An assessment of the impact of the Black village communities, their associated land-use and related practices on water quality of the Kat River in the Eastern Cape, South Africa.

A thesis submitted in fulfilment of the requirements for the degree of

MASTER OF SCIENCE

of

RHODES UNIVERSITY

By

MALIXOLE KNOTTIEN SOVITI

January 2002

Abstract

Amongst others, the South African National Water Act No. 36 of 1998 acknowledges that access to sufficient safe and clean water is a basic right to all South Africans. However, it is well known that millions of inhabitants of rural communities in South Africa are still deprived of this right. Many rural communities in South Africa are thus consuming unsafe, untreated water everyday, thereby exposing themselves to waterborne diseases. The main reason of concern however is the fact that, nevertheless, little is known about rural water quality in South Africa as most water quality work is being undertaken in urban areas. The study's aim is two fold: first, the study examines the impact of Black rural communities's land-use and related activities on water quality and second is specifically, to study the washing practices of the rural communities in the upper Kat River area.

To understand the potential impacts of the upper Kat River Black village communities and their associated land-use practices on the quality of upper Kat River catchment, prominent land-use and related activities in the area were investigated. Study area maps were studied and field surveys undertaken to observe major land-use and related activities in the area. The results of the study show that most used land in the area is being utilised for agricultural activities. Settlements and commercial forestry also occupy considerable areas of land. The literature survey suggests that such land-use could have a considerable degrading impact on the quality of both surface and groundwater.

The study also investigated the impact of the in-stream use of detergents on water quality in the upper Kat River valley, Eastern Cape - South Africa. In-stream washing practices of certain communities in the upper Kat River valley were investigated and the impact of detergents on water quality was assessed. Recovery of the flow from the input of detergents was also measured. During the study, it has been ascertained that doing laundry by the stream is the common practice in the study area. Water quality analysis results show a remarkable increase on the levels of chloride, turbidity, and electrical conductivity in water as a consequence of direct input of detergents practice into the river during the washing. The recovery of the water quality at a distance of 1km from site of input was almost complete.

Water quality monitoring programme was undertaken to establish a link between land-use and the quality of water. In a water quality study routine carried out for a period of 40 weeks on a twice monthly frequency, the state of the flows of the river was determined; water samples were collected at pre-determined points; and the *in situ* analysis of selected water quality variables

(with the exception of the faecal coliforms whose analysis was carried out in the biotechnology laboratory) was carried out.

Results of the study showed that the concentration of the studied water quality variables in the area varied widely with time. A clear distinction in concentration of variables such as electrical conductivity, turbidity, pH, total hardness, chloride, and nitrate was evident at the high compared to the low flow period of the study. The concentration of the studied water quality variables in the upper Kat River catchment area also seemed to vary over space. The concentration of variables such as electrical conductivity, pH, total hardness, chloride, nitrate, potassium, number of faecal coliform bacteria per 100ml was observed to be higher in most of the tributary streams than the main river. Turbidity however was orders of magnitude higher in the Kat River than the rest of the tributaries. Most importantly however, results of the study showed that there is a strong link between the quality of water and land-use and related activities in the area. The spatial results of the study showed a strong connection between some land-use and the concentrations of water quality variables. For example, areas of intense grazing were noted with high concentrations of nutrients like nitrate and a higher number of faecal coliform bacteria per 100 ml of water.

It was established during the study that land-use and related activities in the upper Kat River valley are negatively impacting on the quality of water thereby rendering it less fit for use for domestic purposes. The continued use of the polluted water by the communities is thus accompanied by a danger of the outbreak of waterborne diseases like cholera. When the concerned communities met in a workshop to discuss the issue of quality of their water, they committed themselves to:

- shunning water polluting activities,
- at least boiling their drinking water before consuming it.

The communities also requested a meeting with the Department of Water and Forestry officials to request a treated, piped supply of water.

Acknowledgments

I am indebted to my supervisors, Prof. K.M. Rowntree and Prof. C.G.Palmer for their patience and dedicated effort on providing guidance and support during the compilation of this work. I would like to express my sincere gratitude to Prof. P. Rose and Ms Anna.Clarke of the Biotechnology Department for permitting me to use their laboratory facilities for faecal coliform bacteria experiments. Anna was also very helpful during the experiments.

Special thanks go to my colleague Mr. A McMaster for his assistance with GIS related activities of this project. Many thanks to all staff members of the Geography Department, Rhodes University for their continued assistance, support, and encouragement. Many thanks go to my friend and colleague, Monde Duma for your invaluable advices, support and encouragement. My appreciation also goes to our HOD, Prof. R. Fox, Mrs Glyn Armstrong and other staff members of the Geography Department. Particularly, Mrs Armstrong's patience, help and understanding during the time of my illness was inexhaustible.

This project would not have been complete if it was not for the support and understanding I received from a fellow tenant and friend Nocawe and her family, with whom I often had to leave my son Luthando, sometimes in most awkward times. Their love and support is unreservedly appreciated. I particularly feel greatly indebted to my seven year old son Luthando as I sacrificed so much of the time we could have spent together, investing it in this project. To him I say: " *utata ukuthanda ngokungazenzisiyo sana lwam*". My unreserved gratitude also goes to my Darling, F. Nakani for the undivided attention, unreserved support, encouragement and limitless understanding she offered during the most challenging times of this project, and particularly when I was helplessly ill.

My sincere gratitude also goes to the Unilever (United Kingdom) and the National Research Foundation for funding this study.

Table of Contents

Abstract ii

Acknowledgements iv

Table of Contents v

List of tables xi

List of figures xii

List of plates xv

Chapter 1

General Introduction 1

1.1 Introduction 1

1.2 Introducing the target research communities 3

1.2.1 Selecting the target communities 3

1.3 Study area 6

1.3.1 Biophysical characteristics of the study area 6

1.3.2 Historical background to the study area 8

1.3.3 Service centres 8

1.4 Land-use in the study area 8

1.5 General water quality issues in the study area 9

1.6 Aims and objectives of the study 9

1.6.1 Aims 9

1.6.2 Objectives 9

1.7 Structure of the thesis 11

Chapter 2

Land-use and related activities 12

2.1 Introduction 12

2.2 Impact of different land-uses and related activities on river water quality 13

2.2.1 Forestry plantations 14

2.2.2 Effect of rural agricultural practices on the quality of water 14

2.2.3 The impact of rural settlements and poor sanitation services in the quality of water 20

2.2.4 The impact of poor quality of water on the health and welfare of the user communities 23
2.2.5 The water quality variables 24
2.2.5.1 Physical properties 24
2.2.5.2 The biological constituents 27
2.2.5.3 The process related constituents 27
2.3.5.4 The physio-chemical constituents 28
2.3 Methods and techniques 33
2.3.1 Determining the land-use and related activities in the selected villages 33
2.3.2 Assessing a possible link between land-use and water quality 36
2.4 Results and Discussion 36
2.4.1 Land-use and related activities in selected villages 36
2.4.2 General layout of villages in the study area 42
2.4.3 Establishing the nature of basic services in the area 44
2.3.3.1 Social background of the study communities 45

Chapter 3

Washing practices in the rural upper-middle Kat River area 47
3.1 Literature survey 47
3.1.1 Introduction 47
3.1.2 Development of detergents 47
3.1.3 Properties of detergents 50
3.1.3.1 Phosphates 50
3.1.3.2 Boron 50
3.2 Detergent Study Methods and Techniques 52
3.2.1 Introduction 52
3.2.2 Washing practices in the study area 52
3.2.3 Identification of the washing sites 53
3.2.4 Studying the in-stream washing practices 54
3.2.5 Chemical properties of detergent solutions 54
3.3 Results and Discussion 56
3.3.1 Describing the washing practices in the study area 56

3.3.1.1 Washing practices in the Kat River valley 56
3.3.1.2 Aspects of interest at Balfour 62
3.3.2 Analysing selected chemical properties of detergent solution 63
3.3.3 Studying the in stream washing practices 63
3.3.3.1 The impact of the in-stream washing on water chemistry of the Kat River and the Balfour tributary 64
3.3.4 Discussion 68

Chapter 4

Water Quality Monitoring 70
4.1 Water Quality Monitoring methods and techniques 70
4.1.1 Introduction 70
4.1.2 Identifying the target communities 70
4.1.3 Identifying the sampling sites for general water quality, and sampling 70
4.1.3.1 Identifying the sites for the general water quality study 70
4.1.3.2 Sampling 71
4.1.4 Determining water quality in relation to the village activities 72
4.1.4.1 Selecting variables of concern 73
4.1.4.2 Water quality assessment tools 74
4.1.5 Determining the impact of water quality on the health and welfare of the study communities as well as making recommendations as to how to improve the water quality 76
4.1.6 Results analysis tools 76
4.1.7 Caltulating loads from original data 76
4.2 Results on water quality 77
4.2.1 Introduction 77
4.2.2 Hydrology of the study area 77
4.2.3 Turbidity 80
4.2.3.1 Spatial variation 80

	4.2.3.2 Temporal variation	80
4.2.4	pH	84
	4.2.4.1 Spatial variation	84
	4.2.4.2 Temporal variation	84
4.2.5	Chloride	84
	4.2.5.1 Spatial variation	84
	4.2.4.2 Temporal variation	84
	4.2.5.3 Chloride loads	85
4.2.6	Total Dissolved Salts	92
	4.2.6.1 Spatial variation	92
	4.2.6.2 Temporal variation	92
	4.2.6.3 TDS loads	95
4.2.7	Total hardness (TH) presented as Calcium Carbonate ($CaCo_3$)	95
	4.2.7.1 Spatial variation	95
	4.2.7.2 Temporal variation	96
	4.2.7.3 Polyvalent metallic cations loads	96
4.2.8	Nitrate	100
	4.2.8.1 Spatial variation	100
	4.2.8.2 Temporal variation	100
	4.2.8.3 Nitrate loads	100
4.2.10	Ammonium	105
	4.2.10.1 Spatial variation	105
	4.2.10.2 Temporal variation	105
4.2.11	Faecal coliforms	107
	4.2.11.1 Spatial variation	107
	4.2.11.2 Temporal variation and the	
	4.2.11.3 Bacteria loads	108
4.2.12	Potassium	108
	4.2.12.1 Spatial variation	108
	4.2.12.2 Temporal variation and loads	108
4.3.12	Quality of groundwater in the upper Kat River area	112

Chapter 5

Water Quality Discussion 113

5.1 Spatial dynamics of water quality variables 113

5.2 Temporal variation of the water quality variables 115

5.3 Impact of water quality variables in health and welfare of the user communities 116

Chapter 6

Concluding discussion 140

6.1 Introduction 140

6.2 Project review 142

6.3 Reviewing the aims and objectives of the study 143

6.4 Lessons learnt in the Kat River area 145

6.5 The South African situation (South African National Water Act No. 36 of 1998) 147

6.6 Recommendations on how to improve water quality or mitigate the impacts of poor water quality on health 148

References 149

Appendices 171

Appendix 1: Nature of Basic Services in the Balfour village 171

Appendix 2: Nature of Basic services in all villages studied 173

Appendix 3: Describing the washing practices at Balfour 175

Appendix 4: Washing practices in all villages 177

Appendix 5: A comparison of tap water chemistry with 5g, 10g and 15g of Omo and Surf washing powder and a Sunlight bar soap 180

Appendix 6: Situation analysis in three washing sites studied 180

Appendix 7: Studying the washing practices at Hertzog (1) 181

Appendix 8: Studying the washing practices at Fairbairn (4) 181

Appendix 9: Studying the washing practices at Balfour (9) 182

Appendix 10: Discharge in the upper Kat River catchment 183

Appendix 11: Turbidity in the upper Kat River area 185

Appendix 12: pH in the upper Kat River area 187

Appendix 13: Chloride in the upper Kat River catchment 189

Appendix 14: Total Dissolved Salts in the upper Kat

	River catchment	191
Appendix 15:	Total Hardness expressed as CaCo3	193
Appendix 16:	Nitrate in the upper Kat River	195
Appendix 17:	Ammonium in the upper Kat River catchment	197
Appendix 18:	Faecal coliforms in the upper Kat River catchment	199
Appendix 19:	Potassium in the upper Kat River catchment	201
Appendix 20:	Water Quality Workshop Report	203
Appendix 21:	In-depth literature survey on detergents	209

List of Tables

Table 1:	Aims, objectives and methods of the study	10
Table 2:	Main land-use in the study upper-middle Kat River	40
Table 5:	Aims, methods, and methods and techniques	52
Table 6:	Substances which are general indicators of water quality	74
Table 7:	Water Quality Analytical Kits against the Spectroquant SQ 118 results	75
Table 8:	High Flow period mean loads of the selected water quality variables in the study area	91
Table 9:	Low Flow period mean loads of selected water quality variables in the study area	91
Table 10:	Results of the upstream walk along the Hertzog stream	112
Table 11:	Water quality condition at Site 1	117
Table 12	Water quality condition at Site 2	120
Table 13	Water quality condition at Site 3	122
Table 14	Water quality condition at Site 4	124
Table 15	Water quality condition at Site 5	126
Table 16	Water quality condition at Site 6	128
Table 17	Water quality condition at Site 7	129
Table 18	Water quality condition at Site 8	131
Table 19	Water quality condition at Site 9	132
Table 20	Water quality condition at Site 10	134
Table 21	Water quality condition at Site 11	136
Table 22	Water quality condition at Site 12	138

List of figures

Figure 1:	The study area	7
Figure 2:	Typical irrigation system and its environment	16
Figure 3:	Land-use categories in the upper Kat River area	41
Figure 4:	Average monthly income in the study area	44
Figure 5:	The most common kind of sanitation in the area	44
Figure 6:	Number of taps per community	45
Figure 7:	Frequency at which laundry is done by the community members in the study area per week	57
Figure 8:	The laundry frequency at home per week	57
Figure 9:	The frequency at which laundry is done at the river per week	57
Figure 10:	Family members doing washing in the study area	59
Figure 11:	The most commonly used laundry detergents in the area	59
Figure 12:	The frequency of detergents purchase in the study area per month	59
Figure 13:	The average consumption of laundry detergents per kilogram per village per month	60
Figure 14:	Number of people doing washing per time in the area	60
Figure 15:	Reasons for doing washing in groups	60
Figure 16:	The most commonly used places for laundry in the study area	62
Figure 17:	Other things washed at the river besides clothes in the area	62
Figure 18:	Impact of Omo washing powder on water quality – laboratory analysis of selected chemical variable of detergent solutions of increasing concentration	64
Figure 19:	The electrical conductivity trends in three washing sites	64

Figure 20:	Turbidity trends in three washing sites	65
Figure 21:	pH trends in three washing sites	65
Figure 22a:	Chloride concentrations in three washing sites	66
Figure 22b:	Nitrate concentrations in three washing sites	66
Figure 23:	Spatial dynamics of flow in the upper Kat River area	78
Figure 24:	Flows, turbidity and pH dynamics in the upper Kat River	79
Figure 25:	Spatial changes of turbidity in the upper Kat River	81
Figure 26:	Temporal turbidity variation in the upper Kat River	82
Figure 27:	Temporal turbidity changes in Balfour River	83
Figure 28:	Spatial pH changes in the upper Kat River	85
Figure 29:	Chloride, Total Dissolved Salts and Total Hardness trends in the upper Kat River area	87
Figure 30:	Spatial dynamics of chloride in the upper Kat River area	88
Figure 31:	Temporal chloride trends in the upper Kat River	89
Figure 32:	Temporal chloride trends in the Balfour River	90
Figure 33:	Spatial changes of Electrical Conductivity (EC) in the upper Kat River area	94
Figure 34:	Total hardness spatial variation in the upper Kat River area	97
Figure 35:	Temporal total hardness (calcium carbonate) trends in the upper Kat River	98
Figure 36:	Total hardness (calcium carbonate) temporal trends in the Balfour River	99
Figure 37:	Nitrate, ammonium and faecal coliform trends in the upper Kat River area	101
Figure 38:	Spatial variation of nitrate in the upper Kat River	102
Figure 39:	Nitrate temporal trends in the upper Kat River	103
Figure 40:	Temporal nitrate trends in the Balfour River	104
Figure 41:	Ammonium in the upper Kat River	106

Figure 42:	Ammonium in the Balfour River	107
Figure 43:	Faecal coliforms spatial dynamics in the upper Kat River	109
Figure 44:	Temporal faecal coliform trends in the upper Kat River	110
Figure 45:	Temporal coliforms temporal dynamics in the Balfour River	111

List of plates

Plate 1:	Cropland on the river banks of the Kat River	38
Plate 2:	Intensive grazing in the study area	38
Plate 3:	Close proximity of settlements and croplands to the Kat River	38
Plate 4:	One of the rural villages in the upper Kat River area	39
Plate 5:	Commercial Forestry in the upper Kat River catchment	39
Plate 6:	A typical village layout in the study area	42
Plate 7:	Some of the prominent features found in a rural area in the Kat River area	43
Plate 8:	The most common kind of sanitation (pit latrine) and its close proximity to the river in the study area	46
Plate 9:	Most popular washing place in the area	61

Chapter 1

General introduction

1.1 Introduction

It is well known and accepted that the adequate supply of fresh and clean drinking water is a basic need of all human beings (WHO, 2001, Edugreen, 2001, DWAF, 1993). However, it has been observed that millions of people globally are deprived of this right (Edugreen, 2001). The WHO (2001) reveals that the majority of the global population does not have continuous access to clean piped water. It is estimated that at present, more than 1.2 billion people in developing nations do not have access to safe water (Corum and Everett, 2001). Eketeh *et al*.,, (1998) claims that 50 percent of the world's population does not have access to safe drinking water.

It is known that urban areas generally have better access to good quality water than rural areas, partly because people in urban areas on average earn higher incomes and, therefore, can better afford to pay for the services than can their rural counterparts (Edugreen, 2001). For 80 percent of rural families globally, untreated river or ground water is the only available water (Children's Water Fund, 2001). According to DWAF (2000), Black South Africans suffer by far the highest infant mortality and water-related diseases rates in all of Africa in relation to per capita GDP. DWAF (2000) blames this condition on minimal access to water. DWAF (2000) reveals that South Africa is one the twelve most lethal countries in the world as indicated by its infant mortality rate, largely because of water-borne diseases. This is not surprising if one considers that 18 million people in South Africa do not have a basic supply of water (DWAF, 2000). The present government is attempting to rectify the situation through a number of programmes. The Manickavasagan (1996) advises that improvements in water quality and sanitation services are crucial factors in reducing poverty and improving the quality of life.

River and ground water in rural areas is susceptible to impacts from several pollutants. Likely water pollutants in rural areas include sewage, decomposing organic matter, pathogenic agents and agricultural pollutants comprising fertilizers and pesticides (Aggarwal, 2001). The origins of such pollutants include the deliberate dumping of waste materials in water systems and the consequences of human activities like the chemicals from agriculture. Bleuten (1989) holds the opinion that quantified information regarding all sources of pollutants is crucial if water quality is to improve.

In South Africa, this situation of the unavailability of good quality water to the poor rural communities was worsened by the deliberate neglect of the former Black rural areas by the apartheid government. According to DWAF (2000), 73 percent of South African households do not have tap water in their homes and more than 18 million people in South Africa do not have a basic water supply.

A growing concern in third world rural areas is an increase in waterborne diseases. Where water is collected from unprotected sources, risks to individuals of being infected by waterborne diseases are likely to be highest (UNCED, 1992's Agenda 21). Hence people in rural areas are more vulnerable to water-borne disease risk than their urban counterparts where a reticulated supply is available. In this way diseases like cholera are more prevalent in rural than urban areas.

A number of authors have observed that rural land-use and related activities contribute significantly to the pollution of surface and groundwater in these areas (Bleuten, 1989; DWAF, 2000; Pretorius. 2000; Calvo, 1990, Jennings and Sneed, 1996 etc). Goudie (1981) emphasises the role which human settlements play in the types and amounts of pollutants delivered to the river system.

Rural areas in Third World countries are underdeveloped. One of the main features of underdeveloped settlements is a lack of the proper sanitation facilities. A study by Pretorius (2000) demonstrated strong correlations between the main sanitation levels in Klein Modder sub-catchment in the Free State province of South Africa and the levels of microbiological pollution emanating from the catchment.

Domestic animal kraals are an inseparable feature of most rural households. Walker *et al.,* (1998) identified domesticated animal wastes as one of the most prominent non-point sources of acutely toxic microorganisms. They based their argument on the earlier works by Ellis and McCalla (1978); Reddy *et al.,* (1981) and Mawdsley *et al.,* (1995) who indicated domesticated animal wastes as the likely source of pathogenic bacteria, enteric viruses and parasitic protozoa. These trends were confirmed by the work of Conrad *et al.,* (1999) who put manure in the top three of listed pollutants which contaminate groundwater, (the other two being sludge and soil biota).

Walker *et al.,* (1998) also referred to the work of Sandery *et al.,* (1996) who detected microorganisms found in animal wastes in natural waters. During wet periods, faecal loads are swept into the river courses, adding loads of organic matter and nutrients into the river system. More often than not, pathogens can be part of that faecal load (Davies and Day, 1998). Davies and Day (1998) list three consequences of organic pollution of water bodies, which are as follows:

- De-oxygenation of river water resulting from the consumption of oxygen during the decomposition of organic matter. Consequently, the aquatic community structure may be significantly affected as this situation encourages the flourishing of hard species, and eliminates the sensitive ones.

- As a consequence of the nutrient enrichment, surface water bodies may be eutrophicated.

The study by Conrad *et al.*, (1999) found nitrate concentrations as high as 268 mg/l were found in the sludge-contaminated groundwater.

- The introduction of pathogens into water increases chances of water users of being infected by the waterborne diseases.

Walker *et al.*, (1998) report that water contaminated with the protozoan parasite, *Cryptosporidum parvum,* found in domestic animal waste in Milwaukee, Wilconsin, infected approximately 400 000 people in 1993. In many rural parts of KwaZulu-Natal, South Africa, between August 2000 and March 27th, 2001 more than 70 000 cases of cholera have been reported. Consequently, some 161 people have since died. (WHO, 2001).

1.2 Introducing the target research communities

1.2.1 *Selecting the target communities*

It has been observed that most water quality investigations have tended to focus on urban areas. This trend is not only observed in South Africa, but globally. There is little work documented on the impact of Black rural land-use and land-use related activities on water quality. It would appear that little is known about the field in South Africa. This study aims to make a contribution in that regard. Rural communities were therefore selected for the study.

During the country's past, certain population groups enjoyed benefits to the detriment of other population groups. Black communities were the most affected. Of particular relevance to this study is the fact that, most of these communities were deprived of access to a reticulated and developed water supply. The South African Water Act of 1956 in DWAF (1999) linked water rights to land rights whereby one had an absolute control over all water arising from the ownership of land. More often than not, such land was allocated to the White farmers. Other population groups retained communal rather than private ownership of land thereby not having any access to water. Thus, more often than not, most Black communities had to be content with whatever water they could get, irrespective of the quality. Consequently, WHO (2001) observed that the fatal outbreaks of water-borne and water related diseases were not uncommon in these areas.

If one considers the picture portrayed by DWAF (2000) that Black rural South Africans experience the highest water related illnesses in all of Africa, it is apparent that the Black people of South Africa are in a water quality crisis. Bleuten (1989) has advised that for water quality to improve, quantified information of all kinds of inputs is required and it is the aim of this study to provide quantified information on the subject of the water quality impacts of selected rural Black communities' land-use and related activities.

This study was also linked to a larger global corporation report on rural domestic washing patterns in the study area (Chapter 3). The company was interested in knowing the impact of direct in-stream washing on the quality of water. Specifically, the company was interested in quantifying the impact of direct input of detergents on water quality. Waste-water in urban areas reaches surface water bodies via sewage treatment effluents. This includes water with detergents. In rural areas however, there are no sewage works and most waste-water (as reported in chapter 3) enters the surface waters directly.

The upper Kat River area was selected as the study area for this thesis for a number of reasons including the following:

- Compared to other local catchments, the Kat River has fewer complexities for research. For example, the Buffalo River could not be selected because of the input of pollutants by industry and large firms that are located on several points along the catchment. The Great Fish River is impacted by several towns, and can therefore not be characterised as a rural catchment. There are very few river-using communities in the Great Fish River. There are also no obvious Black communities along the Great Fish River who would be using the river for laundry. The Keiskamma River has difficult topography with deeply incised dongas, and accessibility to the catchment is therefore difficult.

- The primary aim of the study was to assess the impact of land-use, and related activities of rural village communities, on water quality. For this aim to be achieved, good relations with communities in the study area had to be established. The task of determining the impact of rural land-use and related activities on the quality of water could never be complete without involving the communities concerned. Methods for interacting with the communities are known to be notoriously difficult, and can take a long time to accomplish (Motteux, 2001). The community work that has been done in the upper Kat River (Nel and Hill, 1996; Nel and Motteux 1999; Magni and Motteux, 2000 and Motteux, 2001) has resulted in rural communities that are informed and readily accessible.

- A pilot water quality study carried out earlier in the area identified concerns about the quality of river water in the area, which this study addresses in more detail.

- The communities of the study area noted the Kat River's poor water quality during a series of capacity building workshops conducted in the area (Motteux, 2001). Communities again echoed these water quality concerns during the interviews conducted in the study area. Considering that most communities in the study area are dependent on the river water for all or most of their water needs, these concerns could not be ignored.

This study has established that the majority of communities in the Kat River valley do not have access to safe and clean drinking water. They often rely on the river for their water needs. Such needs include domestic uses such as drinking, cooking, washing, doing laundry. The communities also often find themselves affected by the use of the river by domestic stock. Moreover, intensive agriculture in the area also demands its share of river water for irrigation and domestic animal watering. Besides the fact that water quantities are not enough, during dry periods the water quality in the study area may become critical as some water quality variables may reach life threatening concentration levels. In such circumstances, a water quality study is useful in informing the water quality managers about these periods of critical water quality for the better management of either the land-use activities or for the regulation of dam water to keep the flows reasonable so as to prevent the situation of elevated levels of certain water elements in the low flow period.

Based on the literature evidence given above and in Chapters 2, 3, and 4, and the situation in the study area stated above, it was speculated that the quality of surface water in the area is impacted upon by the land-use and related activities. Since this study aims to examine that impact a detailed description of the major land-use in the area is presented in Chapter 2.

Washing practices in the study area have been selected as a land-use related activity of primary focus in the study for a number of reasons, including the following:

- The impact of detergents entering the surface water bodies via treated sewage effluent has been well documented, but little is known of the side effects of the input of raw detergent into water systems. An international detergent manufacturing company commissioned this section of the study towards its intention of establishing the impact of the direct input of detergents to the surface water, which is what is happening during the in-stream washing,
- The time frame of the study and other constraints could not allow that all the land-use related activities to be studied in detail.

A report of the study of the description of washing practices, selective chemical variables of Omo® washing powder and the study of the actual washing activity are presented in Chapter 3.

Other land-use impacts were inferred indirectly from water quality monitoring data that were collected over a 42 weeks period on a fortnightly frequency. A water quality monitoring report is given in Chapters 4 and 5. A discussion concluding the work is presented in Chapter 6.

1.3 Study area

1.3.1 Biophysical characteristics of the study area compiled from Motteux, 2000; Schoombe et al.,, 1997; Barratt, 1998 and Geological Map of Southern Africa, 1970)

Figure 1 illustrates the study area. The climate of the study area is mild. Summer temperatures vary between 20^0C and 35^0C . Winter temperatures vary between 0^0C and 20^0C. Annual average rainfall of the study area is 400mm in the immediate vicinity of Fort Beaufort and 1200mm in the upper Kat River area. The area receives most of its rainfall in the October/November and February/March periods. Rainfall received in the study area varies between low intensity-long duration and high intensity- short duration types. The area is also characterised by great variability of rainfall.

The altitude in the area ranges between 1600 metres at the source of the Kat River, which is the top of the escarpment, and 600 metres at the confluence with the Fish River. The river valleys are deeply incised, and characterised by narrow alluvial terraces bordering the river. The vegetation is largely of the valley bushveld and river thicket type, although, at high altitudes, pockets of Afro-montane forest and grassland vegetation are evident.

The study area's geology forms part of the Beaufort series of the Karoo system. It belongs to the Molteno, Red Bed and Cave Sandstone Stages. Dominant rocks include shale, mudstone, sandstone, and limestone. Geology affects the quality of water resources in a number of ways. These include the following:

- Geology affects the rate at which the river erodes and transports material along its course. In turn, erosion determines the amount of sediment transported by the river, and hence its turbidity.
- The type of rock structure over which the river flows may be one of the major sources of salts in many river systems.

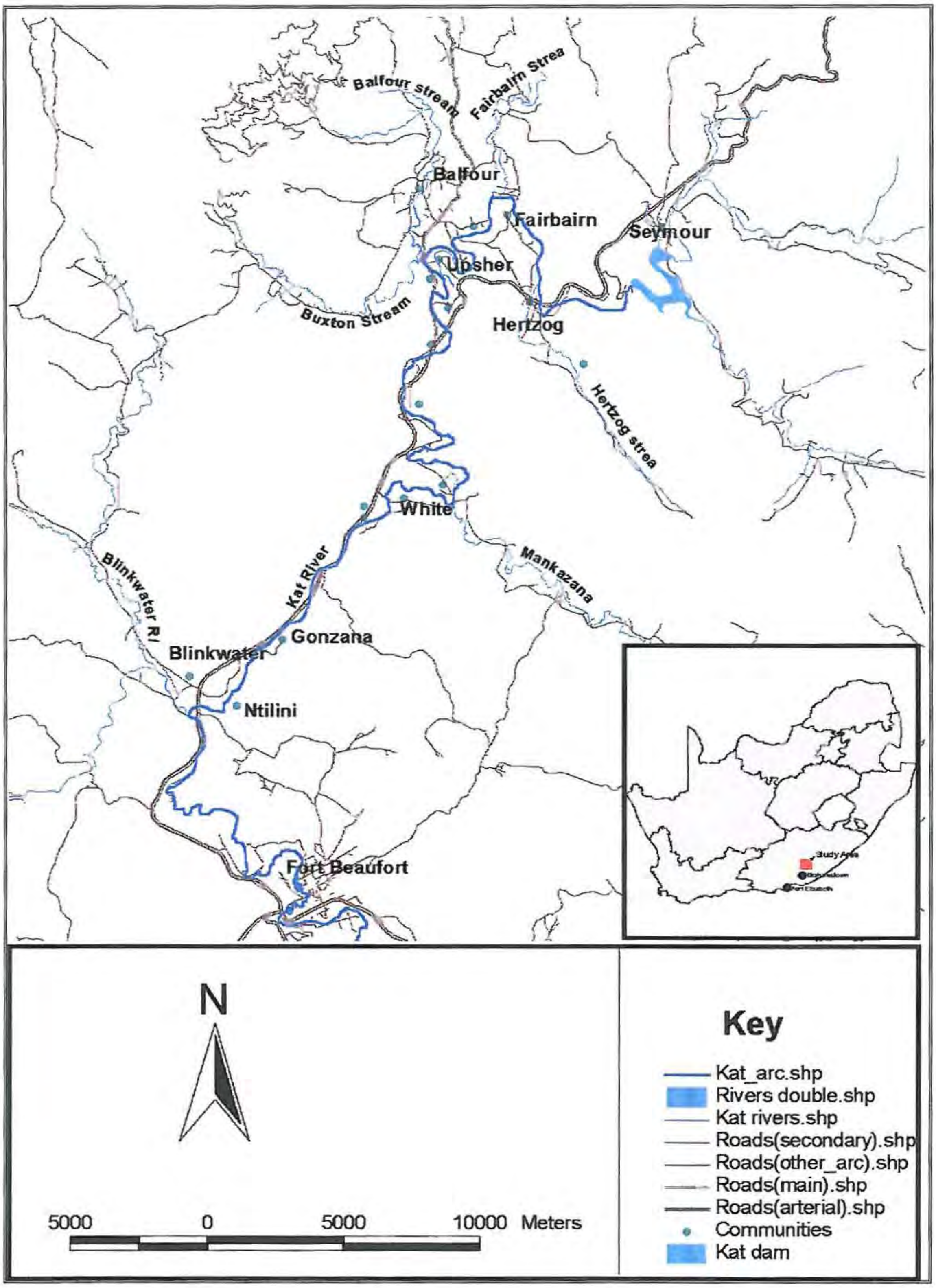

Figure 1: The study area

1.3.2 *Historical background to the study area*

Figure 1 shows all communities involved in the study with an inset showing the upper Kat River area in the context of South Africa. The area is in the mid-reaches of the Kat River. Most of the area belonged to the former Ciskei homeland government. According to the Water Research Commission (WRC, 1997) this area falls into the Tsitsikama and Fish River Water Management Area. The Kat River falls within the primary catchment of the Fish River.

