	Actual Median values	Mean values	Ranges	Standard Deviations	Minimum values	Maximum values
R10	50	60.28571	159	36.31273	20	170
D11	77	78.46667	76	24.46533	49	125
D09	56	66.03704	258	46.37927	21	279
D08	56	58.58333	107	22.44694	10	117
D07	58	70.95833	237	44.23821	10	247
D06	60	63.94286	143	28.4139	10	153
D05	82	79.76923	120	24.7359	4	124
D04	88	93.13793	174	40.8619	24	198
D03	97	103.6207	290	51.68062	24	314
D02	72	82.61644	302	49.06052	4	306
Groen	84	91.8	106	30.02665	49	155
Phil	63	68.54545	161	45.19815	24	185
M19	78	95.71429	310	54.53848	36	346
M18	104.5	110.1316	193	39.95211	10	203
M16	86	90.60714	233	39.93161	33	266
M13A	90	90.10204	147	28.16562	10	157
M12	92	101.9773	348	52.36211	10	358
K15A	64	70.84211	57	18.00698	42	99
k14	96.5	102.0938	196	38.37956	44	240
Trib17	82.5	96.38889	212	37.75713	52	264

APPENDIX G Summary of Descriptive Statistical Analysis for EC data (1996-2002) per site in the Diep River system

EC Sites	Actual Median values	Mean values	Ranges	Standard Deviations	Minimum values	Maximum values
R10	235	251.9524	292	83.71169	131	423
D11	212	228.3333	285	102.6469	95	380
D09	240	225.9889	342.5	81.87009	78.5	421
D08	178	181.7979	190	52.90978	108	298
D07	211	209.8521	236.1	39.07041	62.9	299
D06	242	236.1686	241.1	45.96918	62.9	304
D05	284	311.7778	566	107.8893	63	629
D04	260	264.0414	425.8	83.76638	63.2	489
D03	319	417.1139	1238	294.7702	32	1270
D02	204	215.3233	347	85.87657	76	423
Groen	142	177.65	617.2	140.5097	62.8	680
Phil	514	473.5455	568	154.6825	111	679
M19	74.6	95.32571	241.5	52.1446	38.5	280
M18	123	119.7886	158.9	30.03834	41.1	200
M16	145	141.1286	121.5	24.95742	85.5	207
M13A	177	184.6343	286.8	63.31731	56.2	343
M12	229.5	241.9382	433.1	97.62282	65.9	499
K15A	76.7	77.11053	115.7	32.15319	40.3	156
k14	193.5	194.6031	327	81.01074	22	349
Trib17	147	145.4771	170.3	36.0536	77.7	248

APPENDIX H Summary of Descriptive Statistical Analysis for NO_3-N data (1997-2002) per site in the Diep River system

NO_3-N Sites	Actual Median values	Mean values	Ranges	Standard Deviations	Minimum values	Maximum values
R10	0.65	1.575	7.85	2.278244	0.15	8
D11	0.65	1.292857	4.95	1.606101	0.15	5.1
D09	0.15	1.403846	14.95	3.124546	0.15	15.1
D08	1.1	3.46383	23.45	5.304753	0.15	23.6
D07	2.6	3.371277	13.65	2.601478	0.15	13.8
D06	2.3	2.905882	10.45	2.260557	0.15	10.6
D05	1	1.342692	3.75	1.320814	0.15	3.9
D04	1.75	2.401786	11.15	2.642196	0.15	11.3
D03	0.15	1.218571	4.85	1.393635	0.15	5
D02	1.4	2.026027	7.65	1.868528	0.15	7.8
Groen	4.35	6.021875	18.65	5.893668	0.15	18.8
Phil	2.1	2.072727	6.15	1.945683	0.15	6.3
M19	0.7	1.010526	4.85	1.150432	0.15	5
M18	0.8	1.784783	10.95	2.706114	0.15	11.1
M16	6	6.911111	18.75	5.738144	0.15	18.9
M13A	4.7	5.598438	15.25	4.468374	0.15	15.4
M12	2	3.008	10.55	3.100796	0.15	10.7
K15A	1.8	3.455263	20.85	5.038322	0.15	21
k14	1.3	2.459375	8.05	2.571136	0.15	8.2
Trib17	10.3	10.62417	21.85	7.028857	0.15	22

APPENDIX I Summary of Descriptive Statistical Analysis for PO_4-P data (1997-2002) per site in the Diep River system