The farmlands in the area were used by White and 'Coloured' farmers, with tobacco, potatoes and citrus being the main agricultural products till the 1970s. The reliable flow of the Kat River, regulated by a dam since the 1970s, and fertile valley soils encouraged the practice of successful intensive irrigation farming (Motteux, 1999). The transference of the land to the Ciskei government led to the migration of White and Coloured communities out of the area. As a result, African populations were adversely affected economically, as they were marginalized. They lost their jobs, and were also denied access to any means of production in the area (Nel and Hill, 1996).

According to Nkayi (pers. com., 2000), the government para-statal, Ulimcor took up some ex-white farms to provide farming assistance to support interested farmers in the Kat River. Some farms were transferred to some farmers to manage. Only the these farm managers had the rights to use the land. According to Nel and Motteux (1999), some lands currently lie open with no land tenure. The exception in this instance is the Fairbairn area, in which some land has been privately owned since early 1900s. Part of the area was never transferred to the former Ciskei homeland, and has been under the commercial citrus farmers for generations (Roberts pers. com., 2000).

1.3.3 Service centres

In the former Ciskei area the town of Seymour and the semi-rural Balfour centre are the service centres. These are currently small, impoverished centres, suffering from a legacy of disinvestments, economic collapse, lack of political interest and endemic poverty (Nel and Motteux, 1999). In the remaining part of the study area, Fort Beaufort is the main service centre.

1.4 Land-use in the study area

Figure 3 in Chapter 2 shows all the major land-use activities in the study area. A full description of land-use and related activities in the upper Kat River area is given in Chapter 2. Most land in the valley bottom terraces is utilised for intensive crop farming purposes. HACOP Cooperate farming activities dominates the Fairbairn, and Hertzog areas. Citrus farming is mainly found in the middle Kat River valley, from the Upsher community to below the town of Fort Beaufort. Citrus farmers own the lands they are farming, but in most parts land is owned by the State but is occupied communally. Commercial Forestry is being practised in the upper Buxton River catchement. Mpofu Nature Reserve covers most of the middle BlinkWater River valley.

1.5 General water quality issues in the study area

Most communities along the Kat River do not have access to clean and safe drinking water, and do not have piped water to their homes. Consequently, they rely on the river for their water needs. Pit latrines are often located upstream of where people draw their drinking water. Domestic and wild animals can often been seen either feeding along, or drinking from the river. Human faeces are not an uncommon sight along the stream throughout the catchment. Other forms of waste, particularly domestic, are also evident throughout the catchment.

Whilst the impact of all the above-mentioned pollutants on water quality is acknowledged, it is often the effect of the chemicals from the rural land-use practices that cause concern (Dallas *et al*, 1994). Besides consuming significant volumes of water through irrigation, intensive agriculture in the area also relies on use of chemicals such as fertilisers and pesticides, which are often washed into the streams via overland flow during wet seasons. Oil and diesel often spill into the river from the water pump engines located by the river and contribute to water quality concerns in the area.

The practice of doing laundry in the river, which is common throughout the study area, adds volumes of raw detergent into the river. It is well known that detergents have the potential to negatively affect the aquatic ecosystems (Cairns *et al*,1971; Maki and Bishop, 1979; McCormick *et al*, 1991; Dorn *et al*, 1993; Sherrard *et al*, 1996; Cano and Dorn, 1996; Madsen and Kristensen, 1996; Versteeg *et al*, 1996; Yamagishi *et al*, 1998; Tolls *et al*, 1999; Feitjel *et al*, 1999). One aim of this study was to contribute to an understanding of the specific problem posed by the in-stream use of detergents. Aims and objectives of the study therefore are:

1.6 Aims and objectives of the study

1.6.1 Aims

The following are the broad aims of the study:

- To study the impact of the Black village communities and their associated land use practices on water quality of the Kat River.
- Specifically, to assess the impact of detergent use during in-stream washing on water quality.

1.6.2 Objectives

The following have been identified as the primary objectives of the study:

- to determine the land-use and related activities in the selected villages,
- to describe the washing practices and patterns in the study area,
- to monitor water quality in relation to land-use,
- to assess the health impacts of poor water on water users

- to determine the impact of water quality on the health and welfare of the water user communities,
- in partnership with the communities, make recommendations as to how to improve water quality.

Table 1: Aims, objectives and methods of the study

Aim	Objective	Method
to study the impact of Black village communities and their associated land-use practices on	to determine the land-use and related activities in the selected villages	use of maps of the study area
		use of orthophoto maps
		field visits
		a water quality workshop
		the Global Positioning System (GPS)
		GIS
		literature survey
		use of orthophoto maps
		field visits
to assess the impact of detergent use during in-stream washing on water quality water quality,	to describe the washing practices and patterns in the study area.	a questionnaire survey
		laboratory analysis of the detergent solutions
		Structured interviews
		GPS
		on-site water quality analysis whilst washing is in progress
	to monitor water quality in relation to land-use	collection of water samples from certain pre-determined points along the course of the river
		field and laboratory analysis of these samples
	to assess the health impacts of poor water on water users	water quality workshop
		measuring water quality results against WHO's and DWAF's guidelines
	make recommendations as to how to improve water quality.	water quality workshop

1.7 Structure of the thesis

After this general introduction (Chapter 1), a detailed account of the study of land-use and related activities in the area is given (Chapter 2). This chapter is followed by a chapter aiming to describe the washing practices in the area (Chapter 3). A report of the water quality-monitoring programme carried out in the area is outlined in Chapter 4 and its discussion is presented in Chapter 5. The studies of land-use and related activities; descriptions of the washing practices and patterns and the quality of water in the area are then integrated in a concluding discussion chapter (Chapter 6). Relevant literature survey, methods and results will be presented separately for each component.

Chapter 2
Land-use and related activities

2.1 Introduction

Land and water need to be managed together. Although many authors promote the concept of Integrated Catchment Management (DWAF, 1996; Rowntree, 1995; DWAF, 1995, 1998, 2000; Motteux, 2001), land and water resources are usually managed separately from each other. The managers of these two natural resources seem to be unwilling to face the complexities of integrated management and are comfortable with independent land and water management. This perception seems to be a global one, as is obvious from Agenda 21 (UNCED, 2001), (widely acknowledged as a blue-print document for the management of global natural resources), wherein the management of land and water resources is addressed from totally different perspectives. This perception is a serious limitation in the management of natural resources as the two resources are interdependent. For example, many land-uses and related activities are entirely dependent on the availability of water of acceptable quantity and quality. The use of land in turn has a major impact on water resources (DWAF, 1997). DWAF, 1997: p19 proclaims that "almost every activity which takes place on land affects our water resources in some way".

DWAF (1995) has established that land-use may affect the quantity of water flowing in the rivers in two ways:

- Any land-use activity that reduces the infiltration rate of the rainwater may increase the potential of flooding.
- The abstraction of water for example, for irrigating crops may also reduce the amount of water flowing into the rivers.

It is however imperative to note that land-use not only affects the quantity, but also the quality of water in the streams (DWAF, 1995). Although both urban and rural land-use and related activities negatively impact on water quality, a serious concern for the latter is the lack of clean piped water. This implies that the rural water users have to consume the very water they pollute, thereby exposing themselves to high risk of being infected by waterborne diseases. The World Health Organisation has rated waterborne diseases the number one killer of children in the developing parts of the globe (WHO, 1998) because of the recent noted increases in waterborne diseases (Jennings and Sneed, 1996). Cloete and Venter (2001) claim that a recent cholera outbreak in South Africa is part of an ongoing global pandemic. A realisation that many rural communities in South Africa are consuming untreated polluted water and thus exposing themselves to waterborne diseases is one of the reasons why the aspect of the effect of land-use, specifically in rural areas on water quality is central, to this study.

The land-uses that have been found to be prominent in the upper Kat River area can be divided into two categories:

- regional catchment land-use which include forestry, wildlife management, settlements and agricultural practices
- local catchment land-use and related activities including crop fields, grazing lands, animal kraals, pit latrines and laundry.

Various uses of land could have a marked negative impact on the quality of water of rural areas. The first section aims to explore the potential impact of these different land-uses and related activities on water quality based on a review of literature. The impact of rural settlements on water quality is outlined in this chapter. The prominent land-use related activities which will be discussed in this chapter include agricultural activities such as irrigation of crops, the use and application of agro-chemicals such as pesticides and fertilisers, watering of domestic animals, and in-stream laundry washing. The impact of forestry plantations is also discussed in this chapter. Also, a section exploring the impact of polluted water on health and welfare of communities as well as on aquatic organisms is presented. A discussion of certain physical, biological, process related and the physio-chemical water quality variables is presented. Results of major land-uses in the area are also presented.

2.2 Impact of different land-uses and related activities on river water quality

Chapter 18 of Agenda 21 (UNCED, 1992) lists the following rural land-use activities as the primary causes of poor river and lake water quality:

- poor sanitation services,
- deforestation,
- uncontrolled shifting cultivation,
- poor agricultural practices.

Whilst one cannot by any means underrate the impact of each of the above-mentioned factors on water quality, the WHO (1998) warns of the effects of too much generalisation. It is crucial to acknowledge that each area is unique as some of these factors may not be applicable to some environments. For example, in the study area, only two of the above are applicable. These are: poor sanitation services and poor agricultural practices. Although the water quality effect of the clearance of natural vegetation for the human settlement development and other purposes is discussed in Section 1.1 of Chapter 1, deforestation is not a common practice in the study area and therefore its impact is not likely to be apparent. Forestry plantations are however important in the upper parts of the catchment. Hence, the likely impacts of forestry plantations are outlined. The effect of agricultural practices and rural settlements and poor sanitation services are then discussed in more detail.

2.2.1 Forestry plantations

There have been growing concerns on the impact of forestry on the quantity of in-stream water, particularly because often plantations trees are alien to their host surrounding environment and they thus often consume more water than their indigenous counterparts. Thus, in areas where forestry plantations are dominant, particularly in the upper catchment areas, in-stream flow of water is noticeably reduced. (DWAF, 1995).

Little work has been done, however, on the impact of forestry on water quality. Large scale afforestation has been dominating land use in the United Kingdom (UK) upland area. Concerns regarding the possible impacts of the land use change on the water chemistry of streams flowing through the area have been growing (Reynolds *et al.,*, 1986). Work undertaken earlier by Stoner *et al.,*, (1985) and Reynolds *et al.,*, (1986) in the forested area have reported increased acidity compared to the adjacent catchments flowing through grassland area. Stoner and Gee (1985) have related such changes in the afforested catchments to freshwater invertebrates and fish community alterations. The study by Reynolds *et al.,*, (1986) compares the concentrations of major ions in streams draining afforested area and the adjacent grassland catchments in mid Wales.

The study discovered that sodium and chloride were the main ions of stream water accounting for approximately 52 percent and 60 percent of cation and anion totals respectively. The study showed that concentrations of all major water quality variables, except potassium, were higher in forestry catchments compared to their respective grasslands counterparts. The forested catchment stream-flow acidity was at least 1.5 to 4 times higher.

Forestry plantations also contribute volumes of organic matter into the streams. These materials are then decomposed or oxidised through oxygen dependent biological processes that break down organic matter (Kruger, 1992), resulting in reduced oxygen concentrations. Al-Layla and Al-Rizzo (1989) observed that the biological oxygen demand (BOD) in the Tigris River in Iraq was gradually decreasing downstream of the Saddam dam. This phenomenon could be attributed to the natural self-purification of the river as the organic matter in the water is being extracted biologically. This explanation has confirmed the findings of Velz (1970) that the extraction of the organic matter on streams significantly reduces BOD.

2.2.2 Effect of rural agricultural practices on the quality of water

According to Barlow (1999), the rate at which water is consumed globally is doubling every twenty years. This increase in consumption of water is mainly due to rapid population growth as well as the overall increase in the *per capita* use of water. Continuing increases in the population growth, with related consequences for food production and an increase in a number of countries and individuals striving for better living conditions, will undoubtedly increase future demands on water resources. More water is being extracted to support increasing population through intensive agriculture and other activities. The consequence of this is a growing threat to the world's water resources, especially in rural areas as more and more water is being polluted by man's activities (Velz, 1970).

Falkenmark (1997) points out that the global population is growing at a rate of 90 million each year. She seem to agree with Kundzewicz (1997) that the rapid population growth impacts on global food needs, and hence agricultural practices as greater volumes of food need to be produced to keep pace with the rate at which the population grows. Unfortunately, this implies more and more dependence of the agricultural sector on chemicals that are already threatening the health of aquatic ecosystems. The whole issue of global food security is closely linked to the availability of water. As the United Nations Food and Agriculture (FAO), in its 1996 report puts it, additional water available for irrigation limits the possibility of self-sufficiency in many global regions. Agriculture is water dependent and the availability of water also largely depends on availability or lack of vegetation cover (Szesztay, 1994).

A study by Calvo (1990) indicated that the quality of water in the rural areas of Costa Rica was increasingly deteriorating. It was observed that human activities were introducing volumes of pollutants into the aquatic environments. Such pollutants included physical pollution, chemicals, saline intrusion, bacteria, and agro-chemicals. The author established a link between the areas of general intensive agriculture, particularly where agro-chemicals were intensively used, and the deterioration of the aquatic environment. The study blamed the lack of experience among the farmers, and inadequate water laws, as the primary contributing factors on the impact of agricultural practices on the deterioration of water quality.

In arid, irrigation-dependent agricultural regions, and also where hydrology is characterised by the movement of irrigation water through groundwater shallow systems to rivers, nitrate loading is a concern. This is so mainly because flow in these catchments is maintained by groundwater seepage during much of the year (McMahon and Bohlke, 1996). Chourasia and Tellam (1992) listed a number of processes that are associated with surface irrigation that might be involved in modifying the groundwater. These include:

- fertiliser dissolution would mainly contribute SO_4, Na^+, K^+, NO_3, and Ca^{++} to the irrigation waters,
- evaporation and transpiration would result in an increase in all variables except Ca^{++} and HCO_3^- values which might be truncated by calcite precipitation,
- mixing with existing groundwater is likely to occur after fertiliser has been applied and evapo-transpiration has occurred,

- mixing of average surface water with groundwater would dilute groundwater in all determinants except K^+.
- ion exchange would result if the added irrigation waters, after being subject to the previous processes, gave rise to a cation ratio different from the existing groundwater's,
- mineral dissolution is also possible.

Chourasia and Tellam (1992) revealed that it is difficult to assess the long term impacts of irrigation on water quality, particularly groundwater. This finding was echoed by Pearce and Schumann (1997 – p ii), when they pointed out that "in newly founded irrigation areas, a period of stabilisation should be allowed…". Chourasia and Tellam (1992) warn of the possible consequential problems including the build up of agro-chemicals and noticeable increases in concentrations of dissolved substances as a result of evapo-transpiration.

Improper irrigation causes a number of potentially undesirable impacts on the environment, including salinisation (Figure 2).

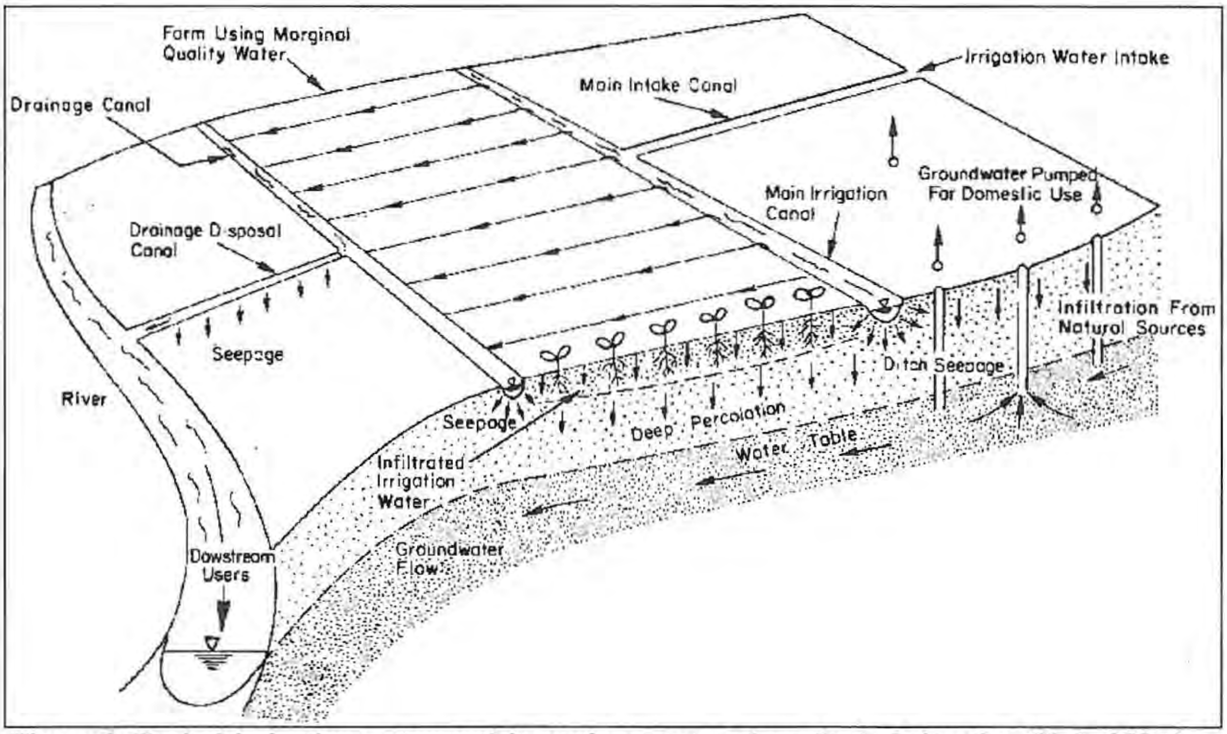

Figure 2: Typical irrigation system and its environment - a hypothetical situation (United Nations Food and Agriculture Organisation (FAO, 1996).

The following observations from Figure 2 are apparent:

- on-farm deep-percolation and seepage of drainage water from the collector and disposal drains within the project has caused water-logging and salinisation in an area just below the project due to the build-up of a shallow water table,
- salts and agro-chemicals have polluted the stream water into which drainage from irrigated field is discharged to the point that it can no longer be used for domestic purposes,
- the content of salts, nitrates, selenium, boron, pesticides and some agro-chemicals is extremely high in groundwater below the irrigated land because the sub-surface drains do not fully intercept the downward flow of percolated water from the irrigated land,
- consequently, groundwater is a potential health hazard to those using it for domestic purposes.
- noticeable undesirable changes in the extent and composition of riparian vegetation has been attributed to waterlogging and salinisation, and change in riparian vegetation by implication results in changes in wildlife population. (United Nations Food And Agriculture Organisation (FAO, 1996).

The concerns of Chourasia and Tellam (1992) regarding groundwater pollution by agro-chemicals were confirmed in a study by Rao (1998), who discovered that the contamination of the groundwater by nitrate due to the widespread intensive use of fertilisers has become a serious ecological problem in many rural catchments of India, and in developing nations worldwide. A study by Walter *et al.*,, (1975) demonstrates that nitrogenous fertilisers, once applied, are converted to the mobile nitrates by natural processes, irrespective of their form and composition. Reports that fertiliser contributes from as little as 3 mg l^{-1} to as much as 1800 mg l^{-1} nitrate to the groundwater have been documented by many researchers (Kondratas and Mikalauskas, 1973; Malik and Banergi, 1981; Handa, 1989; Sankaranarayana *et al.*,, 1989; Sehgal *et al.*,, 1989; Bulusu and Pande, 1990; Mehta *et al.*,, 1990; Hamilton and Mikalauskas, 1992; Klimas and Paukstys, 1993; Kolpin *et al.*,, 1994).

DWAF (1995) illustrates that the main water quality challenges facing developed and developing countries are clearly different. Whilst the former suffer mainly from the problems of chemical discharge, the latter face problems of agricultural run-off into water sources (Jennings and Sneed, 1996). For example, in a study of the Tigris River catchment, Al-Layla and Al-Rizzo (1989) realised that ammonia-N concentrations were gradually increasing downstream. This phenomenon was attributed to the impact of the return flow from the agricultural lands distributed along the reaches. The high levels of ammonia-N found in water was blamed on the excessive use of ammonia fertilisers (Anderson and Darcup, 1976), whilst Wild and Crocket (1971) suggested that the decaying of organic-N to ammonia-N may increase ammonia-N concentrations significantly.

In contrast, nitrite concentrations were found to be decreasing downstream in the Tigris River. Al-Layla and Al-Rizzo (1989) futher noticed a gradual downstream increase in nitrate concentration. The authors related this phenomenon to the considerable amounts of nitrate provided through agricultural return flows. Lornezen and Chen (1977) earlier pointed out that the other contributing factor to the raised levels of nitrate could be the presence of nitrite which converts to nitrate, which in turn does not decay to any significant extent under aerobic conditions. Anderson and Darcup (1976) earlier pointed out that this phenomenon is the consequence of oxidation of nitrite to nitrate. O'Connor and Connoly (1980) listed the following factors which determine the levels of nitrate in water:

- the rate at which nitrification process occurs,
- the rate at which nitrate is assimilated / consumed by the aquatic plants,
- the extent at which ion exchange occurs between nitrate and benthic sediments,
- the presence and extent of the flow from the area of intense agriculture.

It would appear that the other noted source of nitrate are domestic animals. Conrad *et al.*, 1999: 4.48 observed high levels of nitrate and potassium in groundwater underlying an area close to an intensively used trough and gate which had a high loading of manure and no grass cover. These results confirmed the findings of work by Rao (1998: 708) that "the high concentrations of nitrate reaching as high as 324 mg l^{-1} are associated with cattle barns, where a large number of animals are kept in relatively small area". According to Rao (1998) such places can be treated as the point sources of nitrate. Though nitrogenous fertilisers are adding nitrate into the groundwater, point sources are the major contributors of nitrate. Further, the nitrate pollution from animal excrement and urine can be observed daily at the point sources, while the nitrate from fertilisers is mainly seasonal.

A report to the Water Research Commission on the assessment of the impact of agricultural practices on the quality of groundwater resources in South Africa by Conrad *et al.,* (1999) highlighted that some degree of contamination from animal waste was apparent when the analyses of groundwater samples were done. They compared the samples of groundwater taken from an area of bush which is reportedly not formally used for agricultural purposes (control sample), to those collected from groundwater underlying an area close to an intensively used trough and gate which has a high loading of manure and no grass cover. Only faecal coliform bacteria were found in the control samples, whilst samples from the intensively used trough besides the high count of faecal coliform, an elevated nitrate concentration was observed. They suggested the informal livestock grazing in the area as a possible source of the bacteria. Conrad *et al.*, (1999) put manure on the top three list pollutants that contaminate groundwater, the other two being sludge and soil biota.

Al-Layla and Al-Rizzo (1989) showed that faecal coliforms were highest in a manure effluent irrigated area. Irrigation of manure effluent to pasture, congregation of cows near a feeding trough and in gate pasture resulting in piles of manure and destruction of grass cover, and the leaching of animal waste from the constructed channel were identified as the sources of these pollutants. These findings confirmed the findings of Bleuten (1989) that water quality is impacted through the excessive production of manure and application of agriculture via overland flow and groundwater.

Many authors including Ellis and McCalla (1978) and Reddy *et al.,* (1981) identified domestic animal wastes as one of the most prominent non-point sources of the acutely toxic micro-organisms. Their findings were confirmed later by Mawdsley *et al.,* (1995) and Walker *et al.,* (1998), who also pointed out that a number of pathogenic bacteria are found in domestic animal excreta. This discussion was presented in greater depth in Section 1.1 of Chapter 1.In Section 1.1 of Chapter 1, where it is illustrated that some authors like Sandery *et al.,* (1996) and Walker *et al.,* (1998) detected micro organisms found in animal wastes in natural waters. A study by Synge *et al.,*, (2001) established a link between the outbreak of waterborne *Verocytotoxigenic escherichia coli* 0157 (VTEC 0157) in the Scottish Islands and the grazing sheep in the area.

Al-Layla and Al-Rizzo (1989) also noticed that phosphate concentrations decreased downstream in the Tigris River catchment. Noam (1985) explained that the source of phosphate is the wash-off of fertilisers from the agricultural areas. Organic matter was the other noted source of phosphate in the Tigris River. For example, it was observed that when soaked in water, the leaves of vegetables and grass cuttings produce high levels of phosphorus to the extent that these have been blamed for the high levels of phosphate found in urban storm water of Sydney, Australia (Cordery, 1977). Banks (1976) indicated that phosphate is removed from the aquatic environment through:

- the self purification process of the river,
- the uptake of phosphate by algae and zooplankton, and
- sorption to the bedrock sediments.

Al-Layla and Al-Rizzo (1989) also observed a downstream decreasing trend of coliform bacteria. This has been attributed to microbial self purification of the river. Banks (1976) reported the following major sources of faecal coliform bacteria:

- run-off discharge,
- agricultural return flows,
- swimming and animal bathing,
- excrements.

A downstream increasing trend of total hardness, TDS, sulphate, chloride and sodium was observed in the Tigris River. Banks (1976) points to the seepage of very hard water to the river as the primary source of hardness in water. Anderson and Darcup (1976) listed the following major sources of TDS, sulphate, chloride and sodium:

- agricultural return flows,
- run-off,
- dissolution of benthic sediments.

Jain *et al.,* (1998) conducted a study to assess the contribution of point and non point sources of pollution to the River Kali in western Uttar Pradesh (India). They observed that the average potassium content in the upstream section was 5.0mg l^{-1} , while in the downstream, it was 19.8 mg l^{-1}. This increase in potassium content may be attributed to the concentration of run-off from agricultural loads (potassic fertilisers) and waste effluents.

2.2.3 The impact of rural settlements and poor sanitation services in the quality of water

DWAF (1995) warns of the elevated levels sediment in water courses associated with lack of vegetation to retard erosion in overgrazed areas. In Section 1.1 of Chapter 1 the three ways by means of which human settlements impact on the hydrology of the river environment are listed.

As stated in Section 1.1 of Chapter 1, rural areas in many parts of the globe are least developed and they thus do not have proper sanitation facilities. Judging by the level of develpment, it is speculated that most people in the study area lack proper sanitation facilities. Poor sanitation has been identified as one of the major causes of water quality deterioration in many rural streams. For example, a study by Leeming *et al.,*, (1997) indicated that the major cause of the deterioration in water quality and elevated nutrient loads in coastal and rural inland water courses is human and animal waste pollution. Some recent authors like Conrad *et al.,*, (1999) and Pretorius, (2000) have identified improper sanitation facilities like pit latrines and septic tanks as the major contributors of nutrients and pathogens in rural stream.

According to Crabtree *et al.,* (1986) discharging pollutants from rural domestic applications, agricultural, and other sources which are untreated could have both short and long term significant effects on quality of a river system. Toxic pesticides, herbicides, and fertilisers in the form of nitrates, phosphates and carbonated compounds that cause eutrophication get into water resources through farmland run-off (Kruger, 1992). During the wet period, surface run-off sweep both suspended and dissolved matter into the stream (Jain *et al.,*, 1998).

The phytoplankton blooms in the Vaal River-South Africa, were blamed on high levels of chloride, nitrogen and phosphorus. The increase in nutrient level of the Vaal River over years has been attributed the increase in population, the rise in living standard of the population, the increase in agricultural and industrial water demands and the rural uses, (Pieterse and van Vuuren,1997). A study carried out in on the Buffalo River identified water quality problems emanating mainly from the settlements of Zwelitsha and Mdantsane that had poor sanitation facilities. Particularly, salinity and faecal coliform levels reached unacceptable levels in the middle and lower reaches of the catchment. Eutrophication, with related nuisance algal blooms were also noted (O'Keeffe *et al.*,, 1996). The study carried out on the Vaalharts Irrigation Scheme in South Africa, realised that the salinity levels of the water supply had deteriorated since the scheme was commissioned in the mid 1930s. (Herold and Bailey 1996).

Although carried out in an urban setting, in their study of a settlement with limited sanitation and water supply services in Mamelodi, near Pretoria, Grabow *et al.*,, (1986) pointed out that the high number of coliforms and viruses in streams adjacent and below the settlement was perceived as an indication that diffuse effluents from the settlement were considerably polluting river water. A study by Lord and Mackay (1993: p5) carried out in Port Elizabeth implicated the informal settlements in and above the floodplain of the Chatty River to the severe pollution of the river's tributary. Lord and Mackay (1993) also suspected that an informal settlement of Brickfields is a likely source of pollution of the Swartkops River by virtue of the fact that there are no sanitation services provided to the people of the settlement. Results of the study also indicated that soon after the settlement of Motherwell was occupied, a continual flow of polluted run-off was observed. Particularly, runoff contained high nutrient contents as well as high levels of the faecal coliform bacteria. The well-developed residential areas of Redhouse, Zwartkops and Amsterdamhoek, also within a considerable distance from the Swartkops River, were observed to be less of a threat compared to the less developed areas (Lord and Mackay, 1993).

The outbreak of cholera in the underdeveloped rural areas of KwaZulu-Natal - South Africa, in August 2000 has been blamed on poor sanitation and lack of clean water. Between August 2000 and the March 27^{th} 2001, more than 70 000 cases of cholera were reported. Consequently, some 161 people have died during this period, (WHO, 2001). According to the World Health Organisation (1998), it was the outbreaks of such waterborne diseases like cholera and typhoid that drove the sanitary revolution of the 19^{th} century in Europe.

Sherman (1998) linked the high nitrate, ammonium and *E.coli* concentrations in two South African catchments to land-use such as pit latrines which she realised were established in close proximity to the water sources. Also affecting the quality of water in the area are the effluents from houses and farms not connected to a sewer system (Bleuten, 1989). Whilst Conrad *et al.*,, (1999) acknowledge the global contribution of the agricultural sector on diffuse contamination of groundwater, they argue that the problem is exacerbated by domestic point sources including septic tanks and pit latrines as well as disposal of household and agricultural waste materials.

Sanitation problems related to a lack of a reticulated sewage system are not confined to developing countries. In the USA, it is estimated that more than 20 million households use septic tanks to discharge about 2.55 trillion gallons of effluent annually. Septic tanks are known to be relatively safe and effective ways of disposing waste. When the system fails, however, the contamination of surface and groundwater may be the inevitable consequence, resulting in disagreeable odours. Human health problems like gastro-intestinal illness, dysentery, typhoid fever and hepatitis may also result. Moreover, septic discharges are known to contain extremely high nutrients levels, including nitrate and phosphate (Jensen and Gerston, 1986). These findings were confirmed by Jennings and Sneed (1996) who pointed out that septic tanks are amongst primary sources of nitrate into the rivers flowing through third world rural settlements. In most cases, surface and groundwater pollution by the septic tanks occurs in rural areas where these systems are unregulated (Jensen and Gerston, 1986).

McCarty and Semprini (1993) realised that other land-use related activities that impact on water quality include the use of chemicals like hydrocarbons and detergents during laundry. Aromatic hydrocarbons and chlorinated aliphatic hydrocarbons (CAHs) are among the most commonly found chemicals in groundwater. Many of the former are the more soluble components of gasoline, which include predominantly benzene toluene and ethyl benzene anyxylene. These chemicals enter aquatic environment via the hydrocarbon spills or leakage. The latter result from disposal of chlorinated solvents which have commonly been used throughout industry for degreasing. CAHs are thought to be recalcitrant (persist in aquatic environments and are hard to control and manage) (McCarty and Semprini 1993).

Detergents form an integral part of our daily lives. Because of their huge demand, detergents are manufactured on a large scale. In 1990, 840 million kilograms of nonionic surfactants were produced in the United States (Dorn *et al.,*, 1993). Detergents have elements in them known as surfactants, which have been proven to be toxic to aquatic ecosystems. The linear alkylbenzene sulfonate is one of the most common, reported to be in 50 percent of all washing agents in the Japanese market (Yamane *et al.,*, 1984). Alcohol ethoxylate is said to be the most important non-ionic surfactant, with its production amounting to 7×10^5 tons worldwide in 1996 (Tolls *et al.,*, 1999) One way or the other, detergents end up in water bodies. In most first world countries, detergents find their way into surface rivers via treated sewage. In most third world countries, however, as has been established in the study area (Chapter 3), in-stream washing is widely practised. Polluted water from this practice is poured directly into surface water bodies. This implies that detergents come into contact with surface water bodies without any prior treatment. Whilst the impact of the detergents that enter surface water bodies via sewage works on the aquatic ecosystem is well documented (Davies and Day, 1998; Schroder, 1995; Gerike *et al.*,, 1990; Hoffman and Bishop, 1994; Matthijs *et al.*,, 1995; Madsen and Kristensen, 1996; Cano and Dorn, 1996; Sherrard *et al.*,, 1996; Versteeg *et al.*,, 1996; Yamagishi *et al.*,, 1998; Feijtel *et al.*,,1999; Ahel and Giger 1985) little is known of the impacts of the direct input of detergents into surface water bodies. Chapter 3 of this study makes a contribution towards establishing this impact.

2.2.4 The impact of poor quality of water on the health and welfare of the user communities

Poor water quality has several implications for humans, most notably effects are on human health. The WHO (1984) reported that about 80 percent of all diseases in developing countries are water related, for example, malaria, diarrhoea, schistomiasis, river blindness, Guinea worm. Many of these are prevalent in tropical/equatorial areas and are unlikely to be a problem in the Eastern Cape of South Africa. Such diseases account for one third of all deaths in these countries. Over 17 people die per minute globally as a result of water related diseases. The toll per day globally reaches approximately 25 000 deaths.

The single largest cause of disease and death among the poor in South Africa, particularly among infants, is water quality and sanitation related (DWAF, 1995). Approximately 14 million people in South Africa do not have access to safe water, and over 20 million are without adequate sanitation (DWAF, 1997). As a consequence, "thousands of children die annually of avoidable diseases related to poor sanitation and the lack of clean water" (DWAF, 1997: 9). Several types of health effects may occur.

Microbial water contaminants cause infectious diseases (DWAF, 1993). Chemical contaminants on the other hand are associated with acute and chronic effects. These chemical contaminants are also well known for their carcinogenic nature (WHO, 1984). The aesthetic acceptability of water is largely impacted by factors which negatively affect taste, odour, and physical and aesthetic characteristics of water (WHO, 1984). The presence of constituents of aesthetic significance in excess does not necessarily pose any risk to human health, but can affect the palatability and acceptability of drinking water to the consumer (Joint Research Centre, 1989).

The poor water quality also has economic implications to humans. The economic implications of poor water quality include the following :

- the cost of water treatment,
- the costs of maintenance of treatment and distribution systems, and
- the costs to the individual users which include the scaling of geysers and other appliances, corrosion of fittings, and the consumption of soap in hard water (Kempster and Van Vliet,1991).

Also affected by poor water quality are agricultural users. For example, at high levels, chloride has a negative effect on palatability of water and that water's suitability for irrigation of crops. According to DWAF (1993), this may be more detrimental than toxic effects, which occur at far higher concentrations. According to Hart et al (1992), this is so because feed intake declines with a decline in water intake. Pigs have been found to be more susceptible to excess chloride than sheep or cattle. Excess chloride ingestion will manifest itself as salt poisoning (osmotic pressure disturbances). Crops also vary in their sensitivity to chloride. Once the threshold concentration in the soil solution is exceeded, yield reduction will be unavoidable (Pratt *et al.,*, 1990).

Also adversely impacted by poor water quality is the natural environment. The riverine biota are amongst the hard hit ecosystems. According to Dallas and Day (1993), riverine ecosystems usually support a number of different organisms within different trophic levels, such as primary producers, primary consumers, and secondary consumers. Rivers are divided into zones which are distinct with respect to their physical, chemical, and biological characteristics. As a result of differences in climate, geomorphology, geology, and biota, rivers also differ regionally.

Within each region/zone, community composition is determined by water quality, the type of habitat (biotope) available, the degree of water movement, temporal variability of water, and the historical distribution of species. Water quality variables potentially affecting riverine ecosystems may be physical (turbidity, suspensoids, temperature) or chemical [non toxic: pH, Total Dissolved Salts (TDS), salinity, electrical conductivity (EC), individual ions, nutrients, organic enrichment, and dissolved oxygen, and toxic: biocides, and trace metals] (Dallas *et al*, 1994).

According to WRC (1998), each of these variables has an effect, whether beneficial or detrimental, on aquatic organisms. When more than one variable is involved the overall effect can be of concern, for example, variables may be synergistic (when two variables interact to produce a magnified effect), or antagonistic (when toxicity of one variable is reduced by the presence of the other). The following section deals with the effects of each of the 'variables of concern' in both humans and natural environment. The variables discussed in the section that follow are those selected for analysis in this study.

2.2.5 The water quality variables

2.2.5.1 Physical properties

- *Turbidity*

The immediate visual effect of turbidity is a change in water clarity. According to the American Public Health Association (1989), an increase in turbidity affects light penetration. This may have far-reaching consequences for riverine biota.

According to the WRC (1998), it is the continuous high- level inputs that have critical consequences for the riverine biota. As light penetration is reduced, primary production decreases and food availability to organisms higher in the food chain is diminished. According to DWAF (1994), the suspensoids that settle out may smother and abrade riverine plants and animals. Community composition may change, depending on which organisms are best able to cope with the altered habitat. Predator-prey interactions are affected by the impairment of visually hunting predators. Nutrients, trace metals, biocides, and other toxins adsorb to suspensoids and are transported in this form (Dallas and Day, 1993).

Domestically, the primary importance attached to turbidity relates to its role in water treatment (WHO, 1984). According to DWAF (1993), the amount of chlorine required for disinfection of water increases as turbidity increases. Low turbidity, therefore, minimises the required chlorine dose, and reduces the formation of chlorinated organics, as well as taste and odour problems.

According to Kempster and Smith (1985), because of the many advantages associated with low turbidity and the relative ease of continuous turbidity monitoring, it is often used as an indicator of potential water quality problems during treatment. DWAF (1993) notes that the probability of presence of carcinogenic asbestos fibres is increased in conditions of high turbidity. However, this is not a potential problem in the study area. According to WHO (1984), the three general classes of particles that contribute to turbidity in natural water are: clays; organic particles resulting from the decomposition of plant and animal debris; and fibrous particles such as asbestos.

- *pH*

pH is a measure of hydrogen ions and gives an indication of whether a solution is acidic, neutral or alkaline (Dallas and Day, 1993). On the scale from 0 - 14 a pH of 7 is indicative of a neutral solution. Any value below 7 indicates acidity whilst values above 7 indicate the alkaline solutions. According to DWAF (1993), the pH of natural waters is determined by geological and atmospheric influences.

Changing the pH of water changes the concentration of both H^+ and OH^- ions which affect the ionic and osmotic balance of aquatic organisms. According to DWAF (1993) relatively small changes in pH are not normally lethal, although sub-lethal effects such as slow growth and reduced fertility may occur because of increased physiological stress placed on the organism by larger energy requirements. According to Dallas and Day (1993), the studies indicate that a change in pH from that normally encountered in unpolluted rivers has severe effects upon biota.

pH determines the chemical species and thus potential toxicity in which numerous elements and molecules are found in water. For example, aluminium is mobilised following acidification. The potential toxicity of certain metal ions such as ammonia is influenced by pH. Also, pH changes affect the degree of dissociation of weak acids and bases. According to US EPA (1986), this effect is of special importance because the toxicity of many compounds is affected by the degree of dissociation.

According to the Canadian Guidelines (1987), the taste of water, its corrosivity, chlorination efficiency, and the solubility of metal ions are all influenced by pH. For example, a low pH may taste sour whilst high pH results to a soapy taste (Kempster and van Vliet, 1991). The pH of raw water also affects water treatment processes like air stripping and chemical softening (DWAF, 1993).

- *Electrical conductivity (EC)*

Greenberg *et al.*, (1985: 76) describes electrical conductivity as "*a numerical expression of the ability of an aqueous solution to carry an electrical current*". This ability depends on the presence of ions, their total concentration, mobility, valence and relative concentrations, as well as on the temperature of measurement. According to the WHO (1984), the main contributing ions include carbonate, bi-carbonate, chloride, sulphate, nitrate, sodium, potassium, calcium, and magnesium. In addition, Kempster and Vliet, (1991) perceive conductivity as a measure of salinity, "since fresh water normally contains dissociated , electrically conductive dissolved salts, such as, calcium, magnesium and sodium bicarbonates, sulphates and chlorides".

According to DWAF (1993), low concentrations of dissolved salts have nutritional value, more especially the calcium and magnesium salts. At high concentrations, however, salts can have undesirable effects in terms of:

- the aesthetic acceptability of water;
- health;
- economics.

This is confirmed by Kempster and Smith (1985) who declared that the high concentrations of salts result in an unpleasant taste in water and accelerate scaling and corrosion. The United States Environmental Protection Agency - US EPA (1986) has suggested the following physiological effects which may be directly related to high concentrations of dissolved salts:

- laxative effects mainly from sodium sulphate and magnesium sulphate;
- the adverse effects of sodium on certain cardiac patients;
- the effect of sodium on women with toxaemia associated with pregnancy;
- some effects on kidney functioning at high concentrations.

In extremely low concentration, the total dissolved salts may have a slight impact because of a flat, insipid taste (WHO, 1984).

2.2.5.2 The biological constituents

- *Faecal coliforms*

According to Craun (1986) micro-biologically polluted water has long been associated with the transmission of infectious diseases. These diseases include gastroenteritis, amoebiasis, giardiasis, salmonellosis, dysentery, typhoid fever, and hepatitis A. A feature of bacterial pathogens is a generally high infective dose. According to DWAF (1993), 10 - 1000 or more organisms are required to cause infection. Viral pathogens and parasites, in contrast have low infective doses. 1 - 10 organisms are required to cause infection.

According to Grabow *et al.,* (1986), faecal coliforms, and specifically *E. coli*, are the most common indicators of faecal pollution, and hence the possible presence of pathogens in water. The Canadian Guidelines (1987) reveal that faecal coliform bacteria are almost definitely of faecal origin from warm blooded animals.

According to DWAF (1993), faecal coliforms and *E. coli* are rarely found in water and soil that has not been subjected to faecal pollution. According to WHO (1984), soil contaminated by animal faecal pollution has been shown to contribute a great deal to pollution of stormwater runoff, and hence of the receiving water bodies. The Canadian Guidelines (1987) adds that runoff from residential areas is also usually contaminated with faecal coliforms and pathogens. According to DWAF (1993), these, together with discharge of treated or untreated waste water, are the major sources of faecal coliforms and *E. coli* in the aquatic environment.

2.2.5.3 The process related constituents

- *Total hardness (T.H)*

According to the DWAF (1999), total hardness is the sum of calcium and magnesium concentrations expressed as mg/l. Calcium and magnesium are common elements which occur in many minerals. According to DWAF (1993), limestones are probably the most significant sources of calcium and magnesium in natural water. Some other ions also contribute, although at minor scale to hardness. These include zinc, manganese, aluminium, strontium, barium and iron. According to the WHO (1984), water sources rarely contain more than 100 mg/l of the salts which contribute to hardness. It is usually calcium that causes hardness. Hardness in water used for domestic purposes causes the following problems:

- it results in an increase in the amount of soap required to produce a lather when bathing (ASCE/AWWA, 1990);

- it forms scale on the heat exchange surfaces such as cooking utensils, hot water pipes, kettles and geysers (Benefield *et al.*,, 1982);
- whilst some total hardness in water is beneficial to human health as it contributes to the need for the essential elements, calcium and magnesium, excessive total hardness should be avoided by sensitive groups (DWAF,1999).

2.2.5.4 The physio-chemical constituents

- *Nutrients*

Nitrogen is abundant in nature, and is a major element of all living organisms. In natural waters, nitrogen may be present in many forms including ammonia, albuminoid ammonia, organic nitrogen, nitrites, and nitrates. (Dallas and Jay, 1993). In this section, nitrates, nitrites, and ammonia will be discussed.

- *Nitrates*

Dallas and Jay (1993) describe nitrates as the end products after organic nitrogen has been aerobically stabilised. Considerable amounts of nitrates are present in soil, water, and plants (DWAF, 1993). Nitrates get into surface water via fertilisers, agricultural runoff, and groundwater seepage into the streams. Because of their conversion to the organic nitrogen in plant cells through the process of photosynthesis, high quantities are rare in nature (Dallas and Jay, 1993). Nitrates are however found in high concentrations in groundwater.

Nitrates are used in the manufacturing of inorganic fertilisers. Nitrates are also used as the oxidising agents in the chemical industry (DWAF, 1993). Nitrates are used in the manufacturing of explosives as well as the food preservatives (WHO, 1984; Canadian Guidelines, 1987).

The nitrate-nitrogen concentration is typically less than $2mgl^{-1}$ in unpolluted water. Significant sources of nitrate are the decay plant, animal, and human wastes (DWAF, 1998). Municipal and industrial discharges, leachate from waste disposal dumps and sanitary landfills and soil leaching from where inorganic nitrate fertilisers are applied also contribute tremendously to the nitrate loads in rivers and lakes (DWAF, 1993). Also, according to WHO (1984) and the Canadian Guidelines (1987), groundwater may have high concentrations of nitrate as a result of soil leaching and the application of inorganic nitrogen fertilisers.

Of primary concern is the impact of nitrate on human health. As pointed out earlier in section 4.1.2.2, in the environment, the conversion of nitrates and nitrites to one another happens readily. When a conversion of nitrate to nitrite occurs in the gastro-intestinal tract, nitrites are then absorbed into the blood cells, and combine with the oxygen carrying red blood pigment, haemoglobin. The result of this combination is methaemoglobin. Methaemoglobin cannot transport oxygen, and the resultant condition is called methaemoglobinaemia (Kruger, 1992; DWAF, 1993). The condition could be fatal to infants under 3 months old.

Serious and occasionally fatal poisonings in infants have been reported following the ingestion of well waters which contain extremely elevated concentrations of nitrate (Rao, 1998). Handa (1989) reports that approximately 2000 cases of methaemoglobinaemia were diagnosed in the United States and Europe during the period 1945 and 1960 and about 7 - 8 percent of infants died. Handa (1989) also reports that, in Russia, where children were drinking water with as much as 182 mg/l of nitrate, elevated levels of methaemoglobin concentrations were found. Cuello *et al.*, (1976) and Gilli *et al.*, (1984) linked the elevated concentrations of nitrate with an increased risk of gastric cancer. In the study by Xu *et al.*, (1992), conducted in north-eastern China, a very close association between the high levels of nitrate in drinking water supplies and neoplastic changes in the stomach was developed. Reporting from a different perspective, Lunkad (1994) revealed that elevated concentrations of nitrate are undesirable in the fermenting and dyeing industries. The maximum permissible safe limit of nitrate in water for domestic use suggested by WHO (1984) is 45 mg/l.

- *Nitrite*

According to Dallas and Day (1993) nitrite is an intermediate in the conversion of ammonia to nitrate. It is said to be a substance with considerable toxicity. Nitrite products are increasingly used in many human activities such as the industrial production of metals, dyes, and celluloids, sewage effluents and certain types of aquaculture (Lewis and Morris, 1986).

The aquatic species that are particularly sensitive to nitrite concentrations are listed by Dallas and Day (1993: 85). They include the following: *Ictalurus punctatus, Macrobranchum rosenbergii, Micropterus salmoides, Pimephales promelas, Salmo gairdneri and Tilapia aurea.* Lewis and Morris (1986) linked the toxicity of nitrites to fish. Their study showed that because of the mixing of nitrite with haemoglobin, methaemoglobin developed. Consequently, fish were affected by a lack of oxygen. During high activity, which is a period of high oxygen demand, fish were found to be dying of anoxia.

- *Ammonium*

Ammonium is one of the constituents of the nitrogen cycle. It is a common pollutant which is often associated with sewage and industrial effluent. The decomposition of nitrogenous organic matter is a source of ammonium in surface and groundwater.

An ammonium-nitrate relationship exists. As was explained earlier, these substances tend to convert one from the other in the environment. According to Bleuten (1989), an interaction with channel bed, where nitrogen is temporarily immobilised and partly denitrified, results in an increase in ammonium and nitrate concentrations during storm discharges. He explains the process as follows: during peak discharge, given an increased flow velocity, ammonium will be liberated with the organic matter from the bottom sediments, and returns into the surface water where it becomes oxidised. This process results in low oxygen saturation and a rise in ammonium concentration. When most of the easily convertible organic matter is oxidised, oxygen saturation in water increases again and the available ammonium will be subjected to nitrification processes by the bacterial activity and the result will be the temporal increase in nitrate concentration (Dallas and Jay, 1993).

Gammeter and Frutiger (1990) realised that, whether by impeding cellular metabolism or by decreasing oxygen permeability of the cell membrane, un-ionised ammonia affects the respiratory system of many animals. Hart *et al.,* (1992) explained that ammonia might cause fish to lose equilibrium, develop hyper-excitability, increased breathing rate, cardiac output and oxygen intake.

Gammeter and Frutiger (1990) also warned that, in extreme cases, convulsions, coma and death of fish may result. Chronically, ammonium reduces hatching success, growth rate and morphological development. Pathological changes in tissues of gills, liver, and kidneys could also result (Dallas and Day, 1993). Significant lethal effects on macro invertebrate species exposed to increasing concentrations of ammonium were observed by Schofield *et al.,* (1990).

- *Chloride*

According to DWAF (1993), chloride is an essential micro nutrient for plants that is highly soluble and does not sorb to any degree to the bottom sediment. In an aquatic environment, chloride may be an indication of sewage pollution (Shaw, 1983). DWAF (1993) identifies the following three other likely sources of chloride in the aquatic environment: chloride may leach from the underlying rock layers, which often are sedimentary rocks of marine origin; rainwater carrying dissolved salts from the sea may have a significant input of chloride, particularly in streams of the coastal region; and industrial and domestic effluents often carry high loads of chloride.

The consumption of high quantities of chloride from water and salted food are believed to increase one's blood pressure, which in turn may lead to cardiovascular disease (Baird, 1995). The presence of chloride in a water body leads to the increase in the concentration of dissolved salts (DWAF, 1993) whose effects are discussed in section 2.4.1 above.

Since chloride is highly soluble, it is readily transported in soil water through the roots and sent throughout the plant, where it may accumulate. It is when accumulation of chloride in the plant exceeds the plant's tolerance that injury starts manifesting itself in the form of leaf burn. This may have significant impacts on the crop yield. The sensitivity of plants to chloride differs from one species to another (DWAF, 1993).

The effect of chloride in animals has already been discussed in section 4.1.3. According to DWAF (1993) chloride may be more deleterious than the toxic effects, which occur at concentrations much higher. This is due to the fact that feed intake declines with water intake.

- *Phosphate*

Phosphorus is one of various elements that are required for normal growth and reproduction in plants. It is an essential requirement in several processes in life and plays a central role in the functioning of DNA. Phosphate is seldom found in unpolluted water because it is in such a demand from plants, is attached to suspensoids, and becomes bonded to ions such as iron, aluminium, calcium and a variety of organics (Davies and Day, 1998). The sources of phosphates include phosphatic fertilisers, animal excretions and human waste materials (Kruger *et al.*,, 1992). Phosphates are also used as builders in many chemical products like detergents (Schroder, 1995).

Phosphates have a eutrophicating effect on algal growth in stagnant and slow flowing waters, and can thus considerably disturb the ecological ecosystem. Besides that, the actual eco-toxicological potential of phosphate is minimal (Kruger, 1992; Schroder, 1995). Further discussion on phosphate is presented in section 3.1.3.1 in Chapter 3.

Given the knowledge of the uses of land and related activities in the study area and the evidence of the impact of these elsewhere globally on water quality, as provided by the literature given above, it leaves one with a concern that these land-uses might be impacting critically on quality of river and ground water in the area. The communities in the study area have also been complaining about the quality of their water. A study of this nature in the study area is therefore long overdue. The aim and objectives of this section of the study therefore are:

Aim

- to assess the land-use in the upper Kat River area,

Objectives

- to present a land-use map and identify areas of land-use change,
- to establish what farming practices take place on the cropped lands,
- to observe livestock management practices,

- to establish the nature of basic services (water supply, sanitation, waste disposal),
- to assess the potential link between land-use and water quality problems in the study area.

The following section outlines the methods and techniques employed in the realisation of the aims and objectives of this chapter as outlined in section 2.1.1 above.

2.3 Methods and techniques

Major methods employed towards realising the aim and objectives of this chapter are summarised in Table 1 in Chapter. These include the following:

- use of orthophoto maps to identify the target communities and identifying major land-use in the study area,
- field visits to map the major land-uses and identify major land-use related activities in the study area ,
- mapping of major land-use and related activities by the community participants during a water quality workshop,
- unstructured and structured surveys conducted in the study area primarily aimed to determine the land-use and related activities and to select the target communities for the general water quality and washing practices studies,
- using GIS to produce the study area's land-use map from the data collected during the three exercises mentioned above,
- relevant literature was used to assess a link between water quality problems in the area and land-use,
- the observation of any signs of waste and other pollution sources like grazing animals along the course of the river, as well as the washing patterns in each washing site identified,
- conducting semi-structured interviews with influential people in the study area to determine whether insecticides, herbicides, and fungicides were used..

A detailed account of how the target communities were selected is presented in Section 1.2.1 of Chapter 1. Thus, in the following discussion, methods and techniques used to determine land-use and related activities in selected villages and assessing the potential link between land-use and the quality of water are presented.

2.3.1 Determining the land-use and related activities in the selected villages

Orthophotos and topographic maps of the study area were studied with the purpose of identifying major land-use. Four field visits were conducted during the course of the study to identify and map major land-use and related activities in the study area. In each of these visits, a walk was taken across a certain section of the catchment. All major land-use was then mapped on that area's topographic map. A further eight field visits were conducted specifically to study the in-stream washing in several parts of the catchment (details in Chapter 3).

A workshop was conducted to feed-back the water quality findings of the study to the communities (Appendix 20). During the workshop, community delegates were requested to map the major land-uses and related activities. Participants were given an orthophoto map of their respective villages. They were then required to indicate using stickers what activity was taking place and the location of that activity on the map.

Informal and formal surveys were carried out in the area. During the informal survey, four influential people were interviewed in the area. One purpose of the survey was to establish the uses of land in the study area. A questionnaire survey was also carried out in eight villages along the Kat River (Figure 1). Although its primary purpose was to assess the washing practices of each village community, the respondents were also requested to provide information about specific land-uses, such as indicating the type of toilets used by the family and the village. The eight village communities that were interviewed were from Balfour, Fairbairn, Hertzog, Upsher, Gonzana, Blinkwater, White, and Entilini. Although there are many villages in the Kat River valley, the study villages were selected because of their proximity to the Kat River, or to a major tributary of the Kat River. In the biggest of the villages, Balfour, with more than 150 households, 100 households were interviewed. In all villages that have between 100 and 150 households (Blinkwater, Entilini, Fairbairn, and Hertzog), 50 households were interviewed. In smaller villages, with less than 100 households, such as Gonzana, White, and Upsher villages, the target was to interview at least 50 percent of the households. A total of 500 questionnaires were administered. In all the villages, every second household was interviewed.

Surveys take two main forms: structured and unstructured interviews (Shepherd, 1978). Where an interviewer puts questions, and the answers recorded by the interviewer on an interview schedule that sets out the questions and provides room for the answers, the method is the unstructured interview. In unstructured interviews, questions are open ended, and are only used as a guide to the interview. Alternatively, respondents themselves can complete a questionnaire, better known as the structured interview (Shepherd, 1978). The questions in this category are more specific, and the answers are often in categories. In this project, a combination of the two methods was adopted because, as indicated by Townsend (1977), these two techniques are not alternatives, but complementary. As Dixon and Leach (1978 :3) state, *"a good journalist might find out more than a researcher with a bad questionnaire, but he would have greater difficulty in providing evidence for his conclusions"*.

Each of these techniques, when applied in isolation, has advantages and limitations. Advocates of the unstructured interview technique (Atkinson, 1971; Shepherd, 1978; and Townsend, 1977) note the advantage of flexibility. Unstructured interviews are also useful when applied to research areas which have never been explored before or for which little is known (Dixon and Leach, 1978). Thus, the unstructured interviews were conducted with eleven community leaders in the study area during workshops held to promote a Water Users Association. The results enabled the development of questions for a quantifiable survey using a structured interview technique. After the second survey was analysed, many loose ends, contradictions and problems were elucidated by a second set of longer unstructured interviews with nine community leaders in the study area.

The main problem of the unstructured interview lies with recording information, that is, what to record and what to leave out. Moreover, unstructured interviews can easily go off track (Combrink, 1997). Combrink (1997) also advises that maintenance of focus may largely depend on the skill and integrity of the researcher. The semi-structured interviews are, however, more time consuming than structured interviews.

After the initial unstructured interviews, a draft questionnaire was compiled and refined. A small number were duplicated, and used on few individuals at the Tantyi township near Grahamstown to pilot test these questionnaires, after which the questionnaire was modified.

Although structured questionnaires were designed, the actual process of interviewing assumed a semi-structured conversation technique in which the conversation was allowed to go freely on targeted topics. This eliminated the rigidity and inflexibility often associated with the fully structured interviews (Shepherd, 1978). Moreover, because there was a guiding document (in the form of a questionnaire), the interviewer was more in control of the proceedings than in the totally unstructured interviews. Also, the high illiteracy rate in the study area encouraged the adoption of semi-structured interviews.

Data collected from all the sources mentioned above were then used to create a land-use map of the study area. The information was pasted on a topographical map of the study area. The map was the captured through a GIS process known as digitising thereby converting the map from analogue format to electronic format. The map was digitised using ESRI's Arc/Info GIS package. The data was then added to the study area's existing data with ESRI's Arc/View software where it was manipulated and analysed further.

2.2.3 Assess a possible link between land-use and water quality

A literature search was carried out to assess a possible link between land-use and related activities and the quality of water in the area. The results of that search are presented as the literature review in Section 2.2 in this chapter. In this section, it is demonstrated that several regional and local catchment scale land-use and related activities degrade the quality of water. The water quality degradation consequences of the human settlements and the increase in population, afforestation, poor sanitation facilities, domestic animal kraals, agro-chemical and irrigation dependent crop farming and in-stream washing practices are amongst those discussed in Section 2.1.

2.4 Results and Discussion

2.4.1 Land-use and related activities in selected villages

Major land-use categories of the total land area of the upper Kat River catchment are mapped in Figure 3. The following land-uses and activities were identified:

- crop land,
- intensive grazing, (intensive grazing differed from grazing in that these were the noted grazing pastures. Comparatively, larger number of grazing animals was thus always noted in areas of intensive grazing).
- grazing,
- citrus farmland,
- cattle dip,
- abandoned cropland,
- dense settlement, (dense settlement differed from a settlement according to the proximity of households to each other. In a dense settlement, household are very close to each other. Consequently, density of households is relatively higher than a settlement where a distance from one household to the next is bigger).
- settlement,
- commercial forestry,
- settlement grazing,
- sports field

It is apparent that most of the land in the study area was utilized for agricultural purposes. For example, it is observable from Table 4 that more than 54 percent of the land utilized in the area was used for agricultural activities like crop farming (35 percent), grazing (15.06 percent) citrus farming (4 percent) and cattle dipping (0.04 percent). The commercial state forest took about 26 percent of all the land used in the upper Kat River area. Settlements on the other hand occupied 19.4 percent of the land.

There was also noticeable evidence that there had been some change in land-use in the area. This was shown by the fact that about 0.4 percent of the land-use in the area used to be productive but not anymore. The land was initially utilized for crop farming but appeared to have been abandoned for some time. The community members noted that the land was abandoned because of the lack of water. Recreational land in the area is 0.1 percent of the total land being utilized. This refers to land-use other than natural woodland and rough grazing, that is, developed land-use.

From the above land-use study and the evidence specified in the literature discussion in section 2.1, it seems apparent that water quality in the study area could be negatively affected by the human land-use and activities related to that land-use. The greatest impact on water quality possibly comes from agricultural practices, which are the main land-use activity in the upper-middle Kat River area. Particularly, crop and citrus farming that are being supported by intensive irrigation and the agro-chemicals like fertilisers and pesticides are foreseen to be the greatest factor that threatens water of the upper-middle Kat River catchment. Also, according to the previous water quality studies (section 2.1), the impact of domestic animals on water quality is expected to be substantial, particularly where grazing appears to be concentrated.

Plate 1: Cropland on the river banks of the Kat River

Plate 2: Intensive grazing in the study area

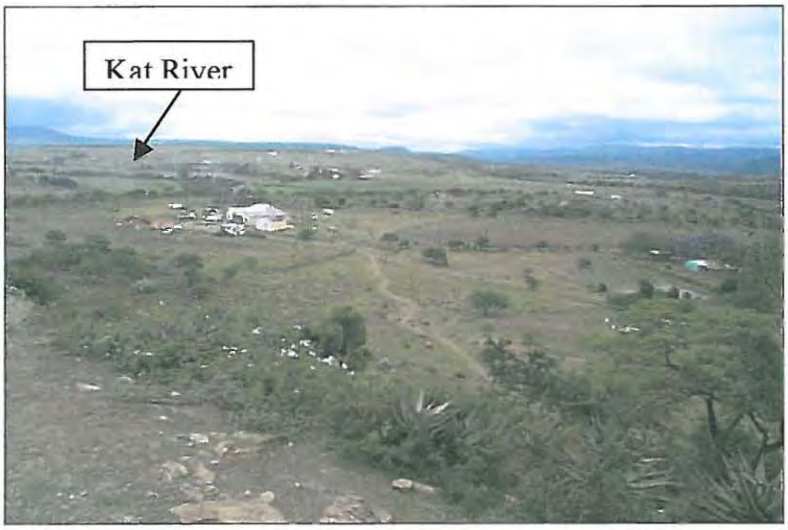

Plate 3: Close proximity of settlements and croplands to the Kat River

Plate 4: One of the rural villages in the upper Kat River area

Plate 5: Commercial Forestry in the upper Kat River catchment

In the literature documented in section 2.1 above, amongst others, the following impacts of agricultural practices on water quality are discussed:

- microbiological pollution especially in areas of intensive grazing and poor sanitation services,
- elevated nitrate and other nutrients' levels in water as a consequence of the faecal and manure pollution and nutrients and other chemicals loaded runoff from the agricultural lands,

The impact of human settlement on water quality is also well known (Section 2.1). Amongst others, the following impacts of human settlements on water quality are documented in section 2.1 above:

- faecal pollution emanating from the septic tanks, pit latrines, lack of sanitation facilities and domestic kraals,
- nutrient enrichment of groundwater, streams and other surface water bodies as a consequence of water coming into contact with fertilisers from the home gardens, manure from domestic kraals,

pit latrine leachate, improperly functioning septic tanks etc.

Covering about 26 percent of the total land-use in the study area, commercial forestry with coniferous species, is also likely to impact negatively on water quality of the upper Kat River catchment. Because it originates from the forest area, the impact of the forest is likely to be manifested on the Buxton and Balfour Rivers' water quality. The impacts the forest might be having on water quality of the Buxton River include the following:

- higher acidity levels of water depending on the tree species being used,
- higher concentrations of major ions like sodium and chloride in river water,
- nutrient enrichment of stream water as a result of continuous supply of organic pollutants from the forest.