PO4-P Sites	Actual Median values	Mean values	Ranges	Standard Deviations	Minimum values	Maximum values
R10	0.05	0.10725	0.975	0.214798	0.025	1
D11	0.24	0.244286	0.475	0.155735	0.025	0.5
D09	0.025	0.068269	0.395	0.08551	0.025	0.42
D08	3.17	4.704255	17.55	4.428868	0.15	17.7
D07	2.15	2.567872	7.53	2.033014	0.17	7.7
D06	0.63	0.859559	2.905	0.746925	0.025	2.93
D05	0.24	0.503846	6.645	1.271121	0.025	6.67
D04	0.55	0.816607	2.495	0.643518	0.025	2.52
D03	0.37	0.399571	1.175	0.268526	0.025	1.2
D02	0.95	1.782466	6.9	1.661875	0.1	7
Groen	0.06	0.164375	1.645	0.403901	0.025	1.67
Phil	0.63	0.99	4.2	1.197556	0.3	4.5
M19	0.35	0.967632	10.775	2.402424	0.025	10.8
M18	1.89	3.290435	11.52	3.45388	0.08	11.6
M16	3.37	3.5175	5.97	1.450138	0.93	6.9
M13A	2.09	2.339032	5.24	1.263594	0.26	5.5
M12	1.07	1.2152	2.57	0.655592	0.24	2.81
K15A	0.22	0.574211	3.075	0.896351	0.025	3.1
k14	0.37	1.243667	5.275	1.89151	0.025	5.3
Trib17	4.54	4.708611	8.2	2.195895	0.5	8.7

APPENDIX J Summary of Descriptive Statistical Analysis for PO$_4$-P data (1997-2002) per site in the Diep River system

pH Sites	Actual Median values	Mean values	Ranges	Standard Deviations	Minimum values	Maximum values
R10	7.9	7.885714	0.6	0.215141	7.6	8.2
D11	8.1	8.1	1.3	0.387298	7.6	8.9
D09	7.8	7.77037	0.8	0.2672	7.4	8.2
D08	7.4	7.358333	1.4	0.299527	6.6	8
D07	7.5	7.48125	1.2	0.257365	6.8	8
D06	7.8	7.834286	1.1	0.260026	7.4	8.5
D05	7.9	7.877778	1	0.262141	7.4	8.4
D04	7.9	7.858621	1.2	0.267952	7.2	8.4
D03	7.95	7.975	1.4	0.345067	7.2	8.6
D02	7.6	7.606849	2	0.400114	6.8	8.8
Groen	7.45	7.44375	0.9	0.275605	7	7.9
Phil	8.1	8.054545	0.8	0.242337	7.5	8.3
M19	7.6	7.542105	0.8	0.2219	7.2	8
M18	7.4	7.417391	0.9	0.20372	6.9	7.8
M16	7.5	7.502778	1.1	0.272015	7.1	8.2
M13A	7.7	7.70625	1	0.216925	7.4	8.4
M12	7.8	7.848	1.3	0.28006	7.2	8.5
K15A	7.4	7.394737	1.2	0.29716	6.8	8
k14	7.7	7.64375	1	0.268251	7	8
Trib17	7.55	7.591667	1.3	0.269788	7	8.3

APPENDIX K Summary of Descriptive Statistical Analysis for SS data (1996-2002) per site in the Diep River system

SS Sites	Actual Median values	Mean values	Ranges	Standard Deviations	Minimum values	Maximum values
R10	5	14.57143	102	22.15981	5	107
D11	16	21.46667	56	16.67704	5	61
D09	19	27.37037	147	32.91966	5	152
D08	10	14.22917	66	14.23845	5	71
D07	14.5	19.02083	108	21.67309	5	113
D06	10	18.97143	167	32.03903	5	172
D05	23	29.74074	127	25.31432	5	132
D04	19	29.31034	153	30.85462	5	158
D03	30	54.77778	276	60.62301	5	281
D02	20	54.15068	1025	134.8703	5	1030
Groen	5	13.4375	79	19.79215	5	84
Phil	5	37.54545	335	100.4484	5	340
M19	13	26.57143	228	44.59839	5	233
M18	13	19.18421	105	19.91584	5	110
M16	19.5	27.71429	117	22.72501	5	122
M13A	15	23.83673	102	20.22823	5	107
M12	28.5	43.15909	351	58.12654	5	356
K15A	24	37.94737	278	61.02593	5	283
k14	21.5	67.75	955	178.1728	5	960
Trib17	12	18.96296	96	21.37973	5	101