Table 2:Main land-use in the study upper-middle Kat River

Land-use	Area	Percentage of land-use	Total percentage per land-use group
Cropland	93719	35	54.1
Intense grazing	41393	15	
Grazing	248	0.06	
Citrus farmland	10739	4	
Cattle dip	247	0.04	
Abandoned farmland	1064	0.4	0.4
Dense settlement	5067	2	19.4
Settlement	46969	17.4	
Commercial forest	69125	26	26
Sports field	358	0.1	0.1
Total land-use	268929		

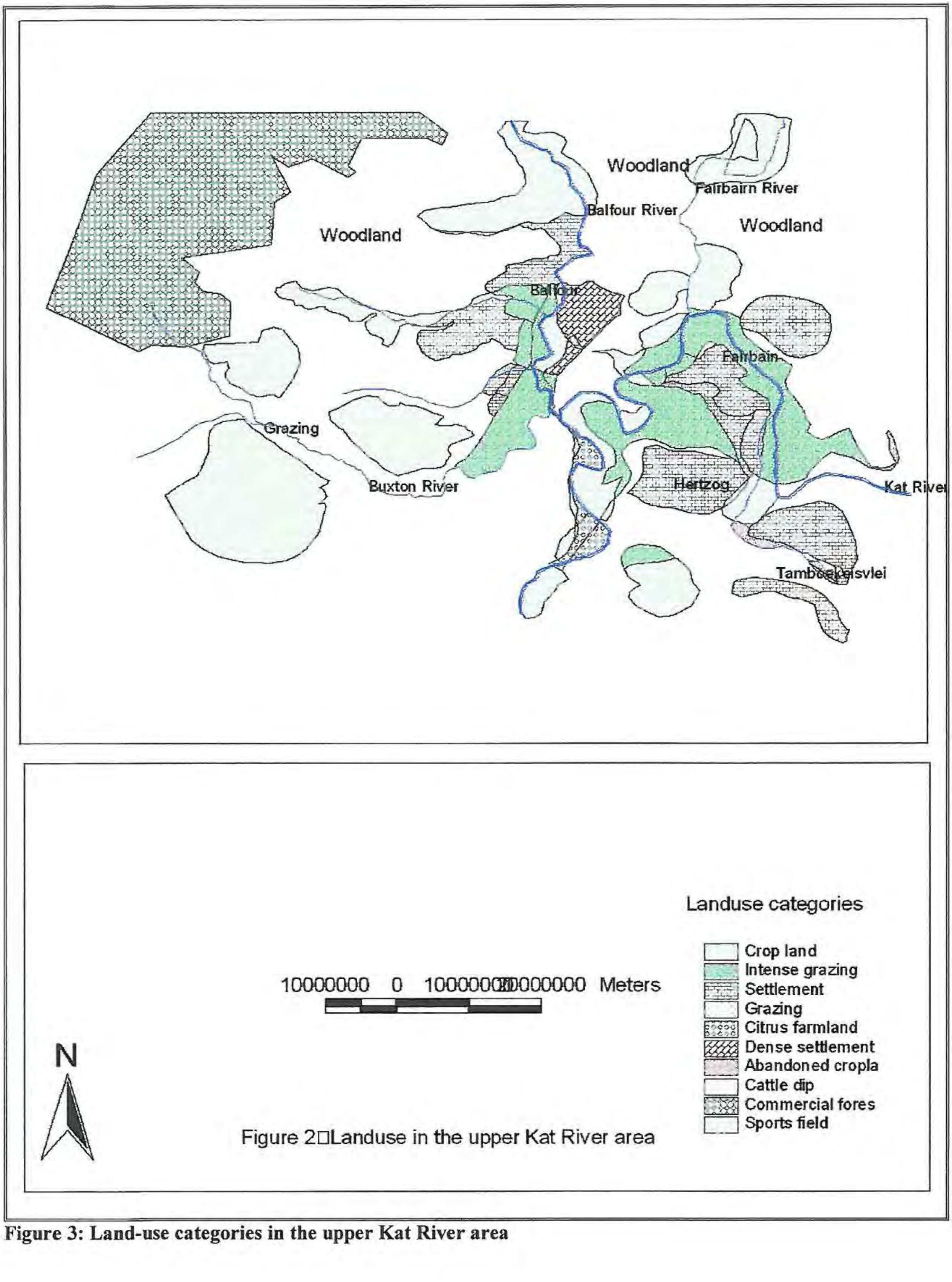

Figure 3: Land-use categories in the upper Kat River area

2.4.2 General layout of villages in the study area

Most villages in the area are rural. Although there is a substantial number of homesteads in each settlement, normally, there is a considerable distance between one homestead and the other. Hence, the density of housing in these villages could be said to be fairly loosely packed. In each village in the study area, the following land-uses and related activities are noticeable:

- homesteads,
- crop land/s
- grazing land/s,
- school/s
- each village usually has a site in the river where they draw water for domestic uses,
- also, each village has a site by the river on which they do their laundry
- at least two sites in the Kat River and one in the Hertzog stream where people are drawing water to irrigate their crops.

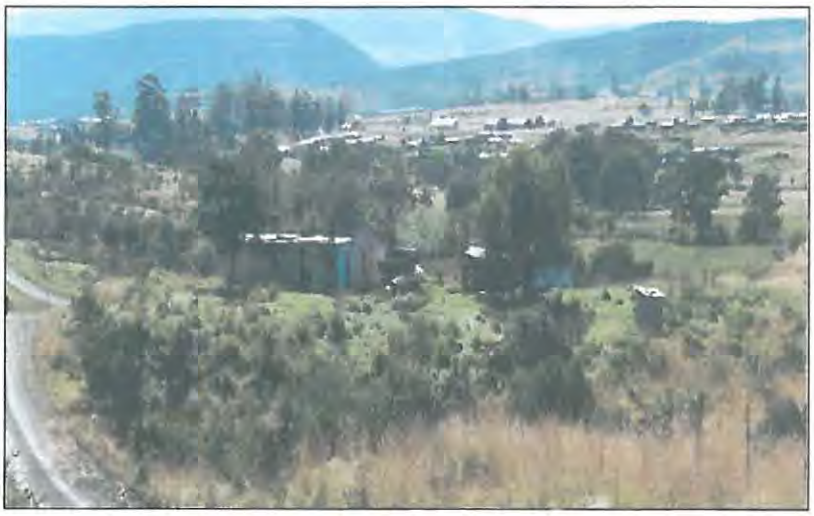

Plate 6: A typical village layout in the study area

The following major features are usually noticeable from each homestead in the area:

- a number of huts made from mud and thatched with grass,
- domestic animal kraal/s,
- a garden,
- normally, unimproved pit latrine,
- in some homesteads, a rain water tank is noticeable.

The exception to the above scenario is the Balfour village. Balfour is a semi-rural village. Compared to all other villages, the houses in Balfour are closer to each other than in other villages. Hence, it could be said that the arrangement of houses in Balfour is relatively denser.

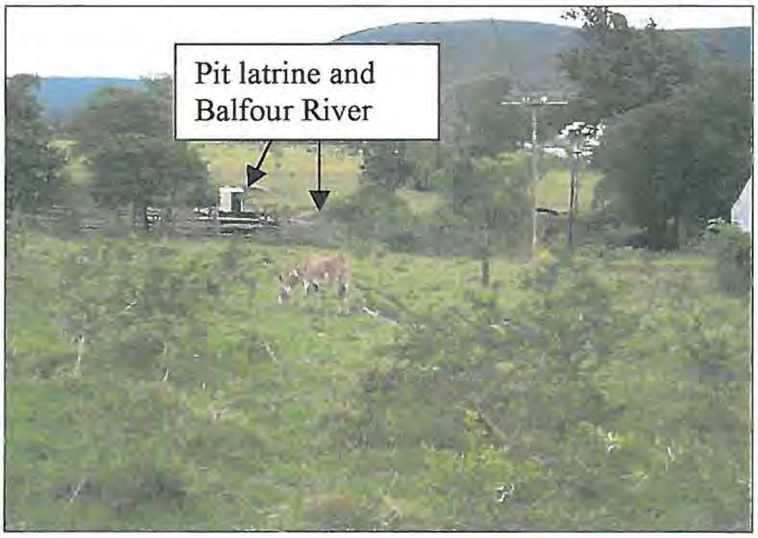

Plate 7: Some of the prominent features found in a rural area in the Kat River area

In the Balfour settlement, there is usually one house per household. The following are the main land-uses in Balfour:

- houses,
- shops (general trading stores, bars, restaurant, hotel, barber shop, salons etc),
- local government offices,
- schools,
- police station,
- crop lands,
- grazing lands,
- cattle dip,
- a number of taps is also noticeable in every neighbourhood in the Balfour village,
- 3 sites in the Balfour river where people do their laundry,
- 2 sites in the Balfour river where people draw water for domestic uses,
- 1 site in the Balfour River where people pump water for irrigation

Each household in Balfour usually has the following:

- a dwelling unit,

Each household in Balfour usually has the following:

- a dwelling unit,
- a ventilated improved pit latrine,
- a vegetable garden, and
- some families have animal kraals.

2.4.3 Establishing the nature of basic services in the area

The summarised findings from the eight communities interviewed regarding the nature of basic services and washing patterns are presented in Figures 4 – 6 and Appendix 2, whilst Appendix 2 outlines the specific situation at Balfour village. The results of other villages are provided in Appendices 1 - 7.

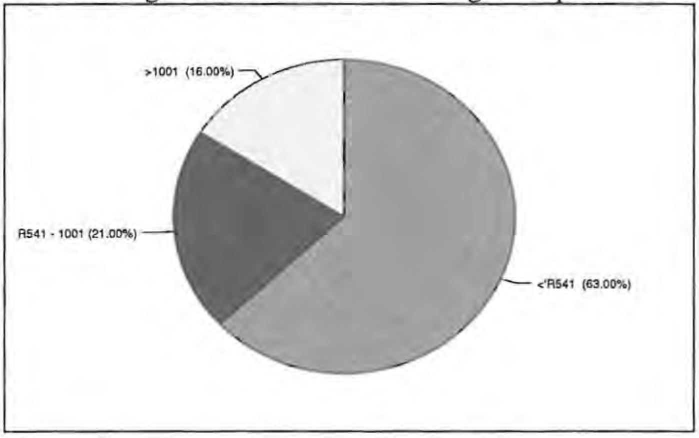

Figure 4: Average monthly income in the study area

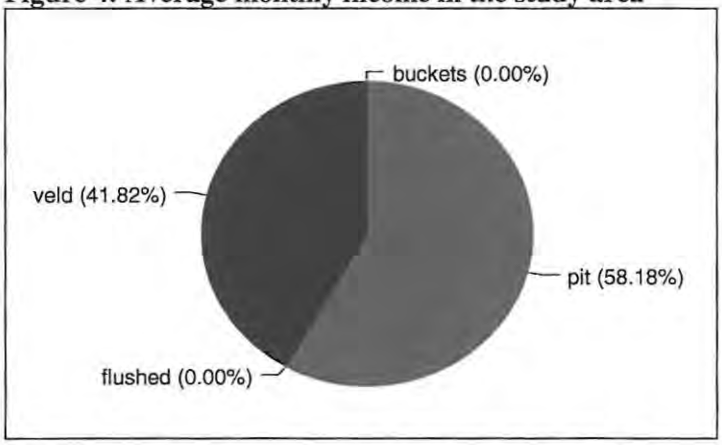

Figure 5: The most common kind of sanitation in the area

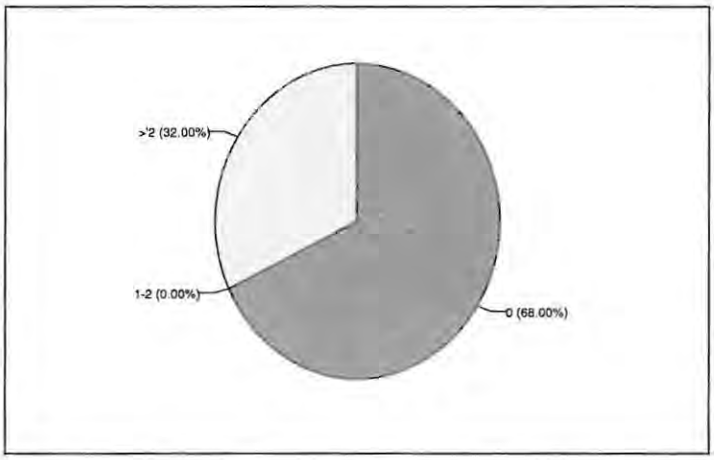

Figure 6: Number of taps per community

The social background trends revealed by structured interviews conducted in eight black village communities in the Kat River valley are described below:

2.3.3.1 Social background of the study communities:

Most households (64 percent) have 6 or more family members. In many families (45.2 percent), there was not a single member formally employed and, in most families (about 63 percent), the total family income was well below R541-00 per month (Figure 4). Most families therefore have a low spending power and have to rely on local resources. This situation is further affirmed by the results of the survey that indicate that most (51 percent) families in the study area rely on an old-age social pension grant. Only 39 percent of the community members are employed, and 10 percent rely on selling agricultural produce for survival. The buying power of each household largely depends on the income earned, and this would affect the frequency with which each household buys goods (detergents included), and the quantity of goods bought. Income also affects who does family laundry (most families cannot afford to hire services of someone to do their laundry for them).

Results of the survey (Figure 5) show that the most common kind of toilet (58.18 percent) in seven of the eight villages is the pit latrine. The major problem of the pit system is the leaching of wastes either into the groundwater or into the river, especially if the latrines are built within close proximity to the river.

Results of the survey (Figure 5) show that the most common kind of toilet (58.18 percent) in seven of the eight villages is the pit latrine. The major problem of the pit system is the leaching of wastes either into the groundwater or into the river, especially if the latrines are built within close proximity to the river. Some of the villagers (41.82 percent) do not have any formal sanitation services. They thus use the veld

Plate 8: The most common kind of sanitation (pit latrine) and its close proximity to the river in the study area

and bushes to relieve themselves. Such wastes end up in the surface flows and thus, ultimately, affect water quality. Moreover, young children in the community are not allowed to use the latrines for fear that they may fall into the pit and drown. These children would thus relieve themselves in the veld, or beyond the trees by the river. This waste material will in one way or the other end up in the channel.

Only three of the eight communities studied had access to piped water (Figure 6). The rest rely on river water. Seven of the villages studied had no adequate sanitation services, and all eight villages had no waste collection services provided. These results strongly indicate that these communities are still severely disadvantaged.

Chapter 3

Washing practices in the rural upper-middle Kat River area

This chapter aims to give a description of the washing practices in the study area. A conceptual framework section aiming to explore detergents in detail is presented below (section 3.1). The methods and techniques employed to realise the aim and associated objectives of this project (in Chapter 1, section 1.6) are presented in the following section (section 3.2). The results of a survey and quantification of washing practices in the study area are outlined in section 3.3. A short discussion of the trends established during the analysis of study data is presented in section 3.4.

3.1 Literature survey

3.1.1 Introduction

The use of detergents forms an integral part of our everyday life. Thus, everyday throughout the world volumes of detergents are used. These detergents often end up in surface water bodies, via the sewage works in most developed countries and via the surface flow and through direct input during activities like in-stream laundry practice in many third world countries. Either way, aquatic ecosystems are adversely exposed and vulnerable to the impact of these chemicals, depending on the time of exposure, the toxicity level of the substance, and the type of environment affected (Schroder, 1995).

Literature contained in this section of the study is an in-depth survey enveloping some aspects that were not covered by the study itself. This was done to better understand the impact of detergents on the quality of water and hence on aquatic organisms. Also, the literature assisted to understand the interaction detergents with the aquatic environment.

Thus, this section aims to explore detergents in detail. A brief historical development of detergents will be given. This will aim to trace the origin of developments in the latest generation of detergents we have in our markets. A section outlining the properties of detergents will follow. It is important to know the fate of every chemical entering our aquatic environments, as that will determine the toxicity of that substance to aquatic ecosystems. Thus, a section briefly outlining the fate of detergent surfactants both in the sewer and aquatic environment follows. A brief account of the interaction of surfactants with various physical and chemical environmental factors will be given, and last section will be dedicated to briefly exploring the measures taken by some countries to regulate the input of detergents into aquatic ecosystems.

3.1.2 Development of detergents

Soap has been known to man for almost 2500 years. The Phoenicians are reported to have prepared soaps in 600 BC and used it as an article of barter with the Gauls. It also would appear that soap was known to the Roman people during the era of the Roman empire (Gwinn, *et al.*, 1986).

According to Gwinn *et* al., (1986) early soap makers used animal fats and wood ash to make soap. This process involved adding simple wood or plant ash containing potassium carbonate. Fat would then be added to the solution which would then be boiled. As water evaporated from the solution ash would be added continuously. During the process, neutral fat would be gradually parted. A chemical reaction would then take place between the fatty acids and the alkali carbonates from the plant ash, a process known as saponification, and the end product would be soap. Decisive steps have been taken since these early primitive processes towards improving the manufacturing process of soap.

Soaps as cleaning agents had a number of limitations that led to the search for better alternatives. Gwinn *et* al., (1986) lists the following limitations:

- the reaction of soaps with calcium and other salts present in hard water resulted to the formation of a precipitate. Hence, scum or precipitate would accumulate as a ring around the bath tub, a whitish deposit on glassware, a sticky curd in the rinse water of laundry tub, and a dullness hair condition after shampooing,
- it is also known that soap reacts with traces of acidic compounds, resulting in the formation of a precipitate.

It is from this search for alternatives that detergents were born. In Gwinn *et al.*, 1986, Vol 4, detergents are described as any of the different surface active agents (surfactants), so effective in removing alien matter from dirtied materials and keeping it in suspension. Detergents have a water insoluble part (hydrophobic) (Gwinn *et al.*, 1986), which could be a fatty acid but most often is a long chain carbon group like fatty alcohols or alkylbenzene (Cano and Dorn, 1996). Detergents must also have a water soluble (hydrophilic) part. It is this chemical structure which results in detergent action.

Although detergents began mainly as substitutes for fat based soaps, they soon gained popularity and assumed superiority over soaps because of the following properties:

- detergents are generally either unaffected or very little affected by metal salts and acids in water,
- though detergents may chemically react with these metal salts and acids, the resulting compounds are either soluble or remain dispersed in colloidal form in the solution,
- the solubility of detergents in cold water resulted in their popularity, particularly for domestic applications,
- flexibility in the manufacturing of detergents encouraged manufacturers to focus more on them,
- detergents also generally appear to weaken any interactions there are between protein and lipids.

Despite the popularity detergents had over soap, their high price prevented them from penetrating markets in their early stages. It was only during the 1st World War that Germans encouraged the manufacture of these in large scales as replacements to soap so that available fat could be utilised for other more urgent purposes (Gwinn, *et al.*, 1986).

Detergents have not been without their share of problems. One of the most noted problems is that the early generation of detergents were not readily biodegradable. Consequently, they tended to bio-accumulate in the environment, as they could not be readily oxidised and degraded by the microorganisms.(Kruger, 1992). The use of phosphate as a builder of detergents (Schroder, 1995) has resulted in detergents contributing large amounts of phosphate to the fresh water systems. As a consequence, eutrophication of streams, dams, bays was unavoidable (Gerike *et al.*, 1990; Kruger, 1992; Hoffman and Bishop, 1994; Schroder, 1995). Also, the early detergents developed persistent foam in wastewater treatment plants and in aquatic environments (Gerike *et al.*, 1990; Kruger, 1992).

The new generation of detergents has been developed to address these problems (Kruger, 1992). Thus, in many detergents, phosphate has been replaced by a sodium aluminium silicate, Zeolite A, resulting in a noted decrease in loads of phosphate in the Rhine and Rur Rivers (Schroder, 1995). Also, many of the new detergent surfactants are completely degradable (Kruger, 1992; Matthijs *et al.*, 1995; Madsen and Kristensen, 1996; Cano and Dorn, 1996; Sherrard *et al.*, 1996; Versteeg *et al.*, 1996; Yamagishi *et al.*, 1998; Feijtel *et al.*,1999).

Despite the above mentioned developments to reduce the environmental impact of detergents, the latest generation of detergents has its own set of problems. Ahel and Giger (1985) and Reinhard *et al.*, (1982) reported that the bio-degradation of aromatic nonionic surfactants like alkylphenol ether (APE) often lead to the formation of more persistent intermediates such as alkyl phenol. Jobling and Sumper (1993) revealed that not only these phenols are persistent, but the presence of their traces in water may cause the disruption of the endocrine systems in fish and shellfish.

Yamagishi *et al.*, (1998) identified poly (glycidyl) monofluorooctyl phenyl ether, APE, and a potential mutagen (Reinhard *et al.* 1982) brominated alkyl polyethoxyl carboxylates in treated wastewater. This is an indication that there are still some persistent detergent surfactants. Since surfactants are known to degrade in solution, it is not clear whether sorbed surfactants can biodegrade (Cano and Dorn, 1996). Madsen and Kristensen have warned that the easily bio-degradable poly-cyclic aromatic hydrocarbons (PAHs) may resist desorption and persist at low levels even after biotreatment of contaminated soil.

All natural waters contain microorganisms that require organic matter for growth and oxygen for respiration. If biodegradable organic matter is added to the water, the number of micro-organisms and their respiration rates are increased, resulting in lower oxygen concentrations in water. If the concentration falls to zero, some bacteria in water will derive their oxygen requirements by reducing nitrates and sulfates in water. This will result in the formation of nitrites and sulfur dioxide and, therefore, in lifeless and evil smelling water and oxygen deficiency (Kruger, 1992).

Regardless, of the many problems of detergents, they are still outperforming the soaps as cleaners because of the ingredients, phosphates, boron and surfactants. However, these ingredients have been proven toxic, particularly to the aquatic ecosystems. The following section aims to explore these ingredients.

3.1.3 Properties of detergents

3.1.3.1 Phosphates

The impact of phosphate on water quality is further discussed in Section 2.1.4.4, Chapter 2. Phosphates have a eutrophicating effect which stimulates algal growth in stagnant and slow flowing waters, and can thus considerably disturb the ecological balance. The consequence of eutrophication is that dams and water storing places are filled with and suffocated by algae (Kruger, 1992). According to US EPA (1983), eutrophication was a major cause of the decline in water quality in Chesapeake Bay. This realisation has led to the development of strategies for reducing nitrogen and phosphorus entering the Bay by 40% by the year 2000and the implementation of a phosphate detergent ban in January, 1988.

Besides eutrophication and its impact on aquatic ecosystems, the actual eco-toxicological potential of phosphate is minimal (Schroder, 1995). Kruger (1992), reporting on the impact of the phosphates on humans, warned that phosphate can cause numerous health problems. Such problems may include allergies and poisoning.

Since 1981, orthophosphate has been determined as a measure of soluble phosphate in the Rhine monitoring programme. The annual average loads fell by 77% from 704g/s in 1982 to 158g/s in 1993 (Schroder, 1995). The main reason for the considerable reduction of phosphate load is the replacement of phosphate by Zeolite A as a builder of detergents. In the meantime, the contribution of detergents to the phosphate load in Germany has become negligible. Although detergents now hardly make any contribution to the phosphate load, significant amounts of phosphate are still introduced through faecal matter and agriculture (Schroder, 1995).

3.1.3.2 Boron

Boron is used as a peroxide generator in detergents. There are some indications that boron in environmentally relevant concentrations is capable of developing an eco-toxicological potential with some species (Schroder, 1995). Boron has been accordingly included in the Rhine monitoring programme since 1976. Since then, its loads have been fluctuating between 100 and 400g/s. In addition to detergents, agricultural fertilisers and natural ground pollution contribute to the boron load. Results obtained from another Henkel monitoring programme in the River Ruhr impressively underlined the fact that the combination of readily biodegradable surfactants and efficient wastewater treatment stops surfactant concentrations from rising alarmingly, even with favourable mixing ratios (Schroder, 1995).

3.2 Detergent Study Methods and Techniques

3.2.1 Introduction

This section aims to present the methods and techniques employed in the study to describe the washing practices in the study area (Table 3). These methods include:

- interviews to investigate detergent use;
- simple chemical analysis of detergent solutions;
- quantifying in-stream detergent use;
- in-stream measurements of certain water quality variables during washing events.

The manner in which these are presented below is according to which methods have been employed to achieve each objective.

3.2.2 Washing practices in the study area

Figure 1 in Chapter 1 shows all the eight village communities along the Kat River that were involved in the questionnaire survey. The primary purpose of the survey was to determine the washing practices of each village community. The eight communities that were interviewed are: Balfour; Fairbairn, Hertzog; Upsher; Gonzana; Blinkwater; White; and Entilini communities. Of the many villages in the Kat River valley, the study villages were selected largely due to their close proximity to the river or to a major tributary of the Kat River. In the biggest of the villages, Balfour, with more than 150 households, 100 households were interviewed. In all villages that have between 100 and 150 households (Blinkwater, Entilini, Fairbairn, and Hertzog), 50 households were interviewed. In smaller villages, with less than 100 households, like Gonzana, White, and Upsher villages, the target was to interview at least 50 percent of the households. A total of 500 questionnaires was administered. In all the villages, every second household was interviewed.

Table 3: Aims, methods, and methods and techniques

Aims	Objectives	Methods and techniques
To investigate the extent of in-stream detergent uses.	to describe the washing practices in the study area.	structured and semi-structured interviews.
Assessing the impact of in-stream washing on water quality.	to describe the washing practices in the study area.	structured and semi-structured interviews.
	to identify and study the in-stream washing sites.	structured interviews; GPS; and on-site water quality analysis whilst washing is on progress.
	to analyse the chemical properties of detergent solutions.	laboratory analysis of the detergent solutions.

A detailed review of the questionnaire survey method and how it has been applied in the study is presented in Section 2.3.5 of Chapter 2.

3.2.3 Identification of the washing sites

The questionnaire survey mentioned in Section 3.1 also aimed to determine the location of washing sites in the river. Although questionnaire surveys were carried out in eight villages, in-stream laundry practices were studied only in a few selected villages: Hertzog, Fairbairn, and Balfour (Figure 3). The choice of villages was determined by the results of the questionnaire survey, which indicated the sites of most intensive in-stream washing. The results from the interviews were supplemented by general field observations of washing practices, and nine key people were interviewed with the aim of verifying the village interview results and also of clarifying contradictions and problems that were picked up during the analysis of the questionnaire results.

The results of the structured questionnaire revealed that there is more than one washing site in each of the villages. It was also through the unstructured interviews that it was established that at Balfour, for example, there are three washing sites. The second unstructured interview results which enabled the establishment of the study sites in all three study communities. The most popular washing sites in each village were identified, and hence used as sites of references in this study. The respective communities identified washing sites during the questionnaire surveys conducted in each study community. These were verified by continuous field surveys. Although washing may be done at several washing sites, mainly because of proximity to houses, each village has a main washing site. Bigger villages such as Balfour have more washing sites (Balfour has three)

This study has focussed on these community-recognised, rather than individually-recognised washing sites, as they are perceived by the communities as more permanent in nature than other sites. A common factor about such sites is that they tend to be easily accessible even during the periods of high flow. Also, it has been observed that such sites often have enough running water even during the low flow periods. These sites are also sites from which people draw their drinking water. Therefore, they tend to be multi purposed rather than specialised sites. Hence, these sites have also been identified as some of the general water quality survey sites (Figure 1). Thus, the names given to these sites is common on both the study of the impact of detergents and the impact of land-use and related activities on water quality.

This study aimed to cover a total of three such sites, as follows:

- Hertzog: water quality site 1,
- Fairbairn: water quality site 4,
- Balfour: water quality site 9.

3.2.4 Studying the in-stream washing practices

A pilot study using participant observation and sampling for the analysis of certain predetermined water quality variables at the washing sites was carried out in three of the eight villages to be studied, Hertzog, Fairbairn, and Balfour. Each site was visited three times. On each visit a full day was spent studying the site. The number of people doing laundry per time was noted. The load of dirty dry laundry was weighed with a scale. Detergent was also weighed before laundry took place and after laundry was finished. The general water quality study was carried out on all the washing sites five minutes before and immediately after laundry-water with detergent was poured into the river. Before laundry-water was poured into the river, the following flow and water quality variables were measured: discharge, total hardness, turbidity, pH, electrical conductivity, chloride, phosphate, ammonium, nitrate, nitrite. All variables with the exception of discharge and hardness were measured again shortly after the laundry-water had been poured into the river and at 100m and 1000m downstream at time intervals estimated as being equivalent to the travel times for water between the washing site and the downstream sampling sites. The travel times were estimated from the flow velocity that was determined earlier.

A discharge reading was taken using the velocity-area method and a flow metre (Marsh-McBirney Flo-mate model 2000 portable flow-metre), and the total hardness of water was determined using Visocolor Macherey-Nagel relevant test kit. Before and immediately after laundry water was poured into the river chloride, ammonium, nitrate, nitrite, and phosphate were determined using relevant test kits on the washing site, as well as at 100m and 1000m from the washing site on each site before. Electrical conductivity, pH, and the turbidity of water were determined using the relevant metres (Hanna Instruments HI 8733 conductivity metre, Eutech Cybernetics pH scan WP metre, Orbeco-Helige Analytical Systems Turbidity metre) and, immediately after laundry water with detergent was poured into the river as well as at 100m and 1000m from the washing site on each site before. Laundry water entered the river approximately over an hour, as community members doing laundry did not finish their laundry at the same time. Recovery period of the flow of about 15 minutes was however allowed from one study to the next of the next in-stream use of detergent.

3.2.5 Chemical properties of detergent solutions

A laboratory analysis was conducted to investigate the chemical properties of different brands of detergents. The selection of the properties to be examined in the experiment was based:

- on the suspected ingredients to be found in these detergents as suggested by the literature on previous work on the field (Kruger, 1992 ; Guhl, 1992; Gerike *et al.*, 1990; Matthijs *et al.*, 1995; and Schroder, 1995),
- on the test kits that were available at the time of the analysis.

Solutions of Omo®, Surf®, and Sunlight® soaps were made up (5, 10, 15 g/l). The pH, turbidity, and electrical conductivity of each solution was measured using appropriate metres. Phosphate, chloride, ammonium, nitrate, and nitrite of each solution was also measured using the Visocolor Macherey-Nagel Test Kits.

3.3 Results and Discussion

3.3.1 Describing the washing practises in the study area

The summarised findings from the eight communities interviewed regarding the washing patterns are presented in Appendices 3 and 4. The questionnaire survey conducted in the upper Kat River area served two purposes:

- providing deeper understanding of the nature and extent of water quality problems. The nature of basic services (water supply, sanitation and waste disposal) in the area was established with the survey,
- describing the washing practices in the area.

Survey results that are presented in this chapter are only those which aided in describing the washing practices. Other results of the survey have been presented in Chapter 2.

3.3.1.1 Washing practises in the Kat River valley

Laundry frequency per week

Figure 7 shows the frequency with which laundry is done by the families in the study area per week. The questionnaire survey results show that most families in the study area (44 percent) do laundry twice per week. A fair number (24 percent) does laundry once per week, and smaller numbers (16 percent and 16 percent) do their laundry three and four times per week respectively.

Laundry frequency at home per week

Figure 8 illustrates the laundry frequency at home per week by the communities in the study area. It would seem as though most communities in the study area (40 percent) do their laundry at home at least once or twice per week, compared to the 38 percent who indicated that they never do any laundry at home, and the 22 percent who does their laundry at their homes about three times per week. Whether laundry done at home does impact on the quality of water resources or not is a matter of further investigation.

Laundry frequency at the river per week

Figure 9 shows the frequency with which laundry is done at the river per week in the study area. The information shows that most of the people in the study area (79 percent) do not do any washing by the river per week, compared to 21 percent who indicated that they did some washing at least once per week. It would appear that there is some discrepancy in these results. For example, if 38 percent of the families never wash at home (Figure 8), and 79 percent never wash by the river (Figure 9), it appears that some families (17 percent) never wash.

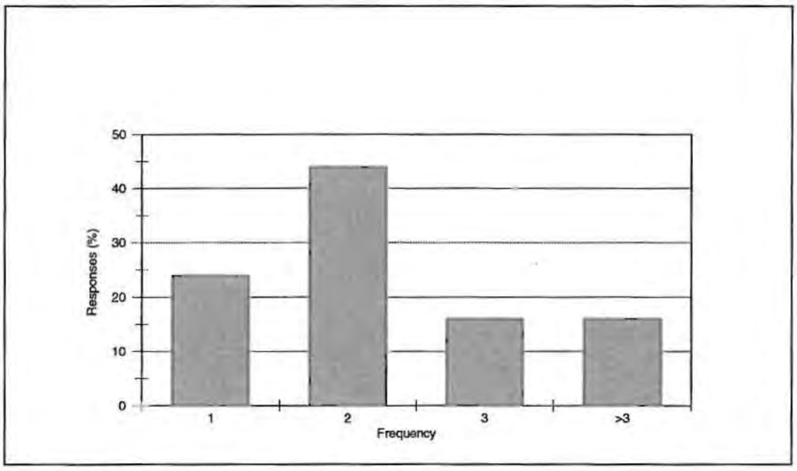

Figure 7: Frequency at which laundry is done by the community members in the study area per week

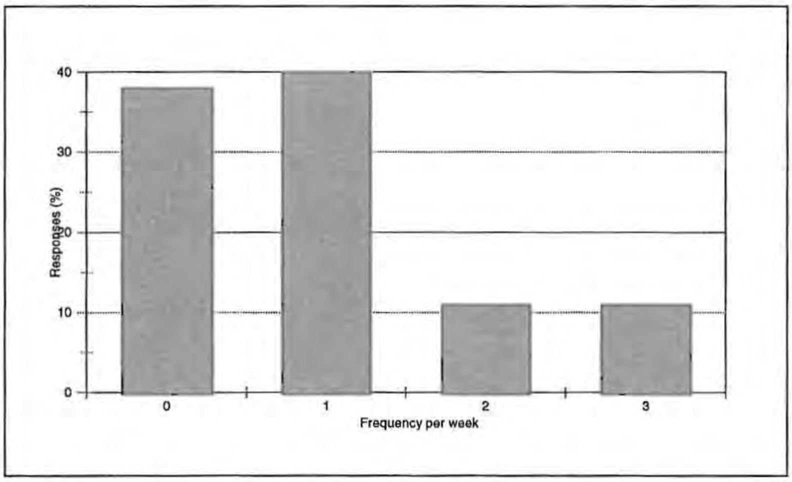

Figure 8: The laundry frequency at home per week

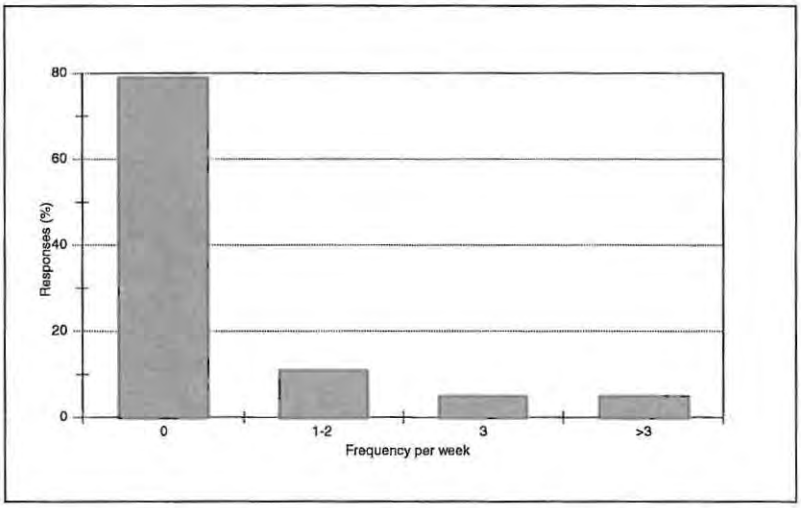

Figure 9: The frequency at which laundry is done at the river per week

Family member doing washing

Figure10 shows the family members doing washing in the study area. In 55 percent of the families in the study area, children wash. In a fair number of the families (44 percent) the mother does the washing, compared to 1 percent of families in which the father does the washing.

Most commonly used laundry detergents in the study area

Figure 11 show the most commonly used laundry detergents in the study area. Results of the survey show that Omo® washing powder is by far the most commonly used laundry detergent (64 percent) in the study area, compared to Surf washing powder (19 percent) and Sunlight bar soap (17 percent).

Frequency of detergent purchase per month

Figure 12 shows the frequency of detergent purchase in the study area per month. Results show that 67 percent of the families in the study area buy detergents once per month. A fair number (21 percent) of people in the area buy laundry detergents twice per month, compared to the 12 percent that buy detergents three times per month.

Detergent use (kg/village/month)

Figure 13 illustrates the average consumption of detergents in kilogram per village per month. About five respondents per study community were requested to indicate the number of households in their village. Results of such survey and the results of the questionnaire survey were used to estimate the consumption of detergent per village. On average, each consumes 136, 99kg/month, and 71 kg/month of Omo®, Surf®, and Sunlight® respectively. In total, eight study communities consume 2448kg of detergent per month.

It is important to note the strong relationship between the 55 percent of families in which children do the laundry (Figure 10) and the 55 percent of respondents who indicated that they do washing in groups (Figure 14). Thus, there is an indication that it is the children who normally washing together at the river. This confirmed a wide outcry from the elderly community members that it is the young generation that still practice the in-stream laundry habit.

There is a relationship between the two responses mentioned above and the most common washing place (48 percent) in the study area (Figure 16). The average of the three responses gives a fair indication that at least 53 percent of the communities in the study area practice in-stream washing. Assuming that the detergent quantity use is the same in every wash load,

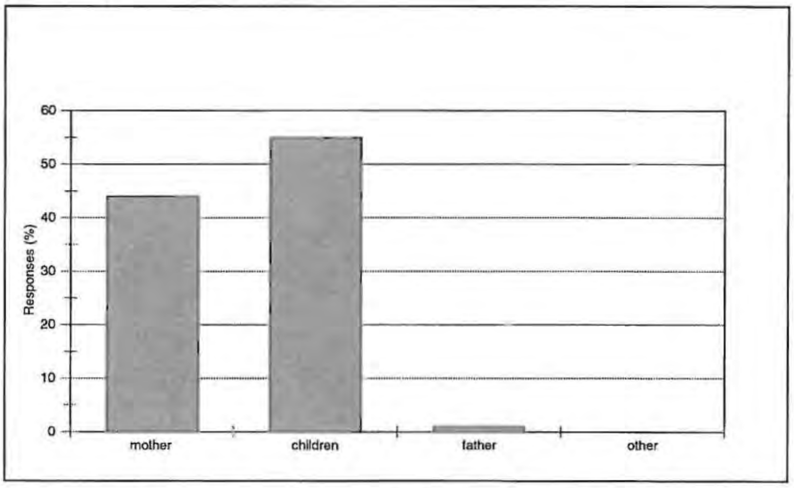

Figure 10: Family members doing washing in the study area

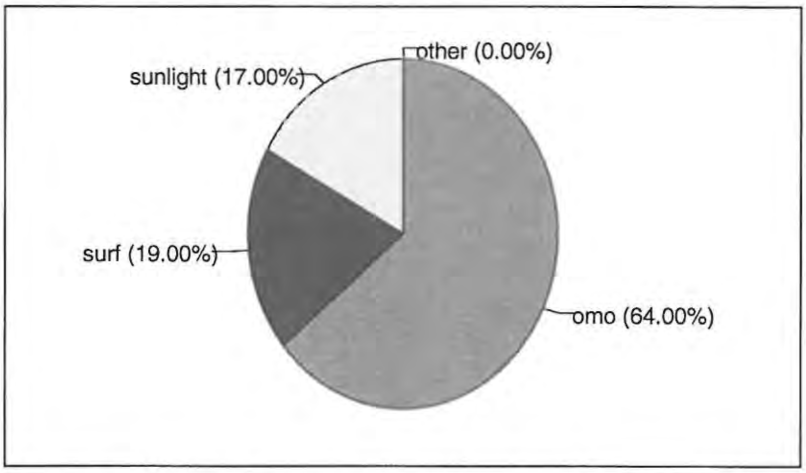

Figure 11: The most commonly used laundry detergents in the area

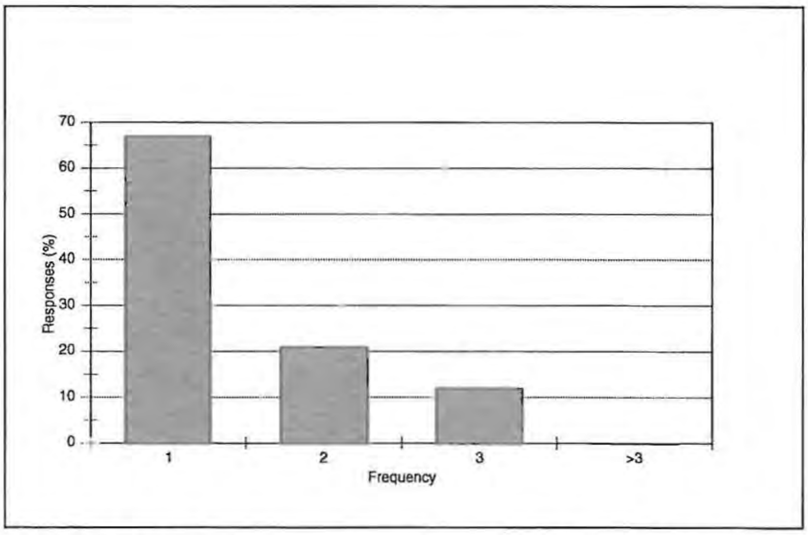

Figure 12: The frequency of detergents purchase in the study area per month

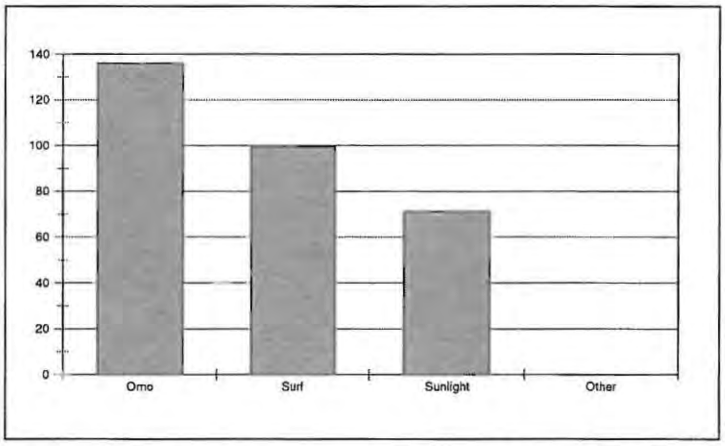

Figure 13: The average consumption of laundry detergents per kilogram per village per month

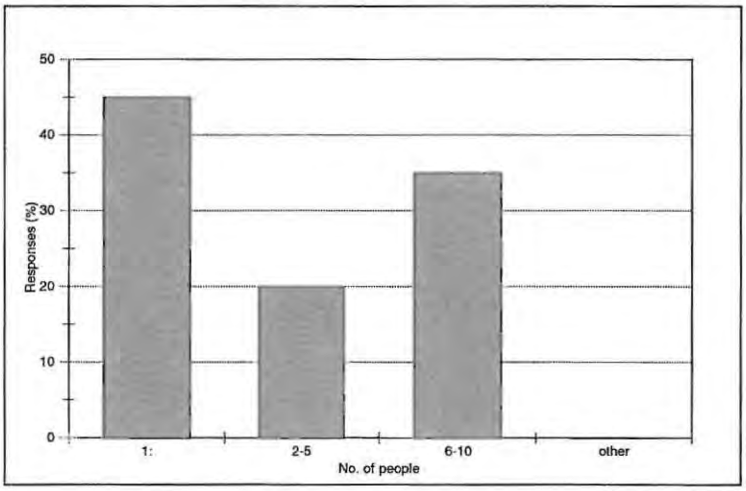

Figure 14: Number of people doing washing per time in the area

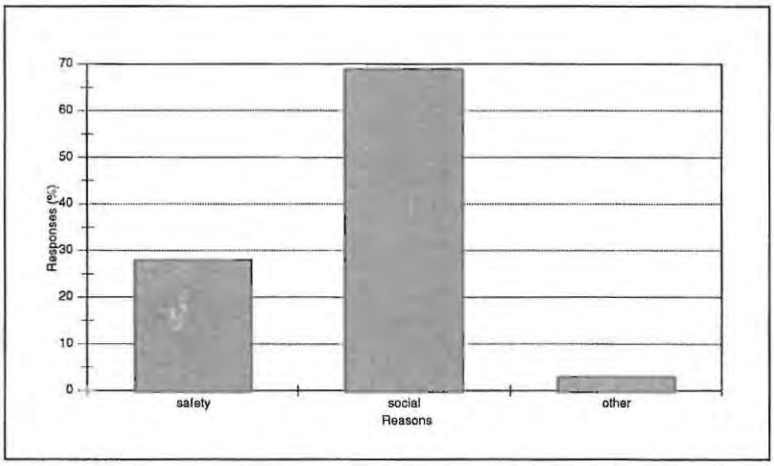

Figure 15: Reasons for doing washing in groups

then 53 percent of the total detergents consumed in the study area (1296kg) would end up in the river channel every month.

Number of people doing washing per time

Figure 14 indicates the number of people doing washing per time in the Kat River valley area. Information shows that most people in the study area (55 percent) prefer doing washing in groups at the river, compared to the 45 percent who do washing at home on their own. The group washing is also indicating the place of washing, as all those who wash in the river noted that they always do washing in groups, whilst all those who wash at homes indicated that they do their laundry on their own.

Reasons for doing washing in groups

Figure 15 gives reasons why most community members in the study area do washing in groups. The results of the survey indicate that social reasons are by far the most common reason (69 percent) why most community members prefer doing washing in groups. In comparison, a fair number of community members (28 percent) indicated safety, whilst only 3 percent cited other reasons as being the driving forces why people do washing in groups.

Most popular washing day in the area

Results of the study indicate that Saturday is by far the most popular washing day (96 percent) in the area compared to Friday (4 percent) and other days (0 percent).

Most popular washing place in the village

Figure 16 indicate the most commonly used washing place in the area. Contrary to the responses on laundry frequency at the river per week, in which 79 percent of respondents indicated that they never did any washing at the river, the river has emerged as the most commonly used washing place (48 percent) in the area. The homes faired at 37 percent and dams and taps at 12 and 3 percent respectively.

Plate 9: Most popular washing place in the area

Other things washed at the river besides clothes

Figure 17 show things washed at the river besides clothes. Results of the survey indicate that humans, motor-cars and blankets are being washed at the river.

3.3.1.2 Aspects of interest at Balfour

Balfour has the highest number of employed people (66 percent) in the study area. Survey results also show that Balfour has the highest bracket of earners compared to other villages, with 52 percent of the communities earning above R1000-00. Results of the survey show that

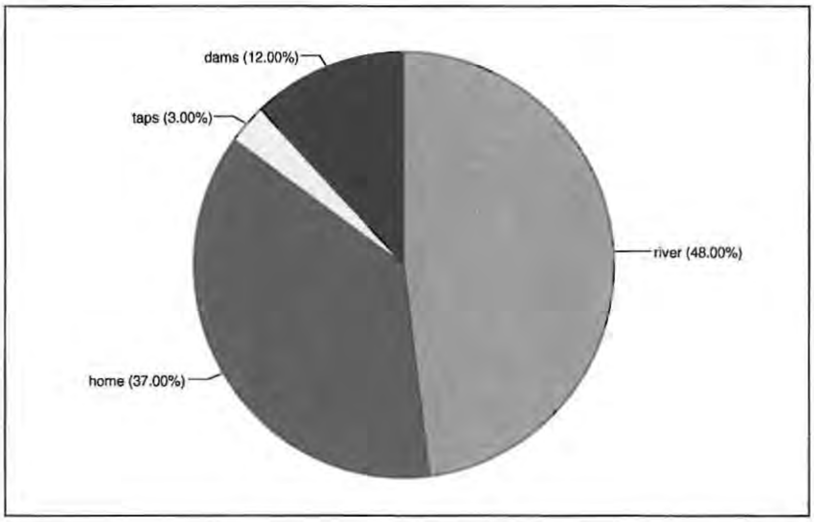

Figure 16: The most commonly used places for laundry in the study area

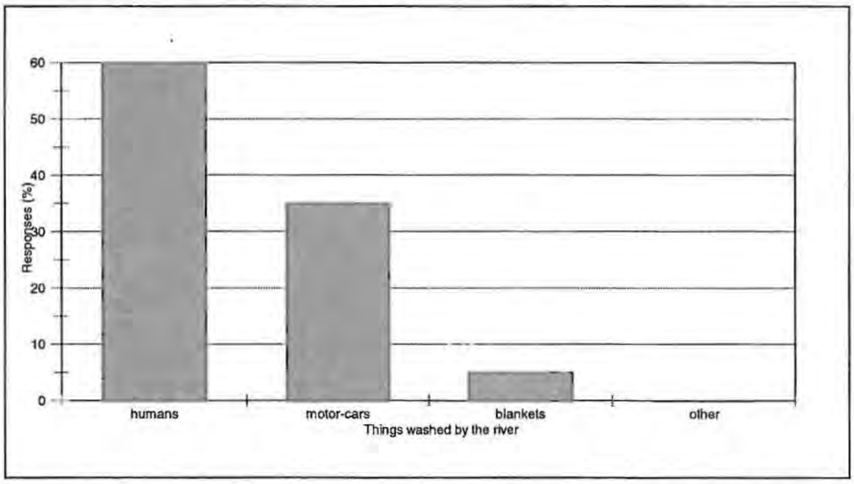

Figure 17: Other things washed at the river besides clothes in the area

Balfour is also one of the three villages that has access to piped water in the study area, the other two being Entilini and Gonzana (Appendices 2 and 4). Balfour is one of the two electrified villages in the study area (the other one being Entilini - Appendix 2).

One would thus easily conclude that Balfour is the wealthiest of all the studied villages. It is however interesting to learn that, although both Balfour and Entilini communities have access to piped water, survey results show them amongst the four villages of most intense in-stream washing, the other two being Fairbairn and Hertzog. The Balfour community, specifically, has indicated that their tap water did not produce any lather, and that much higher quantities of detergents are necessary when using tap water compared to river water. As a follow up to the problem, water samples were collected from each tap at Balfour five times, and analysed. Community's concerns were confirmed, as the tap water was found to be comparatively harder than river water.

3.3.2 Analysing selected chemical properties of detergent solutions

From Figure 18 and appendix 5, an increase in the electrical conductivity, turbidity, pH, and chloride is noted in all detergent solutions as the concentration of detergent increases. Some elements were present in one detergent, but not in others. For example, nitrite and nitrate were found in Omo solutions only, and ammonium was found in Surf solutions only. The results obtained from the analysis indicate that the input of detergent in the water has a degrading effect in the quality of water.

3.3.3 Studying the in stream washing practises

In this section, the results of the pilot study carried out in three washing sites are presented. Appendix 6 gives a summary of the observations carried out on the washing sites. From Appendices 6, 7, 8 and 9 one can observe a relationship between an average amount of detergent used per 1000g of dirty laundry, and the total hardness of water trends.

At Site 1, for example, the average total hardness to date has been 0.94mmol/l ($CaCo_3$ – 9.4 mg/l), and the average amount of detergent used per 1000g of laundry is 33.2mg. In Site 4, where water is slightly harder {1.0mmol/l ($CaCo_3$ - 10 mg/l)}, the average amount of detergent used per 1000mg of dirty laundry is also higher (35.3mg). Site 9 has the hardest water of the 3 sites, {1.54mmol/l ($CaCo_3$ – 15.4 mg/l)}, and also the has the highest consumption of detergent per 1000g of dirty washing, (49.8mg). Similar trends are evident between an average amount of detergent used by 1 person per washing day and the total hardness of water used in washing the clothes. Thus, it is a common trend that the harder the water used in washing the clothes, the higher the amount of detergent used in washing clothes

3.3.3.1 The impact of the in-stream washing on water chemistry of the Kat River and the Balfour tributary

Results of the study of the impact of detergents on water quality of the Kat River and the Balfour tributary are presented in Appendices 7, 8 and 9. Trends of elements resulting from the input of detergents in water are outlined below.

Electrical conductivity

Figure 19 demonstrates the electrical conductivity trends after water with detergent was poured into the river. A sharp increase in electrical conductivity is evident in all 3 sites after an input of detergents into water. The recorded increase is twice the concentration at Sites 1 and 9, whilst it is more than 3 times at Site 4. A clear evidence of recovery becomes pronounced with the distance from the source of pollution. At a distance of 1km from the source, EC in Sites 1 and 9 has almost recovered completely. In Site 4 recovery is also understandable.

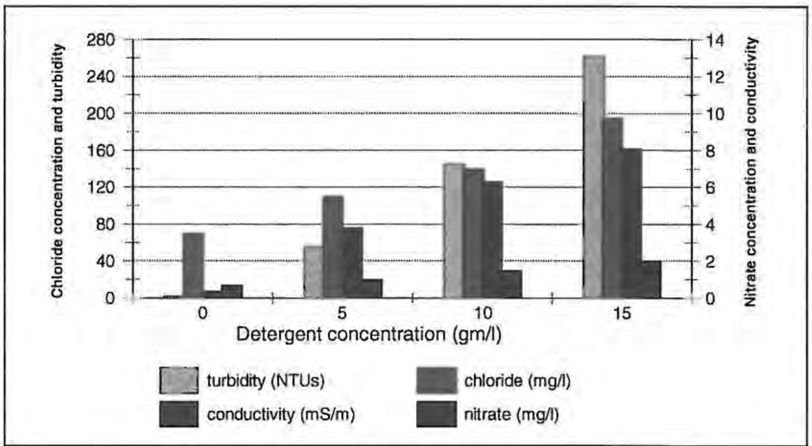

Figure 18: Impact of Omo washing powder on water quality – laboratory analysis of selected chemical variables of detergent solutions of increasing concentration

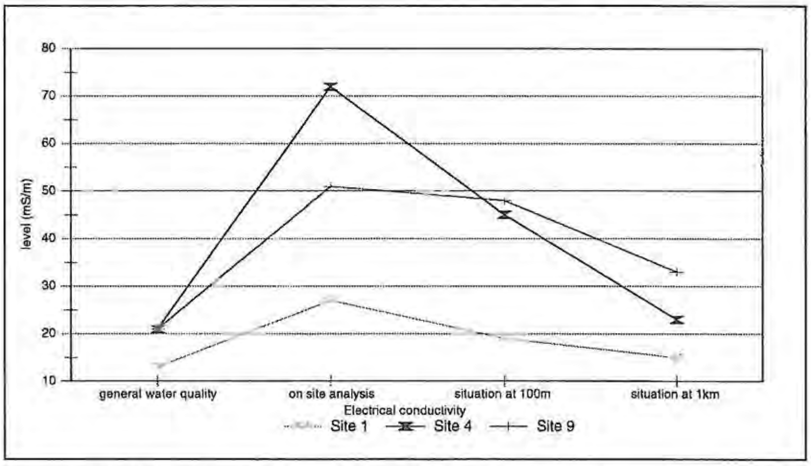

Figure 19: The electrical conductivity trends in three washing sites

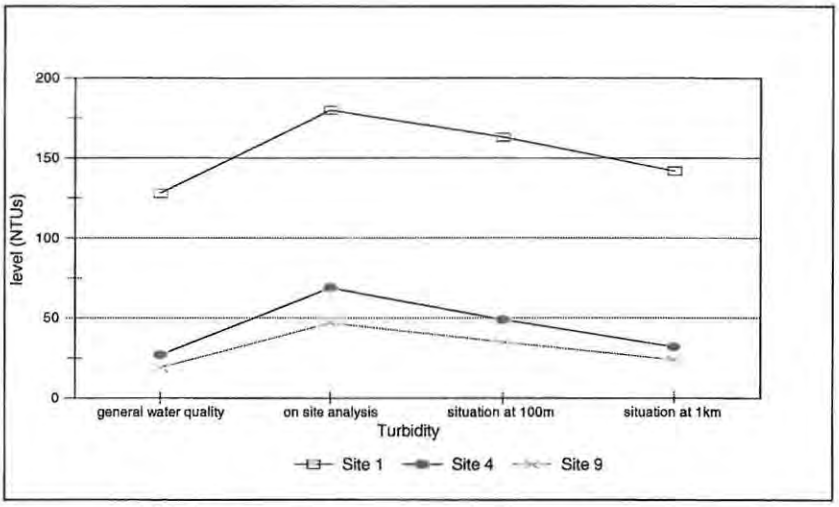

Figure 20:Turbidity trends in three washing sites

Turbidity

Figure 20 shows the turbidity trends from the water samples collected from the respective sampling sites before and after water of the river has come into contact with water with detergents. The recovery is also complete after 1 kilometre from the washing site. Thus, by implication, water becomes more turbid after the input of detergents from washing.

pH

Figure 21 show pH trends established after river water has come into contact with detergents. pH also increases after the detergent input. pH increases by 1.3 units at Site 1, 1.1 units in Site 9 and 1.5 units in Site 4. The recovery is also almost complete after 1 kilometer.

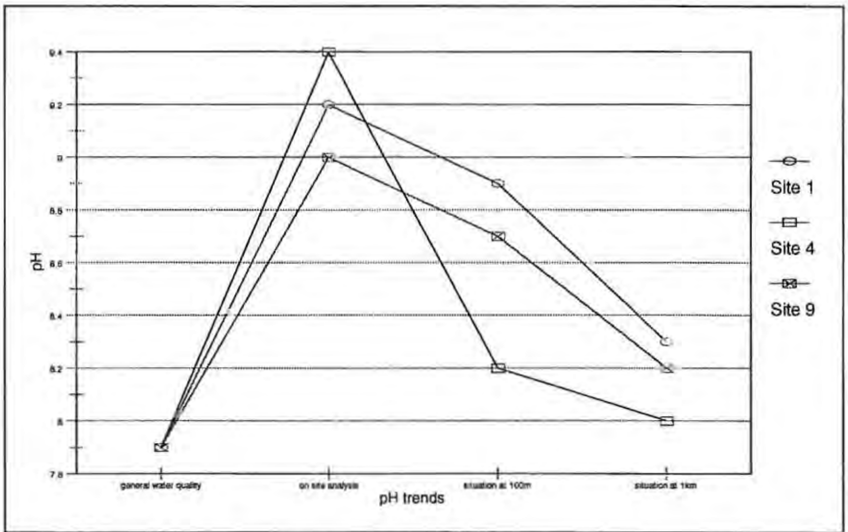

Figure 21: pH trends in 3 washing sites

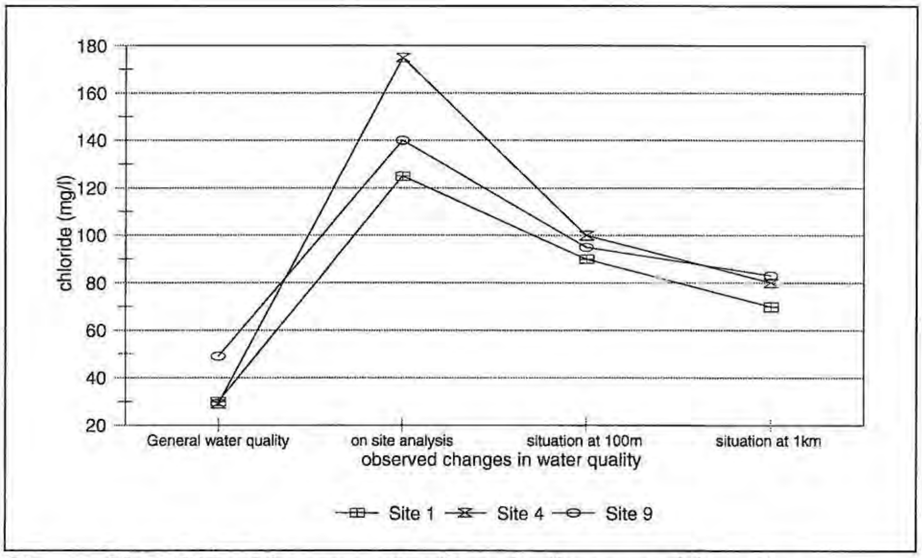

Figure 22a: Chloride concentrations in three washing sites

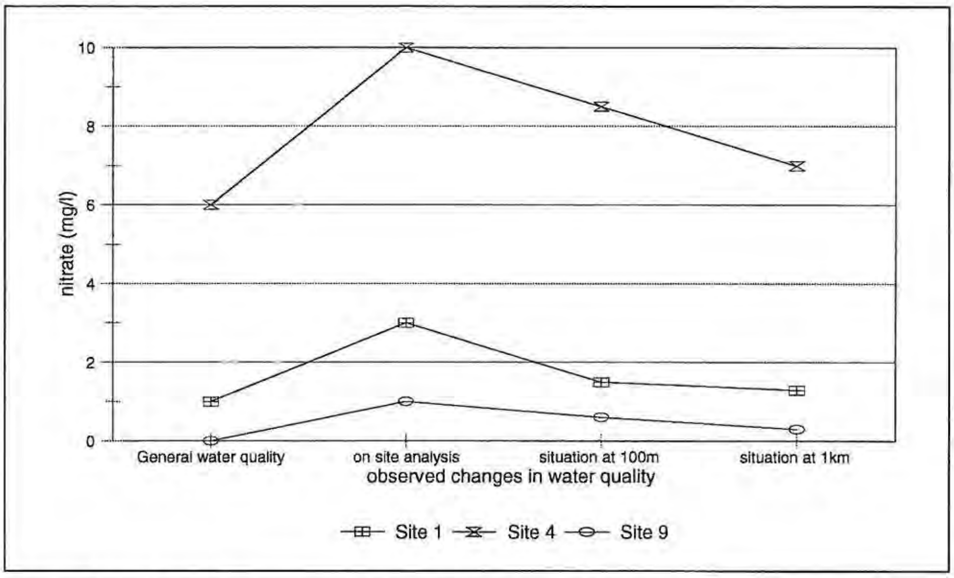

Figure 22b: Nitrate concentrations in three washing sites

Ammonium

In Site 9, ammonium was not observed. But it has been identified in Sites 1 and 4 after an input of detergents in water.

Chloride

Chloride concentration in all samples increased significantly. On Site 1, chloride levels increase by more than 4 times after water has come in contact with detergents, whilst it increases by almost 3 times in Site 9. Chloride concentration increases by more than 6 times in Site 4. Thus, by implication, water has become more saline as a result of input of detergent.

Nitrate, nitrite, and phosphate

An increase in nitrate level in all Sites is also apparent. Nitrite was also more evident after input of detergents in water. Phosphate was not found in any of the sites. Thus, by implication, water becomes more nutrient enriched as a consequence of input of detergents in water.

3.3.4 Discussion

There is no doubt that washing at the river is a practised widely in the study area. There is thus a direct input of detergents into the flow. It is estimated that monthly, more than 1296kg of detergent enter streams directly in the study area. Also, considering that 96 percent of the communities do their washing on Saturday; 55 percent do it in groups; and that the most popular washing place (48 %) is the river, concentrated inputs of detergents into the system are unavoidable.

Literature suggests that surfactants are particularly toxic to the aquatic environment (Bath, 1989; Kruger, 1992; and Pillay, 1994). Surfactants are a wide and diverse group of chemicals, typically consisting of a polar head group that confers the solubility of water, and a hydrophobic tail (typically C_{12} - C_{18} alkyl chains) that confers solubility of lipids (Versteeg *et al.*, 1996). When added to a mixed system such as water and air or water and soil, surfactants result in a decreased interfacial tension. The surface tension is reduced as surfactant is added to water until a point termed the Critical Micelle Concentration (CMCs)is reached.

This reduction of surface tension affects biotic surfaces involved in gaseous exchange, for example, gills. Food absorption surfaces such as guts are also affected. Consequently, the biotic community structure and functioning are affected.

In this study, the main focus has been on water quality in relation to people. However, attention was also paid to the ecological effects of in-stream washing. The washing habit reported on this chapter formed a critical part of a report to the international detergent manufacturing company (Muller *et al.* 2001). This study focussed on investigating the potential ecological effects of in-stream washing in the Balfour River (washing site 9). Muller *et al.* (2001) undertook biomonitoring studies (Chutter, 1998) upstream and downstream of washing site 9.

There was no discernable change in the invertebrate biomonitoring score upstream and downstream of the washing site. The only noticeable change was at a point downstream of a polluted stream. Muller *et al.* (2001) aimed to relate the toxicity of detergents to the in-stream concentration of the active agent in Omo® washing powder [linear alkylbenzene sulfonate (LAS), measured as methylene-blue-active substance (MBAS)]. They simulated a "worst case" washing event using the results of this study. The total mass of a typical Saturday morning was mixed and dosed at washing site 9.

The in-stream concentrations of LAS were then related to the toxicity results (Mkize, 2000 and Tshwete, 2000). Toxicity concentrations of LAS were reached in-stream. These peak concentrations were however short-lived (less than 20 minutes). This, together with the fact that washing event is spread through time probably account for the lack of impact on in-stream biota.

Knowing the mass of Omo® washing powder with which to simulate a washing event was critical to the conclusion reached by Muller *et al.* (2001) that in-stream washing was having a negligible effect on in-stream biota in the Balfour River. However, Muller *et al.* (2001)'s observation does not mean that direct and indirect input of detergents into the stream should not be controlled. In the Netherlands, for example, the Dutch Soap Association (NVZ), Dutch Ministry of housing, Spatial Planning and Environment (VROM) and the National Institute of Public Health and Environment (RIVM) held the Environmental Risk Assessment of Detergents' workshop on April 1992. This workshop was a follow up to the voluntary plan of action agreed upon by the NVZ and VROM that: firstly, the environmental loading of detergents and cleaning products need to be systematically evaluated, taking into account the minimum hygiene needs, and secondly, to consider the necessity of reducing loadings. In the workshop, a comprehensive approach was adopted. The approached entailed determining risk by comparing the predicted no effect concentration (PNEC) with predicted exposure concentration (PEC) (Feijtel *et al.*, 1999).

In the United States of America (USA), there is recent emphasis on improving receiving waters through regulation of point source discharges and non-point pollution. Through the use of water quality based approach to controlling point source discharges, regulatory agencies are reducing toxic discharges. Effluent toxicity testing has become routinely required in the National Pollutant Discharge Elimination System (NPDES) permits issued to municipal and industrial facilities and has been used to set criteria for acceptable effluent quality (Dorn *et al.* 1993). More specifically, the realisation that eutrophication is becoming a constant problem (US EPA, 1983) led to the development of strategies for reducing nitrogen and phosphorus entering the aquatic environment by 40 percent by the year 2000. This in turn has led to the implementation of phosphate detergent ban in January, 1988 (Hoffman and Bishop, 1994).

So far as the phosphates are concerned, considerable efforts have been made to remove them from detergents. For example, in Germany, a specific piece of legislation, the Maximum Phosphate Amendment to the Detergents Act of 1964, was passed with the aim of minimising the use of phosphate as major detergent surfactant. The work by Matthijs *et al.* (1995) and Schroder (1995) aimed to study the effect of the implementation of that legislation.

However, in South Africa, some parts are first world whilst others are still underdeveloped because of the country's past policies that were favouring one population group over others.

Thus, in developed parts of the country, it would be expected that detergents reach the aquatic bodies via sewage works where water is treated before disposal. In the underdeveloped parts of the country, however, the lack of sewage services, water supply and other factors might lead to widespread in-stream washing. This results in detergents getting directly into surface water bodies without prior treatment.

The literature documented in Appendix 21 above clearly illustrates that changes in toxicity of detergent surfactants do occur in the sewage works. In particular, it has been established that the toxicity of detergent surfactants is reduced during the sewage treatment work. These changes however do not occur when detergents go directly into the surface water body.

The studies by Mkhize (2000) and Tshwete (2000) clearly illustrate this difference and its effects on aquatic organisms. Both exposed the same species of mayfly nymphs (*Adonophlebia auriculata* and *Afroptilum sudafricanum*) from the same location to different concentrations of detergent. Tshwete (2000) also used different concentrations of detergent mixed with final sewage effluent and final sewage effluent as toxicants. The findings of Mkhize (2000) and Tshwete (2000) indicated that detergents have considerable impact on aquatic organisms. Tshwete (2000) also realised that the bacteria in sewage treatment effluent lessen the toxicity of surfactants.

The Muller *et al.* (2001) study is reassuring, and specifically in the Kat River, indicated that for both ecological and human health, a wider range of water quality and land-sue activities need to be considered.

Chapter 4
Water Quality Monitoring

The purpose of this chapter is threefold: first is to outline the research methods and techniques employed to satisfy the aim and some objectives spelt out in Chapter 1, section 1.6. Second is to present the results of water quality monitoring conducted in the upper Kat river area. Third is to discuss the water quality trends established during data analysis and determine the potential extent of the water pollution on the health and welfare of the water use communities in the area. Literature review linking land-use to the quality of water is presented in Section 2.2 of Chapter 2. Discussion of the water quality trends is presented in Chapter 5.

4.1 Water Quality Monitoring methods and techniques

4.1.1 Introduction

The purpose of this section is to outline the research methods employed to satisfy the aim and objectives relating to the study of water quality in the upper Kat River area spelt out in the section 1.6 of Chapter 1. The following techniques were utilised to satisfy the aim and objectives of the study

- the collection of water samples from certain pre-determined points along the course of the Kat River,
- the field and laboratory analysis of these samples to assess the concentrations of nutrients and other chemical and physical properties of water,

4.1.2 Identifying the target communities

For the purpose of studying the impact of the Black village communities and their associated land use practises on water quality, three village communities in the upper Kat River were selected. These are: Hertzog; Fairbairn and Balfour Black village communities. As noted in Chapter 3, the area selected for the description of washing practices covered a larger area compared to the water quality study as five more villages were selected. The difference in size between the two studies can be explained as follows:

- to obtain a broader catchment picture of the washing practices in the area, (as required by the company that funded this part of the study) more communities were selected,
- the size of the catchment is too big for the water quality monitoring study of this scale. Thus, accessibility had to be considered.

Section 2.2.1 of Chapter 2 is giving a detailed outline of how study communities were selected.

4.1.3 Identifying the sampling sites for general water quality, and sampling

4.1.3.1 Identifying the sites for the general water quality study

Initially, 11 sampling points were selected (site 1 – 10 and site 12. It was however later realised that the Buxton River might be affecting the quality of water of the Balfour, hence Kat River. Site 11 was thus selected along at the end of July 2000 at the Buxton River to determine this impact. Site 11 was

sampled only 10 times. The 12 sampling sites of the study are illustrated in Figure 1 as follows:
6 sampling sites were located along the upper Kat River and tributaries as follows:

- Site 1 was located upstream of Hertzog community. Above this site some considerable amount of cultivation is taking place. This site is also the first site below that Kat River Dam.
- Site 2 was located on the Hertzog stream at a point just before it joins the Kat River. This site was chosen to indicate both the level of pollution of the stream as influenced by land use activities upstream, which include intensive grazing, crop farming activities, and the old septic tank system, and the extent to which the Hertzog stream contributes to the pollution of the Kat River,
- Site 3 is located on the Kat River between Hertzog and Fairbairn communities (this should be indicating the impact of both the Hertzog stream and the Hertzog community on the water quality of the Kat River),
- Site 4 is located below the Fairbairn community. Results obtained from this site gave an indication of the extent to which the Fairbairn community and related activities such as crop farming and grazing impact on the water quality of the Kat River,
- Site 5 was located on the Fairbairn stream, upstream of its confluence with the Kat River. The level of pollution of this stream and the role the stream is playing on the pollution of Kat River water will be determined from this site,
- Site 6 was located at the point just before the Kat River is joined by the Balfour River. This site was well below the Fairbairn stream. Amongst others, this site reflected how the Fairbairn stream impacted on the water quality of the Kat River and the quality of the extent of pollution of Kat River water compared with Balfour River.

Six sites along the Balfour River and its tributaries was identified as follows (see Figure 1):

- Site 7 was located upstream of the Balfour village (Site 7).
- two streams that join Balfour River below the previous site were sampled to determine the input they were having on water quality of the Balfour River (Sites 8 and 10).
- Site 9 was located on the main stream below Site 8 and below Balfour village. This site indicated the difference in water quality compared to Site 7. It indicated the impact of the Balfour community and Sites 8 and 10 on the water quality of Balfour stream,
- Site 11 was also identified on the Buxton River, which is the significant tributary of the Balfour River.
- Site 12 was located just before Balfour River flows into the Kat River. Site 12 integrates all upstream effects and provides a comparison with the Kat River.

4.1.3.2 Sampling

A fixed-interval monitoring programme as suggested by Bleuten (1989) and DWAF (1999) was adopted. Water samples were collected twice monthly over a period of 40 weeks (from the 15^{th} of

March 2000 to the 16^{th} of December 2000), irrespective of the flow conditions at all pre-determined study sites along the upper Kat River catchment. During this period 21 samples were collected from each site. This is in line with the Department of Water Affairs and Forestry's recommendation that, if a river, stream, spring, or well is being monitored, a minimum of 4 and maximum of 26 samples should be collected per study site per year (DWAF. 1999).

According to Bleuten (1989), data collected from such a programme should be useful in establishing the existing pollution level. The result should also show both spatial and temporal variations of the water quality parameters. DWAF (1999) adds that this data should be useful in assessing the average quality of water.

Bleuten (1989), however, identified the following shortcomings of the fixed interval monitoring programmes:

- such programmes may yield inaccurate concentration levels,
- as a consequence of missing interval from one sampling period to another, peak concentrations can be easily missed.

All samples were collected from the mid-stream with pre-cleaned polythylene bottles. Sample bottle lids were closed whilst the sample bottle was still under water, at an approximate depth of about 15cm as suggested by Jain *et al.* (1998). According to Baird (1995), ensures that atmospheric pollutants do not contaminate the sample.

The discharge at all sampling sites was measured during each visit using an electro-magnetic Marsh-Binney flow metre by the area-velocity method as in Jain *et al.* (1998). Although the flow metre was easy to use, one of its properties was that the sensor had to be under water for any readings to be done. This proved to be problematic in very shallow flows. This meant that in some parts of the river, particularly where the river bed was very shallow, as in Site 1, measuring discharge was always going to be very challenging and prone to instrument error. Also, during the low flow season, determining discharge of an increased number of sites. In some instances it was not possible to do any discharge readings although flows could be observed.

All water quality variables were measured on site by means of portable metres and relevant test kits.

4.1.4 Determining water quality in relation to the village activities

Expenses involved in analysing water quality are high. Expenses for the laboratory analysis are even more, as each sample needs to be preserved to maintain the chemical, especially the nutrient status of the sample. It is for that reason that most of the water quality analysis was carried out on each site in the field. Some samples were collected and taken to the water quality laboratory, from which a more accurate analysis was undertaken. This was done when a critical water quality problem was picked up during the on-site analysis. The purpose of the laboratory analysis was to determine the exact amount of the problematic water quality variable.

4.1.4.1 Selecting variables of concern

As noted above, the process of analysing water samples is expensive. According to United States Environmental Protection Agency - US EPA (1986), the selection of which elements to be analysed is always problematic and should be based on a criteria that best suites the study being conducted. As Dallas et al, (1994: 21) put it:

"Every chemical component and every physical attributes of a water sample contribute to the water quality of the sample. For any sample, tens or hundreds of physical attributes can be measured and any number of the tens of thousands of known chemicals may conceivably be present".

Major ions like sodium, potassium, calcium, magnesium, chloride, sulphate, bicarbonate and carbonate are freely existing in every drop of water in greater or lesser quantities. Other inorganic ions (which include nutrients like nitrogen, phosphorus, and silicon and a host of elements present in trace quantities) are also present, but usually at concentrations much lower than those of major ions. Most of the trace metals are extremely toxic, but are rarely present at toxic concentrations under natural conditions. Many effluents from mines and several industries carry potentially toxic quantities of trace metals and other inorganics (WRC, 1997). The soluble organic compounds (products of the metabolism or decomposition of aquatic organisms) could be present in natural water sample.

In short, there are thousands of water quality variables that could have been analysed in this study. However, it is clearly not feasible nor necessary to include all of them (Dallas and Day 1993). WRC (1998) reveals that, although a great many substances can be found in water, only a few of these commonly occur in concentrations high enough to be of concern to water users. A number of likely sources of pollution have been noted in the study area. Thus, the most important substances assessed in this study are those that are likely to occur in concentrations high enough to cause health, aesthetic, environmental and other problems. These are presented in Table 4 below.

Thus, a number of factors affected the decision of which elements were to be included in the analyses stage of this study. These factors include the following:

- the research aims and objectives,
- the type of pollution problems that are likely to occur in the study area,
- where the assessment is taking place i.e., at the source, the treatment or lack of treatment works or the point of source,
- what the source of water is i.e, river, stream, well, borehole, dam, rainwater tank,
- the kind of problems, if any, that have been experienced with similar sources in the vicinity, and

- the available resources (WHO, 1992).
- also contributing to the selection of 'variables of concern' was the results of studies undertaken under this project such as the questionnaires and the detergent field and laboratory studies.

Table 4: Substances which are general indicators of water quality

Electrical conductivity	Conductivity is an indicator of total dissolved salts (TDS), and also establishes whether it is drinkable and capable of slaking thirst.
Faecal coliforms	This is an indicator of the possible presence of disease causing organisms. It establishes whether water is polluted with faecal matter.
pH value	This has a marked effect on the taste of the water and also indicates possible corrosion problems and potential copper, zinc and cadmium problems.
Turbidity	This affects the appearance, and thus the aesthetic acceptability of the water. Turbidity is commonly high in surface waters.
Nitrate and nitrite	These are common in groundwater samples, particularly in areas of intensive agricultural activity, or where pit latrines are used. Severe toxic effects are possible in infants.
Chloride	This is often elevated in hot, arid areas, and on the western and southern Cape coasts (particularly in ground water). Chloride may cause nausea and vomiting at very high concentrations.
Potassium	This affects the taste of the water and is bitter at elevated concentrations.
Total Hardness	This is a combination of calcium and magnesium. It is associated with scaling and inhibition of soap lathering.
Ammonium	The un-ionised ammonia is highly toxic to fish and other aquatic plants and animals (Boyd, 1982).
Phosphate	This can stimulate the growth of algae and upset the ecological balance of large bodies of water.

Adapted from the Water Research Commission Report (1998)

4.1.4.2 Water quality assessment tools

Field kits

With the exception of the faecal coliforms, all water quality variables listed on Table 1 above were assessed in the field using the relevant kits or tools. All tools and kits used in this study are standard. Nitrate, nitrite, chloride, potassium, ammonium, phosphate, and total hardness, were determined using the relevant portable Marsh and Binney analytical kits. These kits were preferred amongst others because:

- they are less expensive than most instruments on the market,
- they are simple to use and carry,
- an existing problem can be picked up with them,
- they are suitable for the *in situ* analysis, and therefore costs are minimised as samples don't need not be transported over distances, a process which would otherwise require samples to be preserved (Jain *et al.*, 1998). Also, any on site analysis is applauded by DWAF (1993) as it minimises error of analysis often associated with transporting samples. For example, it is has been noted that some water quality variables like nitrate, ammonium, and nitrite are readily

interchangeable through the processes like nitrification (Anderson and Darcup, 1976) and that the longer it takes for samples to be analysed after being collected, the higher are the chances of inaccuracies (Lornezen and Chen, 1977).

One major limitation of these test kits is that they are of a lower accuracy range. To counter this limitation, an internal standardisation was applied. The accuracy level of the kits was determined. Water samples were collected from the Grahamstown Blaaukrantz and Matyana streams. Nitrate was then determined from both samples and distilled water using the test kits and Merck Spectroquant SQ 118.

The determination principle on both the Spectroquant analysis and the analysis using the kits was concerned with a colour reaction of a specified reagent and the contents of the sample. The intensity of the colour in both was a measure of concentration. In both the Spectroquant analysis system and the water quality test kits analysis system, the liquid reagent was measured by counting the drops from a dropping bottle. The powdered reagent was measured out with a spoon. Following are the results of the analysis.

Table 5: Water Quality Analytical Kits against the Spectroquant SQ 118 results

Analysis using the Portable Marsh and Binney Water Quality Analytical Kits			**Analysis using the Spectroquant SQ 118 analysis system**		
Distilled Water	***Blaaukrantz River sample***	***Matyana River sample***	***Distilled Water***	***Blaaukrantz River sample***	***Matyana River sample***
0mg/l	10 mg/l	91 mg/l	0 mg/l	18.6 mg/l	91.2 mg/l

From the results above, a disparity is noticeable that on a Blaaukrantz River sample. The test kits detected 8.6 mg/l lesser than the Spectroquant analysis. On the Matyana River sample, where nitrate concentrations are higher, the only difference between the analysis results is 0.2 mg/l. It would therefore appear that the kits are more accurate on detecting the higher than the lower concentrations of substances in water.

Electrical conductivity was measured with the Hanna Instruments H18633 EC metre. pH of water was assessed using the Eutech Cybernetics pHScanWP 1. Turbidity was assessed with the Orbeco-Analytical System Inc. model 966 portable turbidity kit. All study sites have been located using the Garmin GPS 2 PLUS instrument.

Laboratory

The faecal coliforms were assessed in the specialised facility of the Bio-Chemistry Department. The membrane filtration technique as suggested by Greenberg *et al.*, (1985) and DWAF (1993) was used.

Water samples were brought to the water quality laboratory at temperatures well below 4^0 C where their analysis for faecal coliforms took place immediately.

4.1.5 Determining the impact of water quality on the health and welfare of the study communities as well as making recommendations as to how to improve the water quality.

An upstream walk up the Hertzog stream was undertaken to assess the quality of water used by communities in the area. Sampling was done on regular intervals upstream. In particular, the point that were used by communities for drawing the water were sampled.

A workshop was arranged in which the concerned communities were invited to participate in a water quality issues discussion. It was during this workshop that the research findings of the study were shared with the communities. During the workshop, water related health and welfare problems of the water user communities were determined through the participatory discussions. It was in light of these findings that the recommendations to improve the quality of water were made with the involvement of the communities.

4.1.6 Results analysis tools

In addition to the ordinary spread sheets (Quatro Pro and Microsoft Excel) the water quality data was analysed using the statistical programme Statistica, amongst others, to determine the variability of the data over the study period. ArcView GIS programme was used to display the spatial variability of the water quality data.

4.1.7 Calculating loads from original data

Loads values were obtained by:

- concentration values of each water quality variable per site were obtained,
- discharge volume per site was also obtained,
- each concentration value was multiplied by discharge,

4.2 Results on water quality

4.2.1 Introduction

The aim of this section is to present the water quality results of the upper Kat River area per water quality variable. A brief summary of the hydrological conditions of the study area is given. A section that explores both the spatial and the temporal variations of each variable over the entire study area follows this. Mean results are used to explore the spatial variations of the variables. In particular, the means are used to reveal the following spatial aspects of the selected water quality variables:

- the downstream trends,
- highlight sites with most or least concentrations of the concerned variable.

The time series data are used to highlight the periods of high and low concentrations. To determine a link between the concentrations of water quality variables and hydrology, a brief comparison of dry and wet season variable concentrations is given. Also, compared are the dry and wet season mean loads per selected variable.

4.2.2 Hydrology of the study area

The state of flows of the upper Kat River area are presented in Figures 23 and 24 and Appendix 10. The high and low flows were recorded in the periods between March and July and September and December 2000 respectively. These findings would appear to suggest that the period between March and July was the wettest in the area, with the driest being the period between September and December. For example, mean flow reading at site 1 was more than 3 times higher during the period March to July than the period from September to December. The same is true with all other study sites in the area. For example, the difference between the two periods was about 3.4 times in site 7. No monitoring was undertaken during August to allow the analysis of data collected already and decide on whether it is necessary to continue the monitoring programme.

For the study period, May was the wettest month and September the driest. Muller (2000) suggests that the long-term average of DWAF's data for both the Kat River Dam and Balfour River gauging weirs (1972 - February 2000) show different trends. Both the Kat River Dam and Balfour weir trends, which are both in the study area, are illustrating that over the long term, low and high flow periods are between May and September and November and April respectively. Both are showing June as the lowest and January the highest flow month. A downstream increasing trend in flow volumes is observed in both the Balfour and Kat Rivers. It would therefore seem that this study was carried out during an unusually wet winter. From the results of this study, it is observable that in the Kat River the mean volume of water increased by 0.32 m^3/s between sites 1 and 6 from an overall

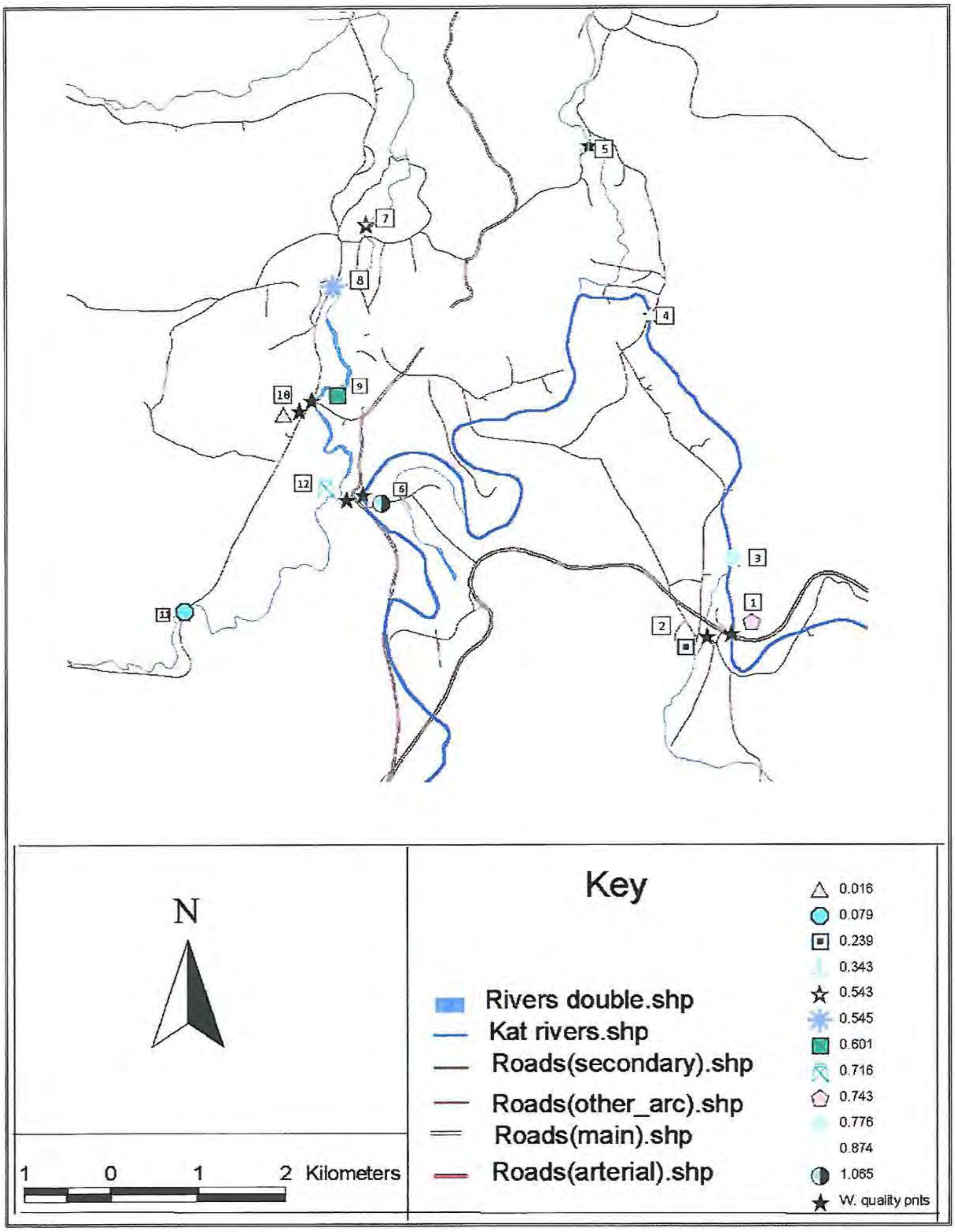

Figure 23: Spatial dynamics of discharge (m^3/s) in the upper Kat River area

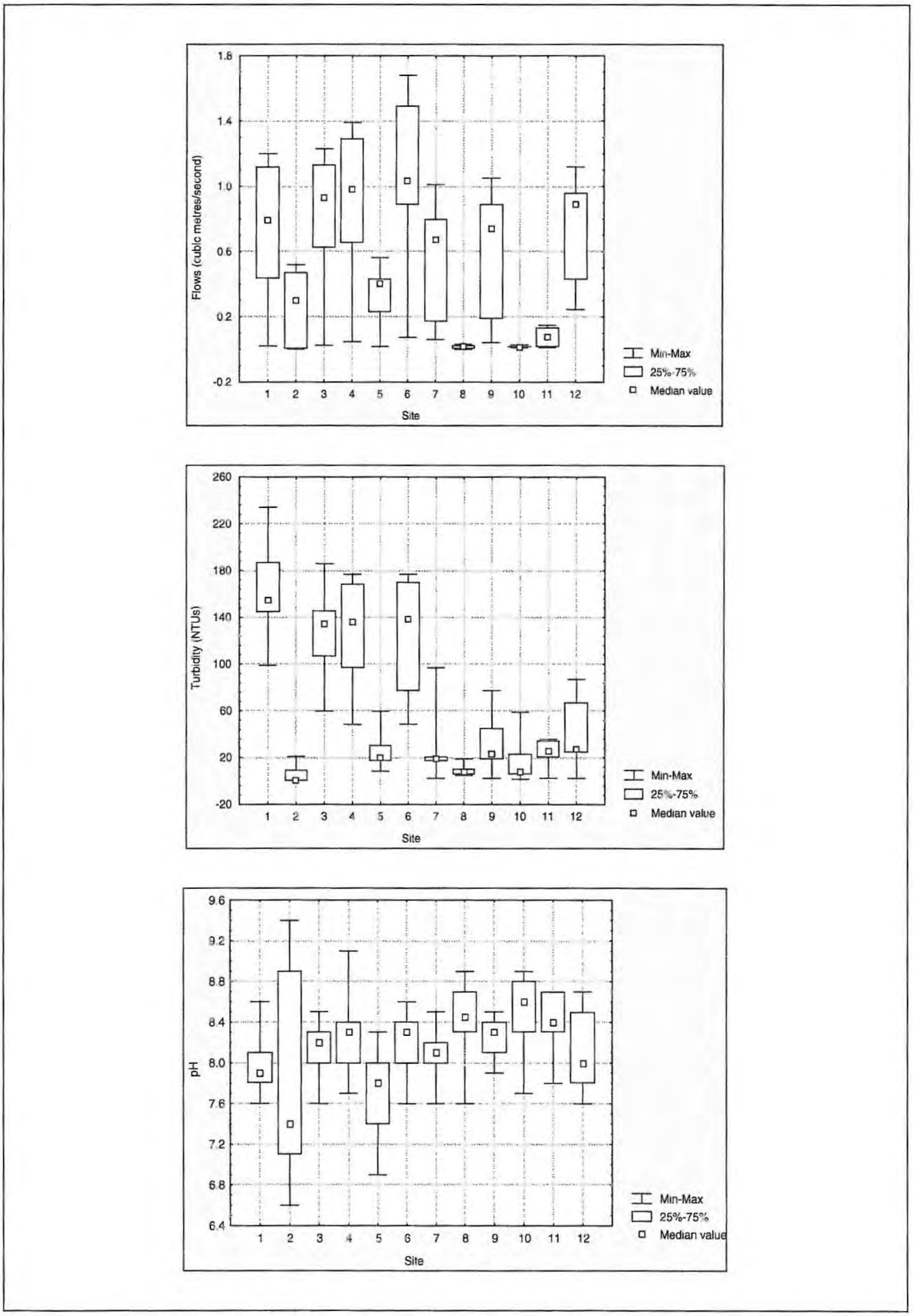

Figure 24: Flows, turbidity and pH dynamics in the upper Kat River.

average of 0.74 m^3/s at site 1 to 1.06 m^3/s at site 6. This is an increase of more than 48 percent between the two sites. In the Balfour River, the increase in discharge volume between sites 7 and 12 is about 0.17 m^3/s. Thus, an increase in flow volume of 32.8 percent is observed between the two sites. Relative to the discharge of the main rivers (Balfour and Kat Rivers), discharges from the small tributaries (Sites 8 and 10) seem to be insignificant. Only tributaries with higher volumes, for example, Hertzog (Site 2), Fairbairn (Site 5) and Buxton (Site 11) seem to have any significant impact in flow volumes of the main rivers It could be observed from the results that there is a greater range between median and maximum and minimum values in the Kat River sites (sites 1, 3, 4 and 6) than those in the Balfour River (sites 7, 9 and 12). This difference could be attributed to the fact that the Kat River flows are controlled by the dam releases whilst flows in the Balfour River are natural.

4.2.3 Turbidity

4.2.3.1 Spatial variation

The mean turbidity readings results are presented in Figures 24 and 25 and Appendix 11. The lowest readings of turbidity are observed in the tributaries, that is, sites 2, 5, 8, 10, and 11. All the turbidity readings at Balfour are below 40 NTUs.

Increasing downstream trend is noticeable in the Balfour River with turbidity increasing from site 7 to site 12. Results of the study show that the Kat River is by far most turbid compared to other streams in the rest of the upper Kat River catchment. One explanation for more turbid water in the Kat River is that the river's flow is from the dam upstream. The extremely high turbid flows in the Kat River may be attributable to two factors which are:

- the high velocity of water and the fact that it is being released from higher elevations results to. Highest turbidity readings have been observed in site 1 and
- bottom feeding fish may be playing an important role in stirring up the sediments (Dr T. Andrews, South African Institute for Aquatic Biodiversity, pers.com).

It would also appear that water of the Kat River becomes less turbid between sites 1 and 4, with little increase in the turbidity being observable between sites 4 and 6.

4.2.3.2 Temporal variation

In the Kat River, however, there is undeniable evidence (Figures 26 and 27) that water is more turbid during the high than dry flow period. At the Balfour River and other streams however, it would appear that water is more turbid during the low than high flow period (Figure 27).

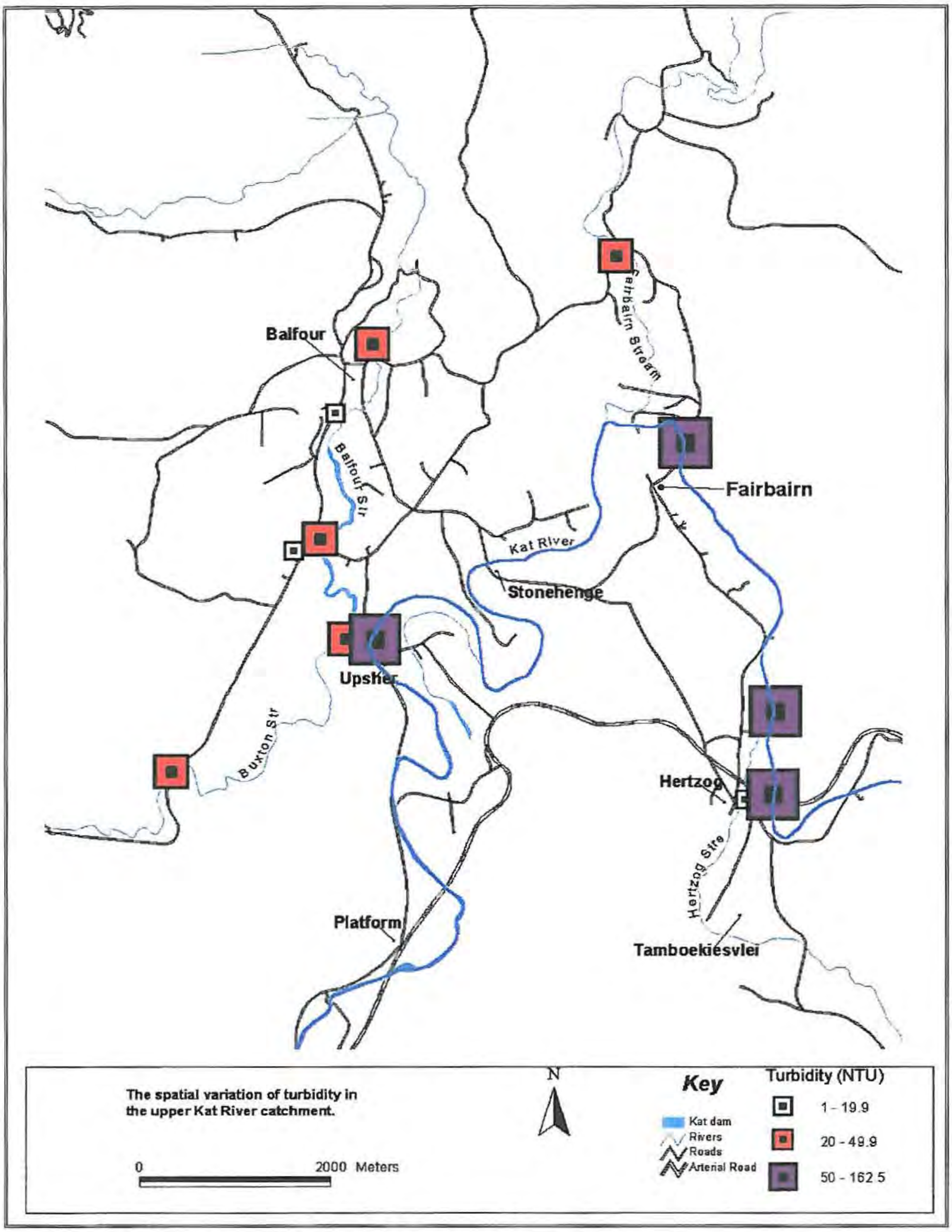

Figure 25: Spatial changes of turbidity in the upper Kat River

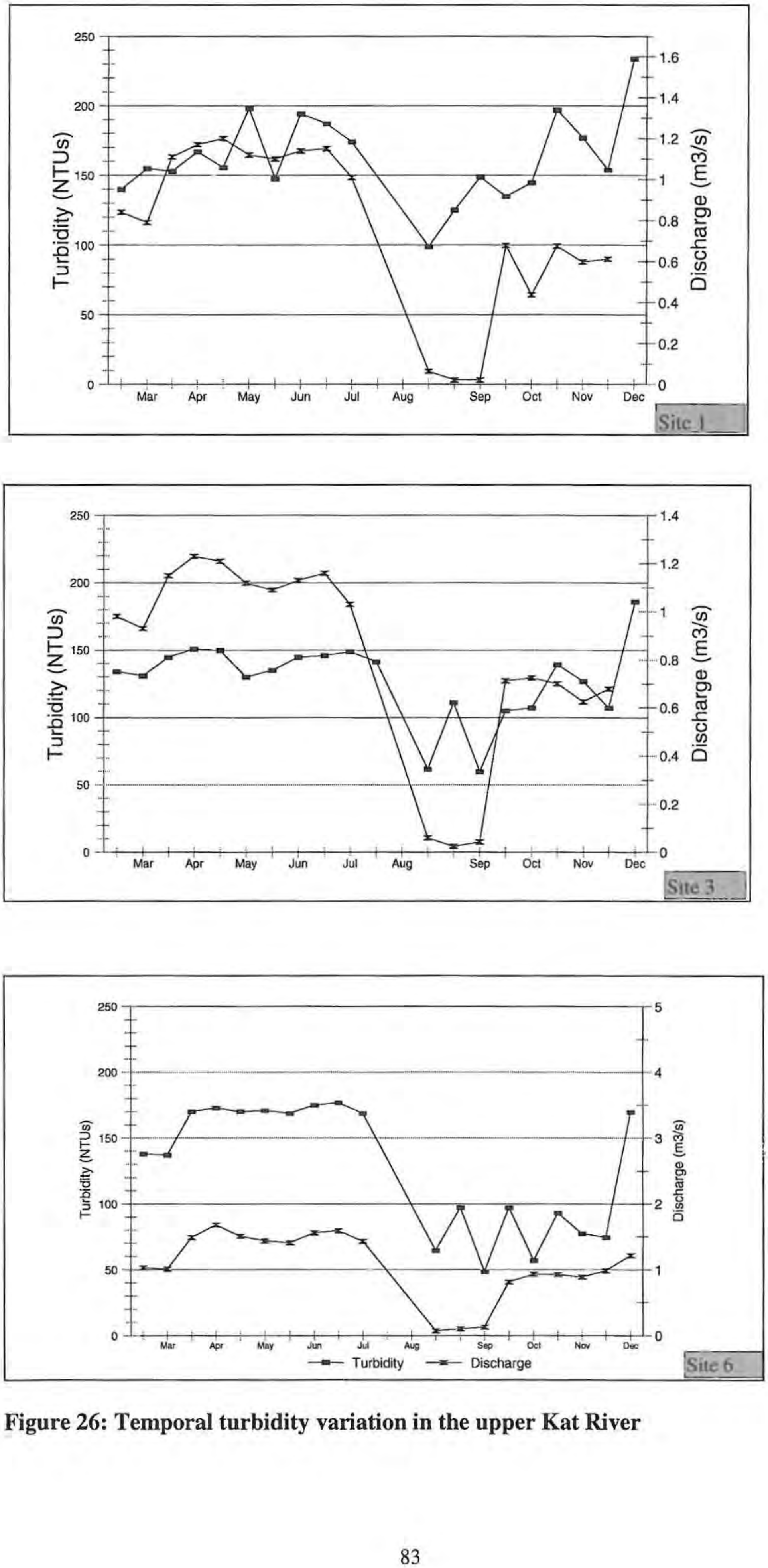

Figure 26: Temporal turbidity variation in the upper Kat River

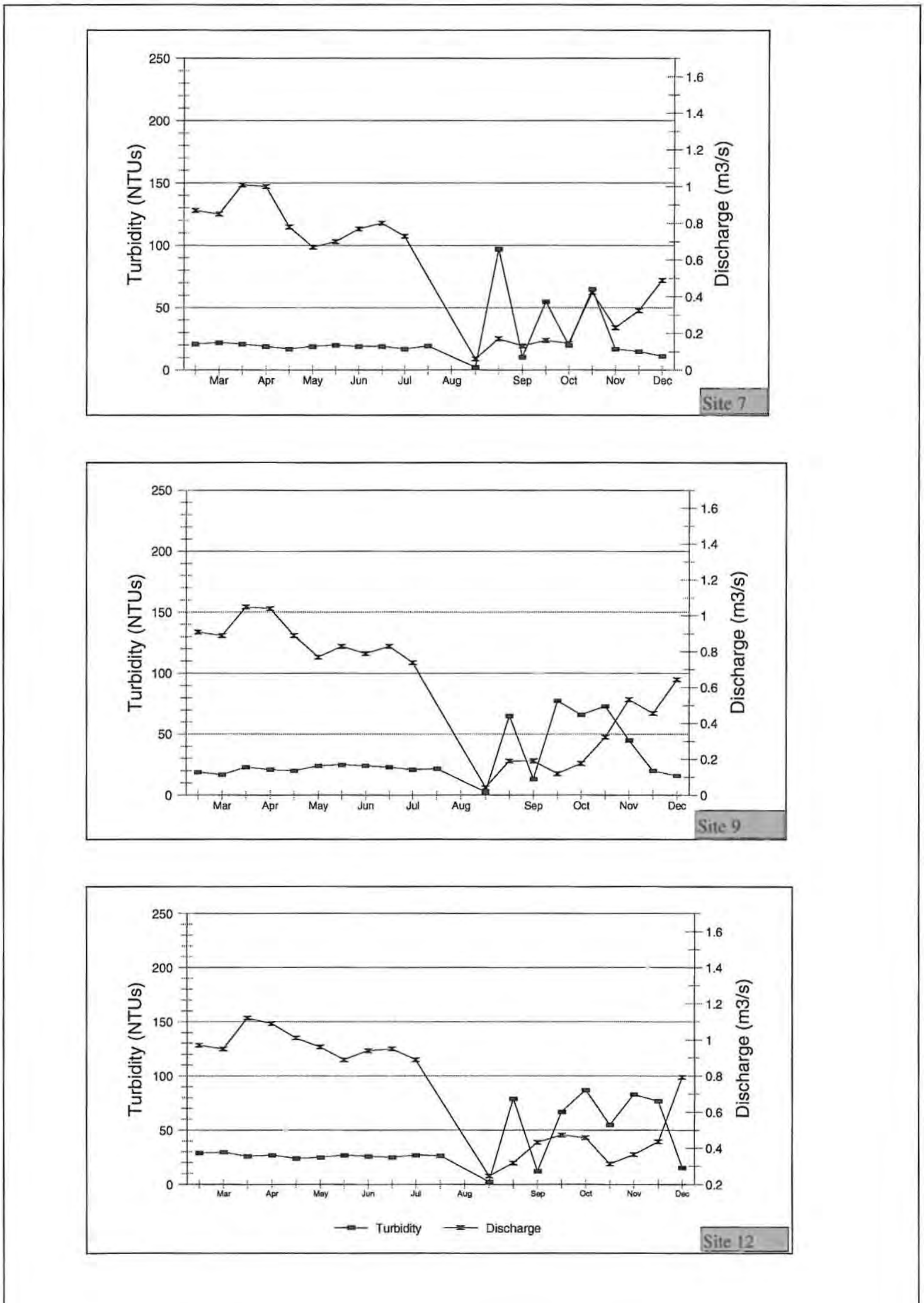

Figure 27: Temporal turbidity changes in Balfour River

4.2.4 pH

4.2.4.1 Spatial variation

Figures 24 and 28 and Appendix 12 outline the variation of pH throughout the upper Kat River area. Results of the study show that pH in the area tend to be alkaline. A slight gradual upward trend from 7.96 to 8.26 is observed between sites 1 and 4 in the Kat River. This trend is followed by the very slight reduction of pH between sites 4 and 6 from 8.26 to 8.23. From the results, it appears that all the Balfour River tributaries (sites 8, 10, and 11) have the highest pH readings and site 5 the lowest. Geology may be impacting on these streams as they are mainly supported by the base flow.

4.2.4.2 Temporal variation

Figures 28 outlines how pH varied with time in the upper Kat River area. In most Kat River sites, it appears that wet season pH values are higher than the dry period's as a gradual slight decreasing trend is apparent from the wet to the dry period. In most sites in the Balfour River however, the direct opposite is true. In these sites, pH readings tend to be lower during the wet than the dry period. In sites 5, 9, and 11 there seem to be very little insignificant variation in pH readings over time. This may be due to the fact that Balfour River baseflow catchment whilst Kat River is a storm flow catchment.

4.2.5 Chloride

4.2.5.1 Spatial variation

The mean chloride concentration results are presented in Figures 30 and 31 and Appendix 13. From the results, it is apparent that, with the exception of Site 5 on the Fairbairn tributary, the tributaries (sites 2, 8, 10, and 11) have higher concentrations of chloride than main rivers (Kat and Balfour Rivers). The highest chloride concentrations have been observed in site 2.

A downstream increase in chloride concentrations is observed in main rivers, that is Kat and Balfour Rivers. From the results, it is observable that chloride concentrations are increasing between sites 1 and 3, with a slight decrease from site 3 to 4. In the Balfour River, a downstream increasing trend in chloride concentrations is also noticeable. For example, an increase of more than 53 percent in chloride concentrations is observable between sites 5 and 7, and about 55 percent between sites 5 and 9.

4.2.5.2 Temporal variation

The variation of chloride over time is presented in Figures 32 and 33. Although peak concentrations were recorded during the low flow period, there is no clear relationship between flow and chloride concentrations.

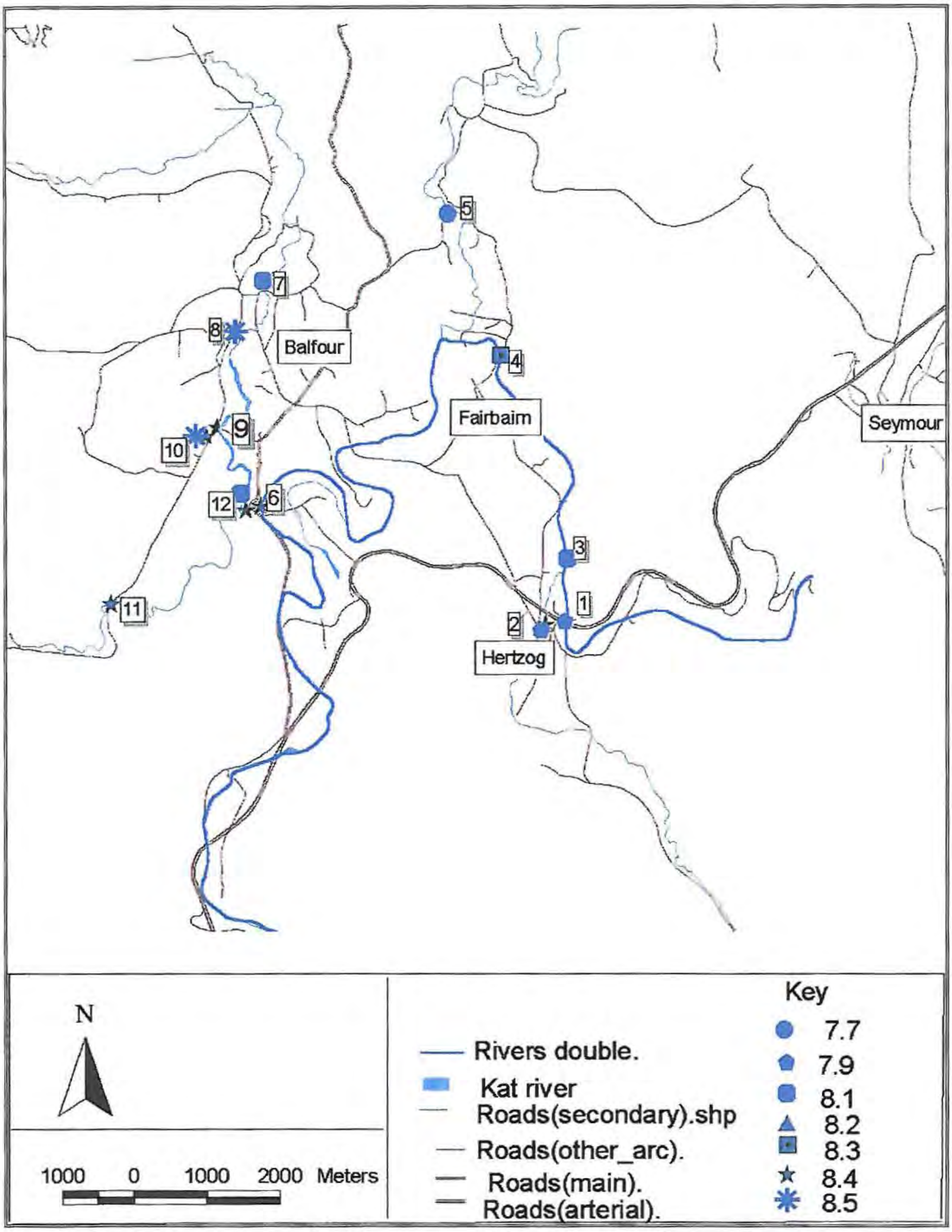

Figure 28: Spatial pH changes in the upper Kat River

4.2.5.3 Chloride loads

The original data was multiplied by the discharge value, then by 1000 to get the total load value that was being transported by the flow on a day of water quality assessment of each variable per second.

second during the dry period. Comparing this load to the wet period mean load of 71884.9 mg/s one will realise that the difference between the two is a massive 70959.9 mg/s. Thus, during the wet season, Hertzog stream carries 767 percent more chloride during the wet than dry period.

During the wet season, Site 2 was the main source of chloride in the study area. This is evidenced by the observation that this site contributed 39644 mg/s more chloride than Site 1. This contribution was more than double the loads transported by Site 1 (31818 mg/s) during the wet season. The higher chloride loads in Site 2 compared to one are a consequence of the chloride input from Site 2. Shaw (1983) realised that chloride in water may be an indication of sewage pollution. For this reason, it is speculated that pit latrines, septic tank and intensive grazing happening upstream of Site 2 may be contributing considerable amounts of chloride into the Hertzog stream. Between Site 3 and 4 chloride loads increase by about 20000 mg/s. Between this site and Site 3 the following major land-use are evident:

- Fairbairn rural settlement,
- grazing,
- intensive crop farming.

DWAF (1993) has particularly identified households as the major contributors of chloride into aquatic ecosystems. Hence, together with grazing and the agro-chemical and irrigation dependent crop farming, Fairbairn village is seen as the major contributor of chloride in Site 4. Very little chloride is coming through from Site 5. Between Sites 4 and 6 however, chloride loads increase from 63743 mg/s to 76183 mg/s. This increase could be attributed to grazing and intense crop farming happening between the two sites.

During the dry period, chloride trends are somewhat from Site 1 to 6. This is the case because Site 2's chloride contribution during the low flow period is insignificant. A slight increase in chloride loads of about 8000 mg/l is observed between Sites 1 and 3. Also, an increase of about 6000 mg/l is observed between Sites 3 and 4. This increase is attributed to Hertzog and Fairbairn rural communities and their land-use including intensive crop farming and grazing.

In the Balfour River, it would appear that main river is the source of chloride during both the high and low flow periods. This is evidence by the fact that, the contributions of all the tributaries (Sites 8, 10 and 11) are insignificant compared to the loads transported by the main Balfour River as evidenced by the loads in Sites 7, 9 and 12. The increase in chloride loads of 23232 mg/l and 16419 mg/l observed between Sites 7 and 12 in high and low flow period respectively is mainly a consequence of the presence of Balfour village community and their related activities like crop farming, grazing and pit latrines.

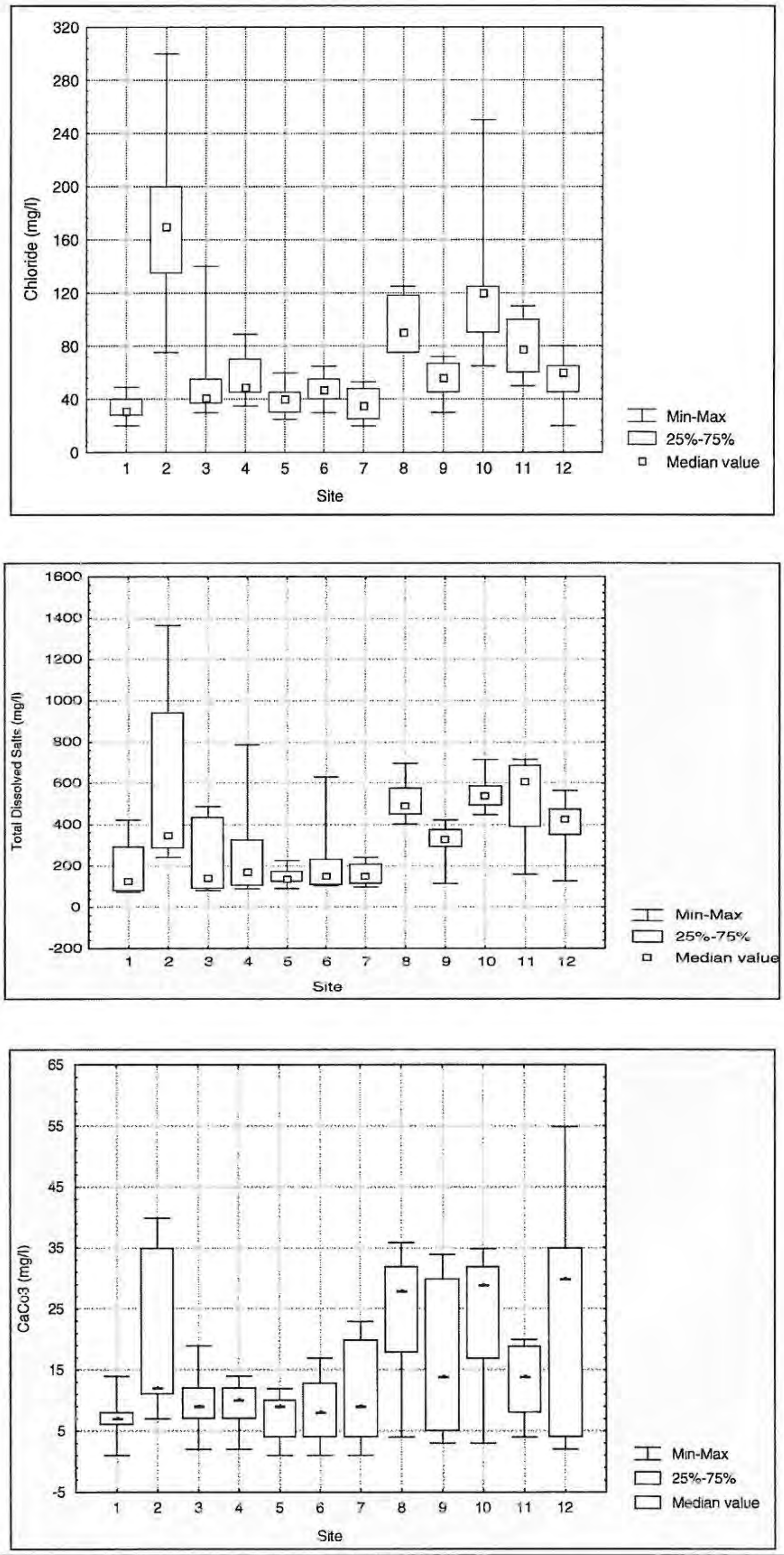

Figure 29: Chloride, Total Dissolved Salts and Total Hardness trends in the upper Kat River area

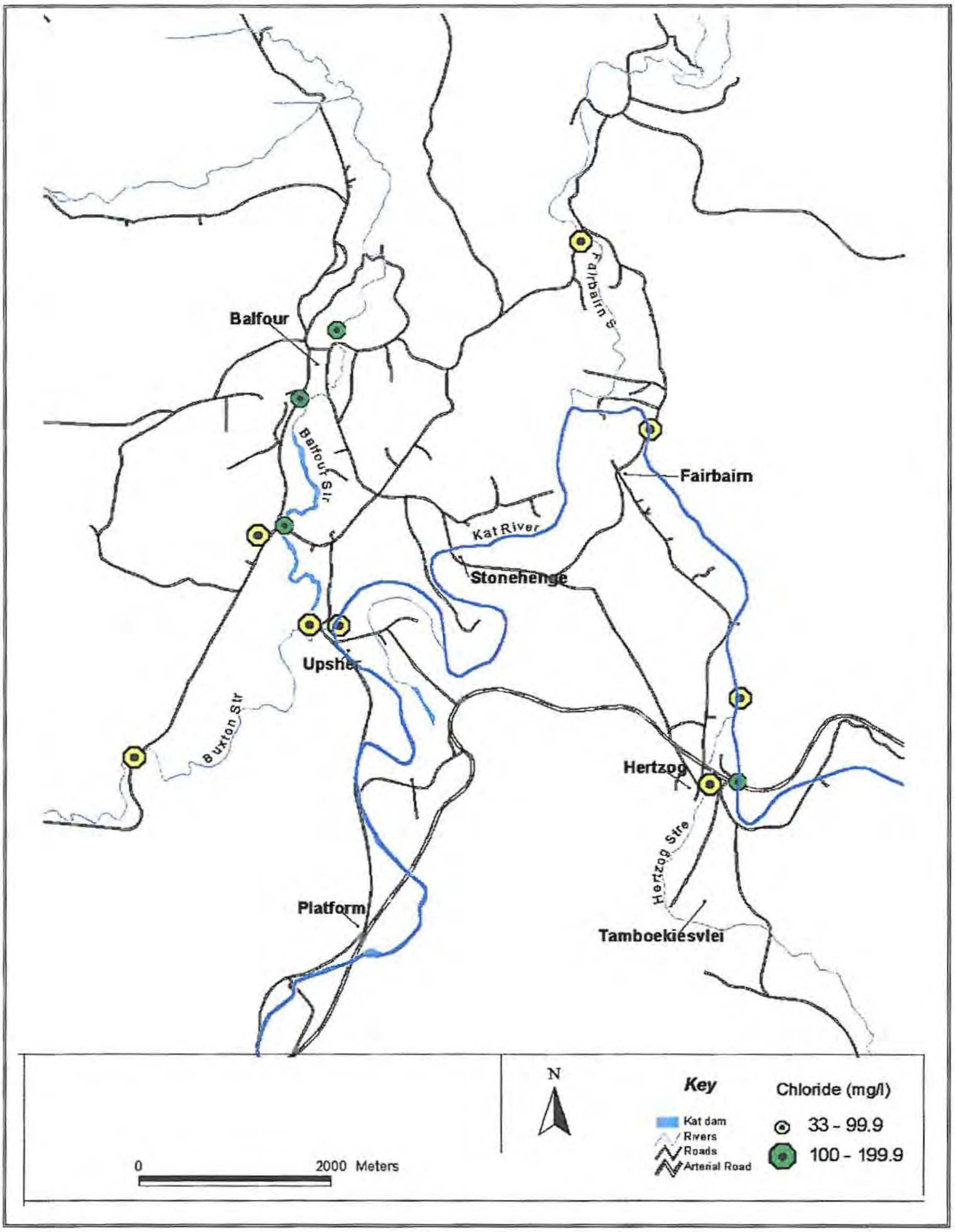

Figure 30: Spatial dynamics of chloride in the upper Kat River area

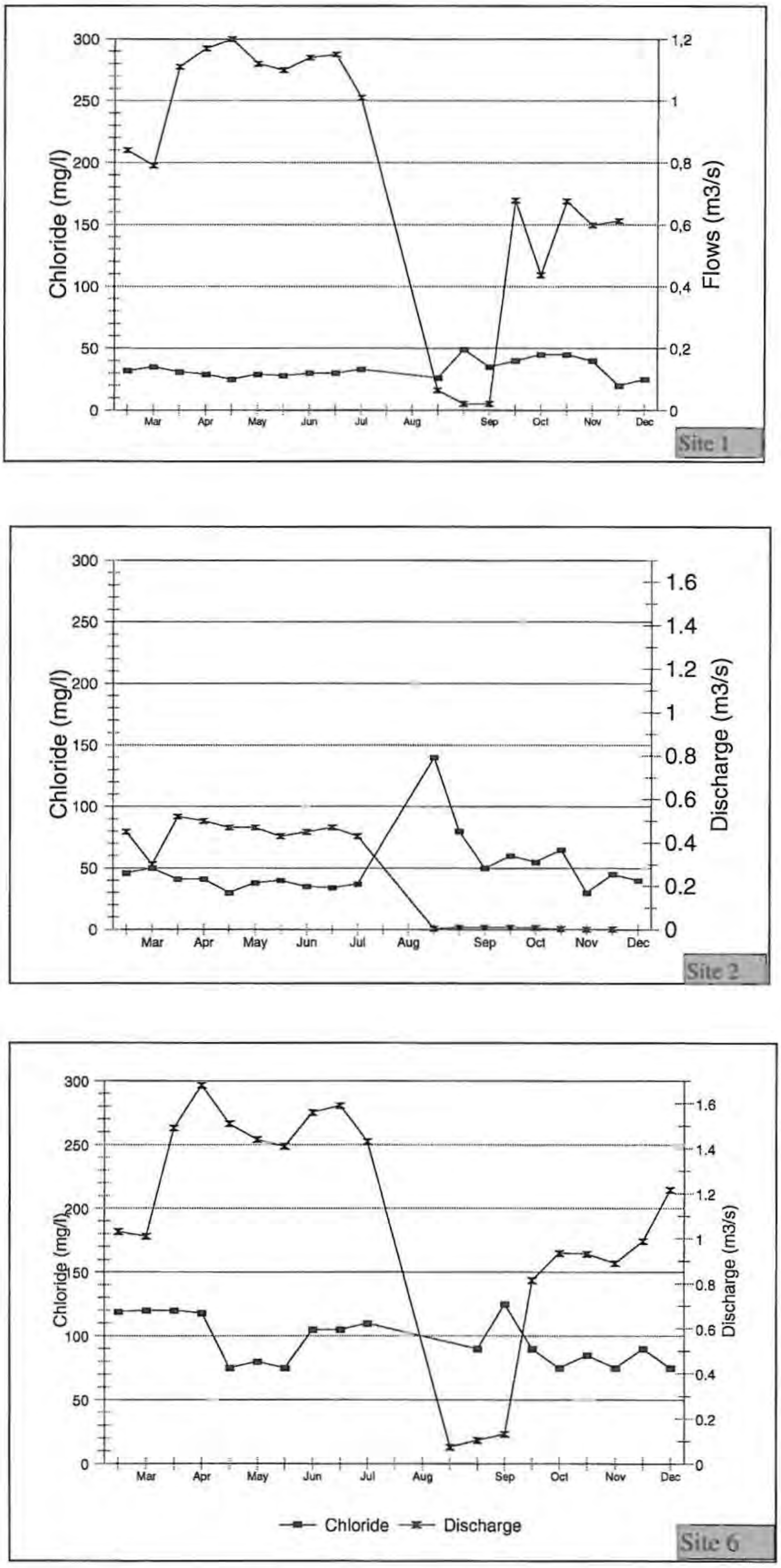

Figure 31: Temporal chloride trends in the upper Kat River

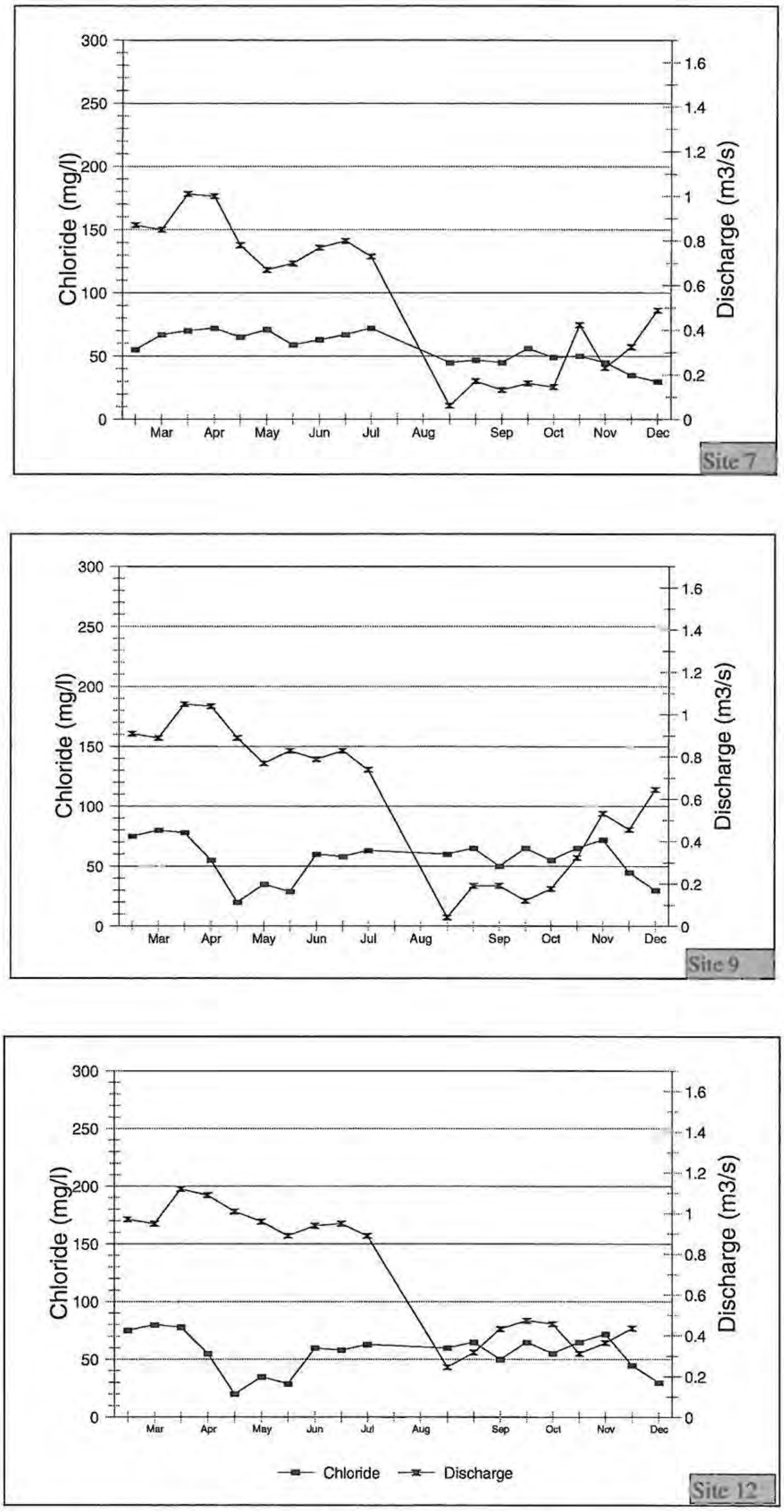

Figure 32: Temporal chloride trends in the Balfour River

Table 8: High Flow period (March – July) mean loads (m^3/s) of the selected water quality variables in the study area

Variable	Site											
	1	2	3	4	5	6	7	8	9	10	11	12
Chloride (mg/s)	31818	71462	42872	63743	2125	76183	36796	2154	96	1940	1310	54324
Total Dissolved Salts (mg/s)	95492	128661	109568	147704	56595	210159	154271	9562	249073	10016	10874	402358
Calcium Carbonate (mg/s)	7777	3689	10042	13680	4216	17841	13662	607	23077	547	332	36894
Nitrate (mg/s)	0	3960	2681	4398	0	900	5038	41	8174	1250	437	7399
Ammonium (mg/s)	0	0	0	0	0	0	0	0	0	0	0	0
Faecal coliforms	Faecal coliform analysis was not done during high flow period											

Table 9: Low Flow period (September – December) mean loads (m^3/s) of selected water quality variables in the study area

Variable	Site											
	1	2	3	4	5	6	7	8	9	10	11	12
Chloride (mg/s)	13889	1014	21741	27884	7843	25380	6133	418	13000	0	7096	22552
Total Dissolved Salts (mg/s)	120129	5052	182974	144842	38554	128223	28432	3085	78443	5821	46398	144971
Calcium Carbonate (mg/s)	3170	210	4624	3063	1115	2525	816	107	1914	169	921	1607
Nitrate (mg/s)	448	6610	4117	6661		21	1042	1724	4378	30	1429	4289
Ammonium (mg/s)	359	1086	1238	680	0	0	0	0	0	0	690	0
Faecal coliforms	243140	6686	299945	380919	28393	337788	27199	3316	113153	5448	65563	277367

4.2.6 Total Dissolved Salts (TDS)

4.2.6.1 Spatial variation

TDS results presented in this work were converted from electrical conductivity (mS/m). The average conversion factor suggested by DWAF (1993) that is 6.5 was used in all conversion calculations. Thus, as suggested by DWAF (1993) each electrical conductivity value was multiplied by a conversion factor (6.5) to get TDS (mg/l). This explanation is illustrated in a formula below adapted from DWAF (1993):

EC (mS/m)* 6.5 = TDS (mg/l)

The variation of the TDS concentrations over the upper Kat River catchment are presented in Figures 30 and 34 and Appendix 14. From the results, it would appear that the tributaries (sites 2, 8, 10, and 11) have the highest concentrations of dissolved salts compared to the main streams, that is, Kat and Balfour Rivers. The only exception is the Fairbairn stream (site 5) from which the overall least concentrations of TDS were recorded.

An upward TDS trend is observable in the Kat River from site 1 to 4. This trend however seems to be disturbed from site 4 to site 6 as decreased TDS concentrations are observed at site 6. In the Balfour stream, downstream increases in concentrations of Total Dissolved Salts are noticeable. This is evidenced by the increase in TDS between sites 7, 9, and 12. In fact, increases in TDS of about 52 percent between sites 7 and 9 and 81.4 percent between sites 7 and 12 are evident.

The other observation that is noticeable from the results is that, generally, Balfour River has higher salt concentrations that the Kat River. This might be explained as follows:

the flows in the Kat River are generally higher compared to the Balfour River. Thus, the Kat River has more mixing capabilities than the Balfour River. Hence, salts and other variables may be generally lower compared to the Balfour River even if the former is transporting more loads than the latter.

- because of the presence of the dam upstream of the Kat River and its releases, the river is storm flow dominated. The Balfour River is base flow dominated. Consequently, the impact of geology was more pronounced in the Balfour than the Kat River.

4.2.6.2 Temporal variation (see chloride)

Results of the study are indicating that there is a close similarity between chloride and TDS temporal trends in the study area. For example, it is noticeable that in both an increasing trend is observable between Sites 1 and 6. It is also evident that in both the major river (Balfour) has the highest loads than the tributaries. Thus, TDS trend graphs are not presented in this work. Figures 32 and 33 illustrate how chloride concentration varied over time in the upper Kat River catchment. A clear distinction in TDS concentrations was observed between the wet (March to July) and dry (September to July) seasons of research.

- From the results it would appear that in most sites (with the exception of sites 9, 11, and 12), TDS concentrations tend to be much higher during the dry than wet periods. For example, in site 1 the wet period mean TDS concentration is 92mg^{-1}, compared to the dry period mean concentration of 259mg^{-1}. Also, in site 2, the wet period mean TDS concentration is 289mg^{-1}, compared to the dry period mean concentration of 881mg^{-1}. Another observable evidence of the difference in wet and dry season TDS concentrations is that, in all sites, peak TDS readings were observed during the dry period. These would then indicate that there is a correlation between the quantity of water in rivers and the concentration of TDS.

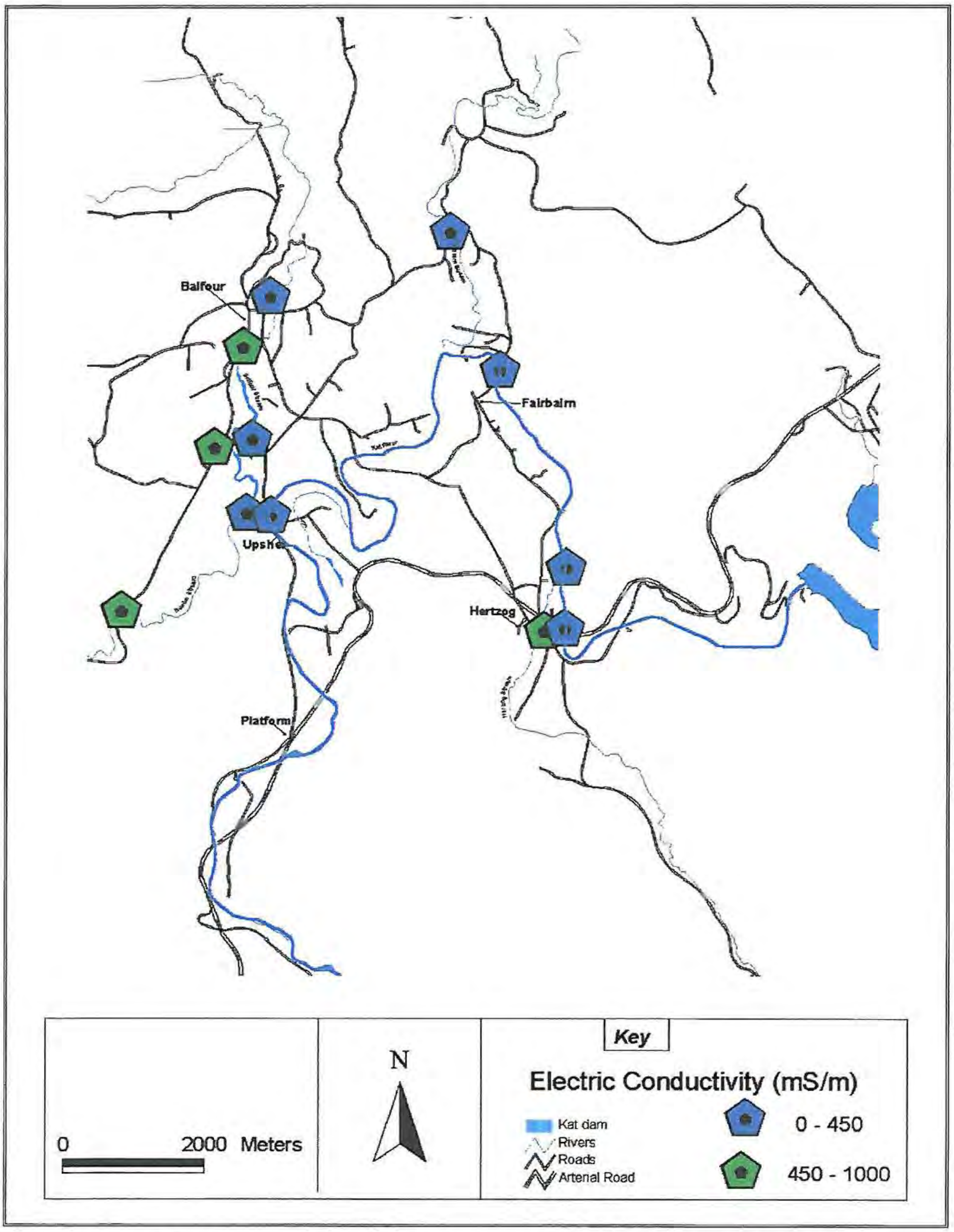

Figure 33: Spatial changes of Electrical Conductivity (EC) in the upper Kat River area

4.2.6.3 TDS loads

Tables 6 and 7 illustrate the loads of the Total Dissolved Salts transported by the rivers and tributaries in the upper-middle Kat River catchment.

A clear distinction is observable between the TDS wet and dry loads. For example, in site 6, the average loads during the wet period were 17.3 percent more compared to the dry period mean load. At the Balfour River, the difference was even more pronounced. At site 12, a difference of more than 60 percent was observable between the wet period mean load and dry mean loads. Results of the study reveal that, although concentrations of dissolved salts were higher in most sites during the dry period, the actual loads of dissolved salts transported were much higher during the wet than the dry periods.

It is observable from the TDS loads results that Site 2 contributed 33169 mg/s more loads into the Kat River during the wet period than the actual load. The high salt content in Site 2 may be attributable to the agricultural practices dominating the up-stream environment of the site and the Tamboekeisvlei and Hertzog rural communities' activities.

TDS increases by more than 100 000 mg/s between Sites 3 and 6 in the Kat River during the wet period. From this observation, it could be inferred that intensive grazing, agro-chemical and irrigation supported crop farming, pit latrines and communities' other activities are contributing considerable amounts of salts into the Kat River. During the dry season, an increase in TDS loads between Sites 1 and 6 is about 8000 mg/s. The contribution of Site 2 is insignificant.

At the Balfour River, it is observable that compared to the main Balfour River, all tributaries contribute very little salts into the system. Increases of 94802 mg/s and 153285 mg/s are observable during the wet period between Sites 7 and 9 and 9 and 12 respectively. According to DWAF (1993) two prominent sources of TDS are geology and the settlements. Although the contribution of the Balfour village cannot be underestimated, it would appear that the major contributor of TDS in the Balfour River situation is the underlying rock. This is evidenced by the observation that TDS loads were already high in Site 7 that is above and therefore not impacted by any community activity.

4.2.7 Total hardness (TH) presented as Calcium Carbonate ($CaCo_3$)

4.2.7.1 Spatial variation

Figures 30 and 35 and Appendix 15 give a summary of the variation of TH over the upper-middle Kat River catchment. It is observable from the results that TH is increasing between sites 1 and 3. From site 3 to site 6, a gradual decrease in TH is evident. In the Balfour River region, a clear upward trend downstream is evident between sites 7, 9, and 12. In fact, the total hardness of river water increases by about 111.4 percent between sites 7 and 12. From the results, it appears that sites 2, 8, 10, and 12 have the hardest water compared to other sites throughout the catchment. It is also apparent that sites 1 and 5 have the softest water. The trends of water hardness observed from the results are again indicating that geology in the area is playing a significant role in water quality in the study area.

4.2.7.2 Temporal variation

Figures 36 and 37 give the variation of TH in the upper Kat River catchment over time. From the results, it is evident that water in sites 1, 2, and 3 is less hard in wet than dry period. An opposite observation is made at sites 4, 5, 6, 7, 8, 9, 10 and 12. Results of the study show these sites to be harder during the wet than the dry period. The trend at site 11 is not very clear. TH readings at this site tend to fluctuate between 4 and $20mg^{-1}$.

4.2.7.3 Polyvalent metallic cations loads

The average amount of polyvalent metallic cations (predominantly calcium and magnesium) loads transported by the river water of the upper Kat River catchment per second is illustrated in Tables 6 and 7. Results of the study show that rivers and streams in the upper Kat River catchment carry more loads of polyvalent metallic cations during the wet than dry period. Example is site 6, where wet loads are 76.5 percent more than the overall mean and a massive 652.4 percent above the dry period mean.

An observation of the $CaCo_3$ results indicates that in both high and low flow periods, the Kat River is carrying higher loads than the tributaries (Sites 2 and 5). For example, Site 1 transport about 4000 mg/l and 2000 mg/l more than Site 2 in high and low flow periods respectively. The increase by more than 10000 mg/l between Sites 1 and 6 during the wet period is an indication that geology in the area makes the water harder downstream.

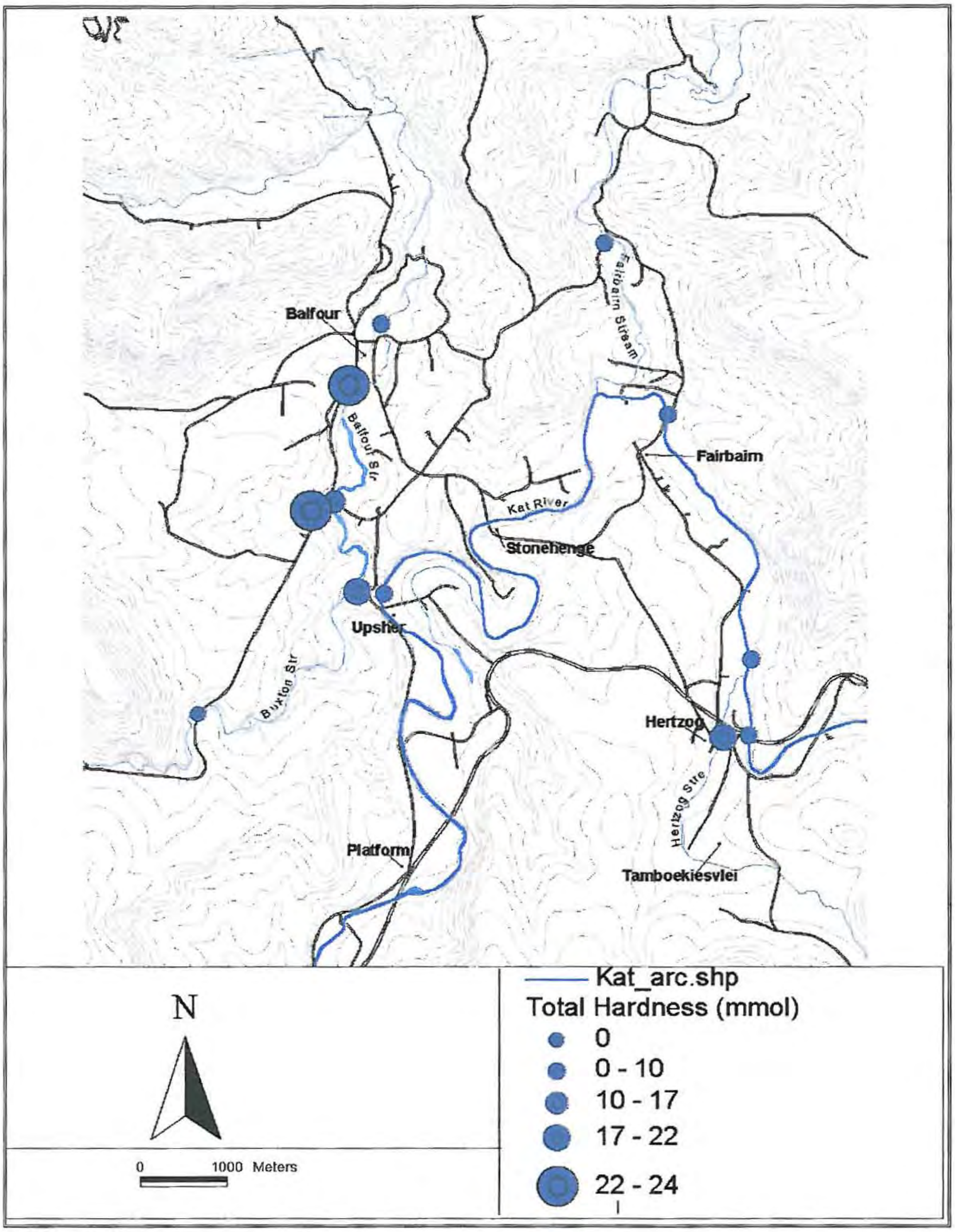

Figure 34: Total hardness spatial variation in the upper Kat River area

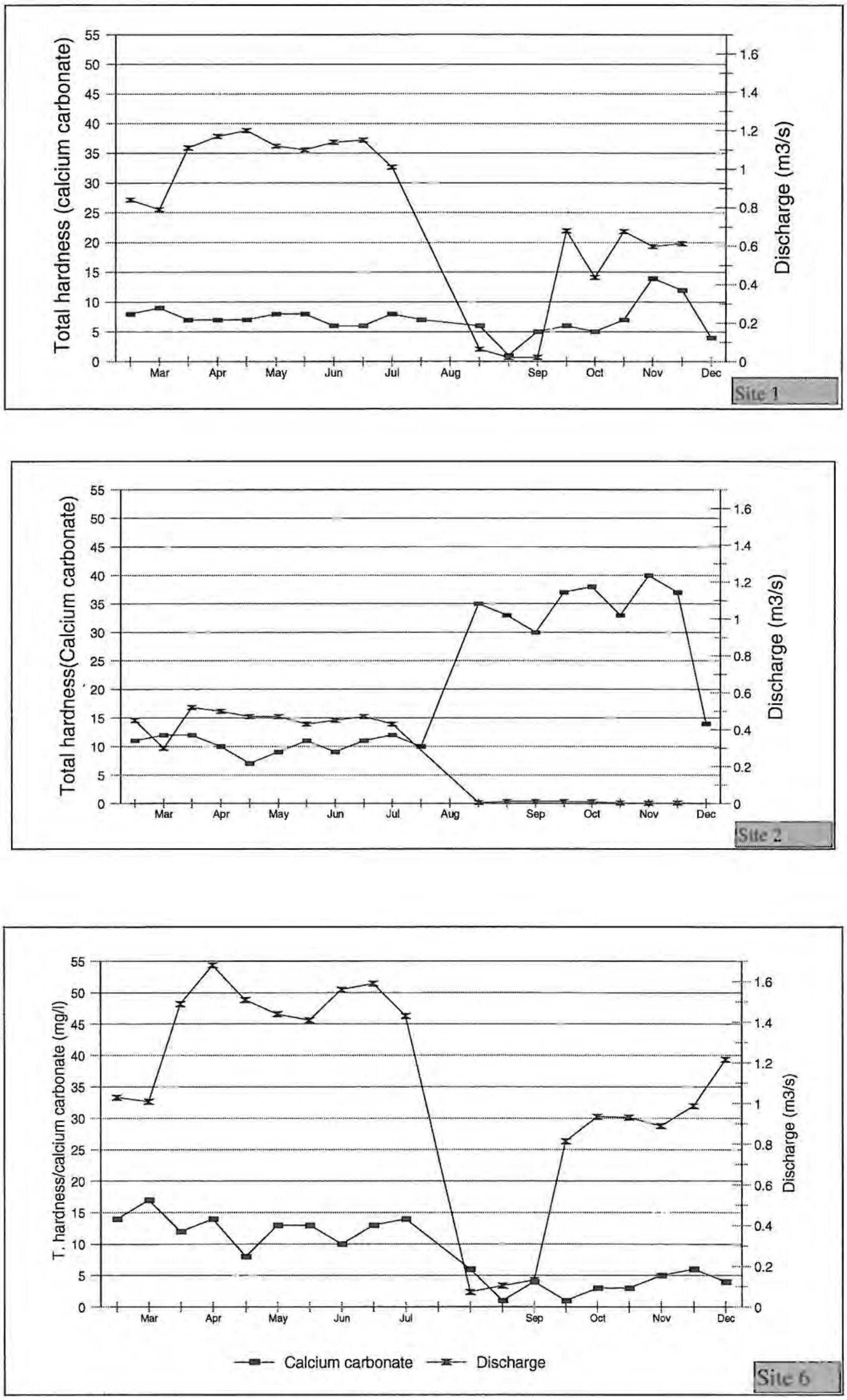

Figure 35: Temporal total hardness (calcium carbonate) trends in the upper Kat River

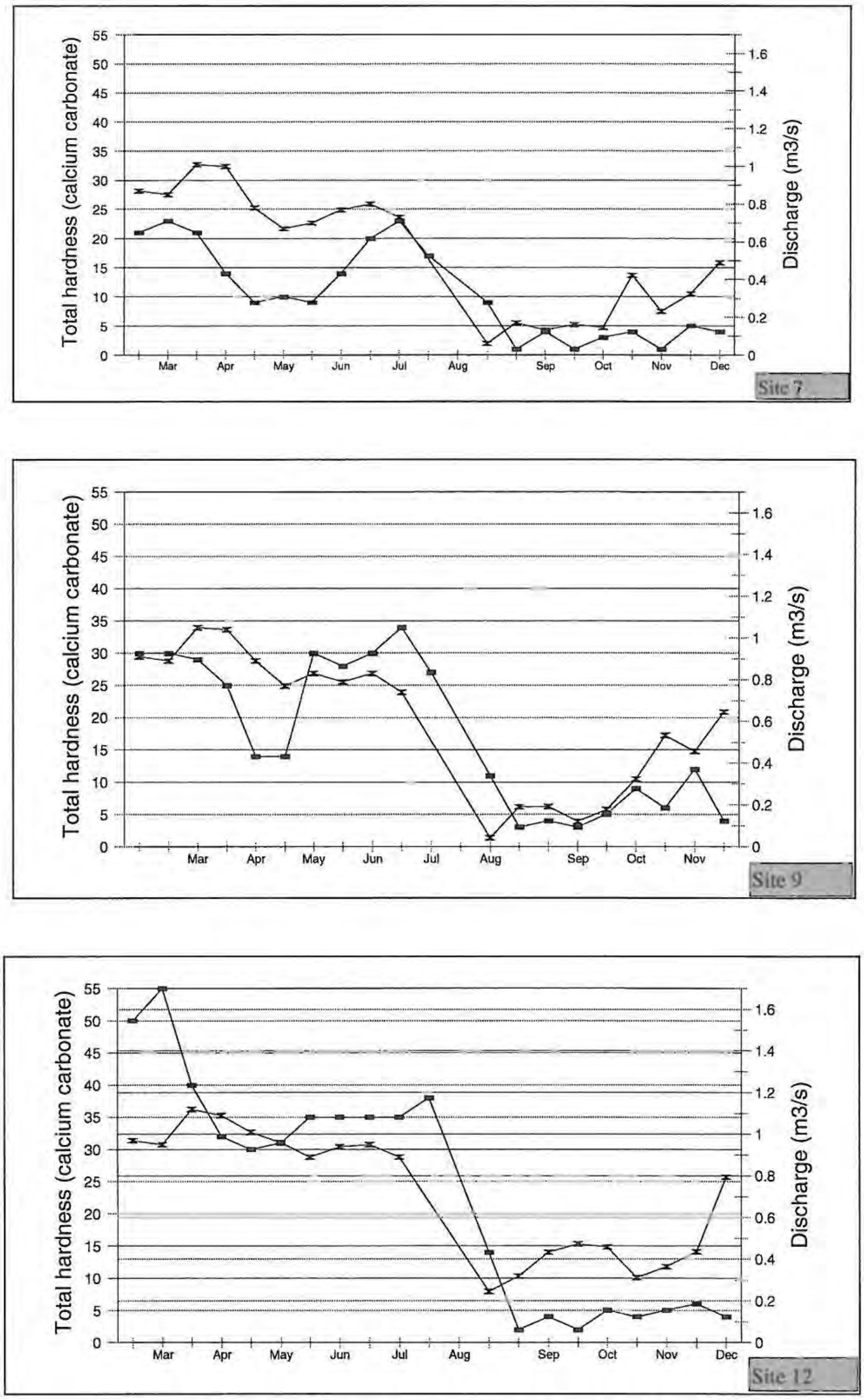

Figure 36: Total hardness (calcium carbonate) temporal trends in the Balfour River

4.2.8 Nitrate

4.2.8.1 Spatial variation

Figures 38 and 39 and Appendix 16 illustrate the variation of nitrate throughout the upper Kat River catchment. From the results, an increasing downstream concentration of nitrate between sites 1 and 4 is evident. Between sites 1 and 3, nitrate concentration increases by 817 percent. Between sites 1 and 4, the increase becomes a massive 1000 percent. Although a slight drop in concentration level is observable between sites 4 and 6 as a result of dilution of Kat River water by the Fairbairn stream, nitrate concentrations are still on average 3.95 mg/l higher at site 6 than site 1. Thus, the nitrate concentration is on average 658.3 percent higher in site 6 than site 1.

A downstream increase in nitrate concentrations is apparent also in the Balfour River catchment. Whilst no nitrate was found at site 7, at site 9 the nitrate concentrations were averaging at 5.05 mg/l. From site 9 to site 12, nitrate concentrations increased by more than 72 percent to an overall mean of 8.8 mg/l. Sites 2 and 11 had the highest concentrations of nitrate. In sites 5 and 7, nitrate was not found.

4.2.8.2 Temporal variation

In Figures 40 and 41 nitrate concentration variation overtime in all sites is outlined. It is observable from the results that in sites 1, 2, 3, 4, 6, 8, 10 and 12 nitrate concentrations tend to be higher during the dry than wet period. For example, in site 1, no nitrate was observed during the wet period. During the dry period though, nitrate concentrations of up to 3 mg/l were observed. At site 9, there seem to be very little insignificant change in nitrate concentration over time. At site 11, nitrate trends overtime are not that clear. In sites 5 and 7, no nitrate was traced throughout the period of study.

4.2.8.3 Nitrate loads

The mean average loads in the upper Kat River catchment is summarily represented in Tables 6 and 7. It is observable from the study results that sites 2, 4, 6, 8, 8 and 12 carry more loads of nitrate during wet than dry period. For example, on average, 3905 mg more nitrate passes through site 9 per second in wet than dry period. This is about 61 percent more nitrate load than the overall mean load (3204.1 mg/s), and 312 percent more than the dry period load (1251.6 mg/s).

The trend at sites 1, 3, 10, and 11 are direct opposite. Results of the study are showing that sites 3, 10, and 11 carry more nitrate loads during the dry than wet period. For example, average load of nitrate

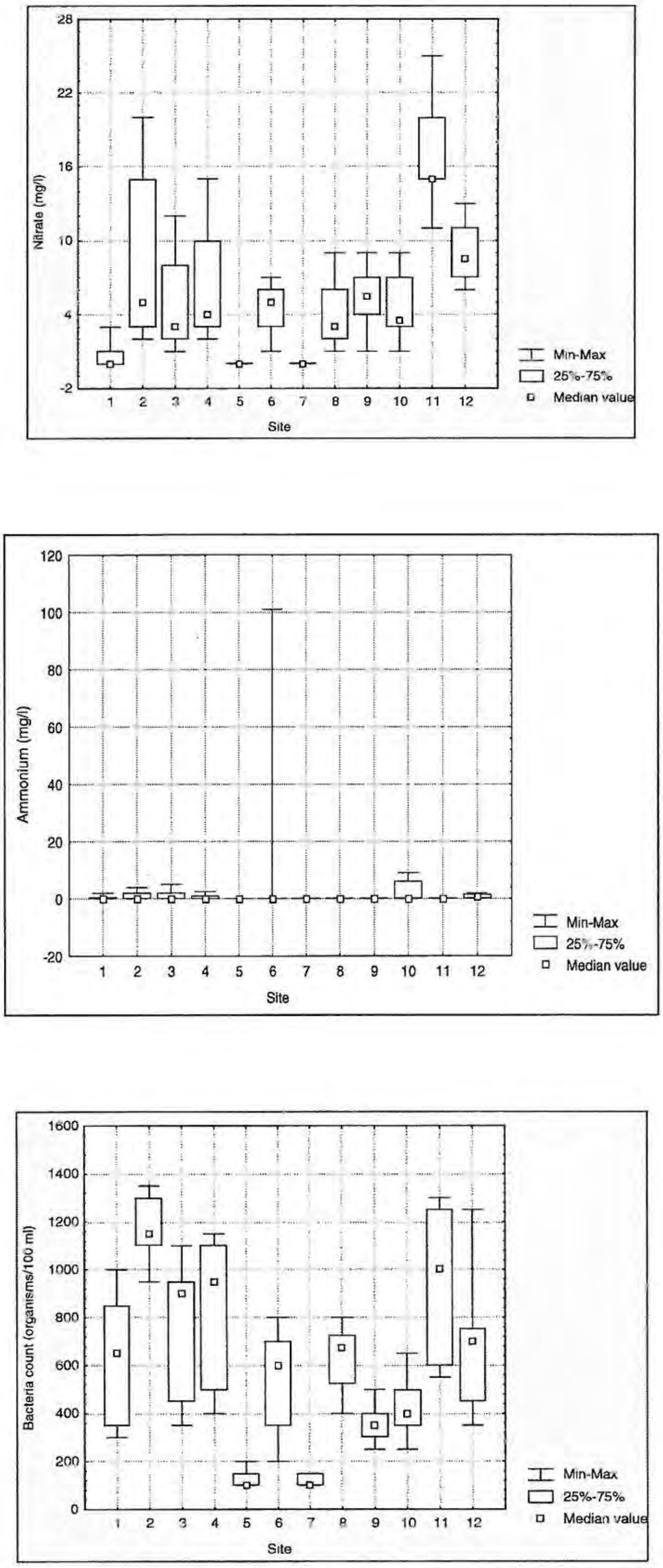

Figure 37: Nitrate, ammonium and faecal coliform trends in the Kat River

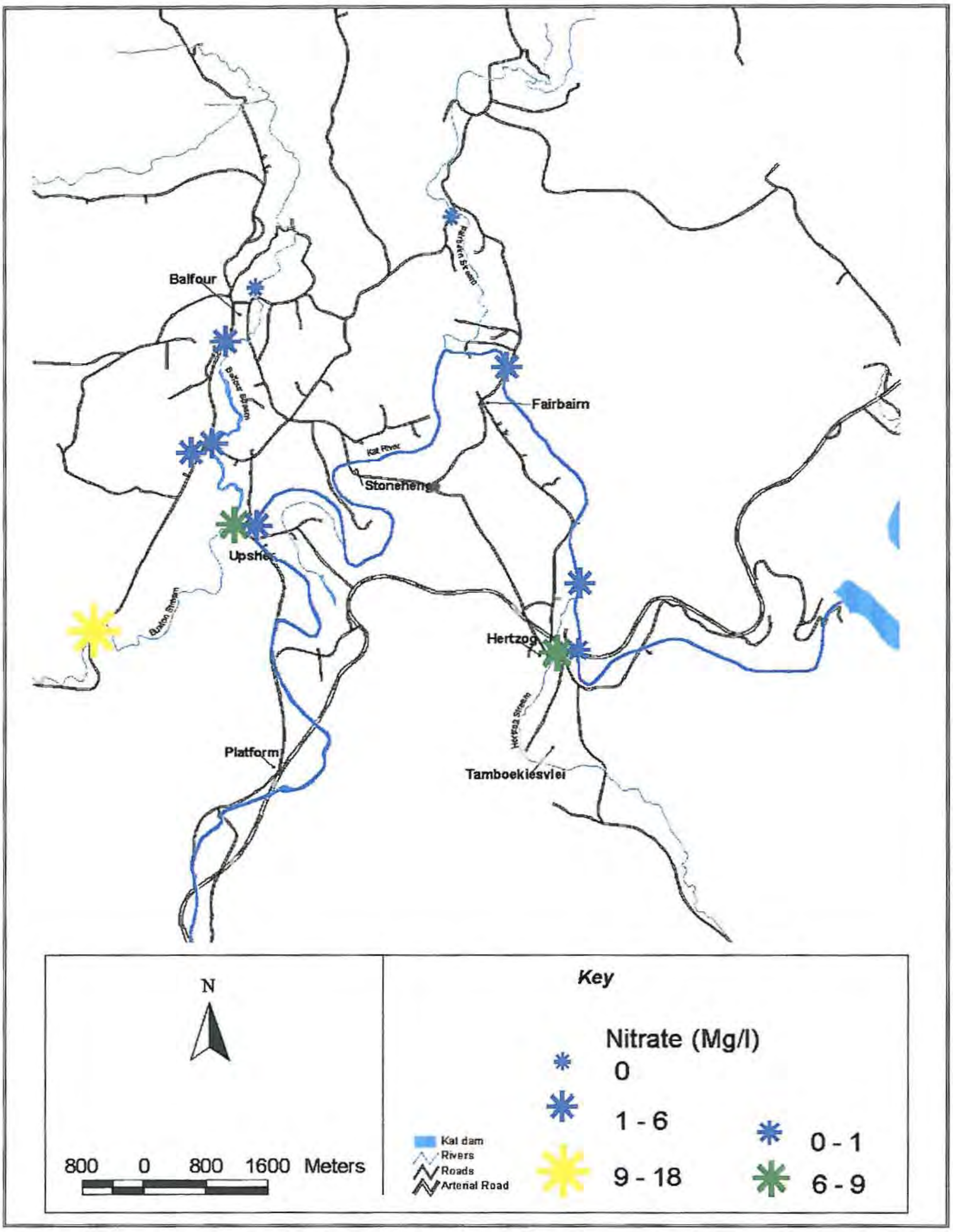

Figure 38: Spatial variation of nitrate in the upper Kat River

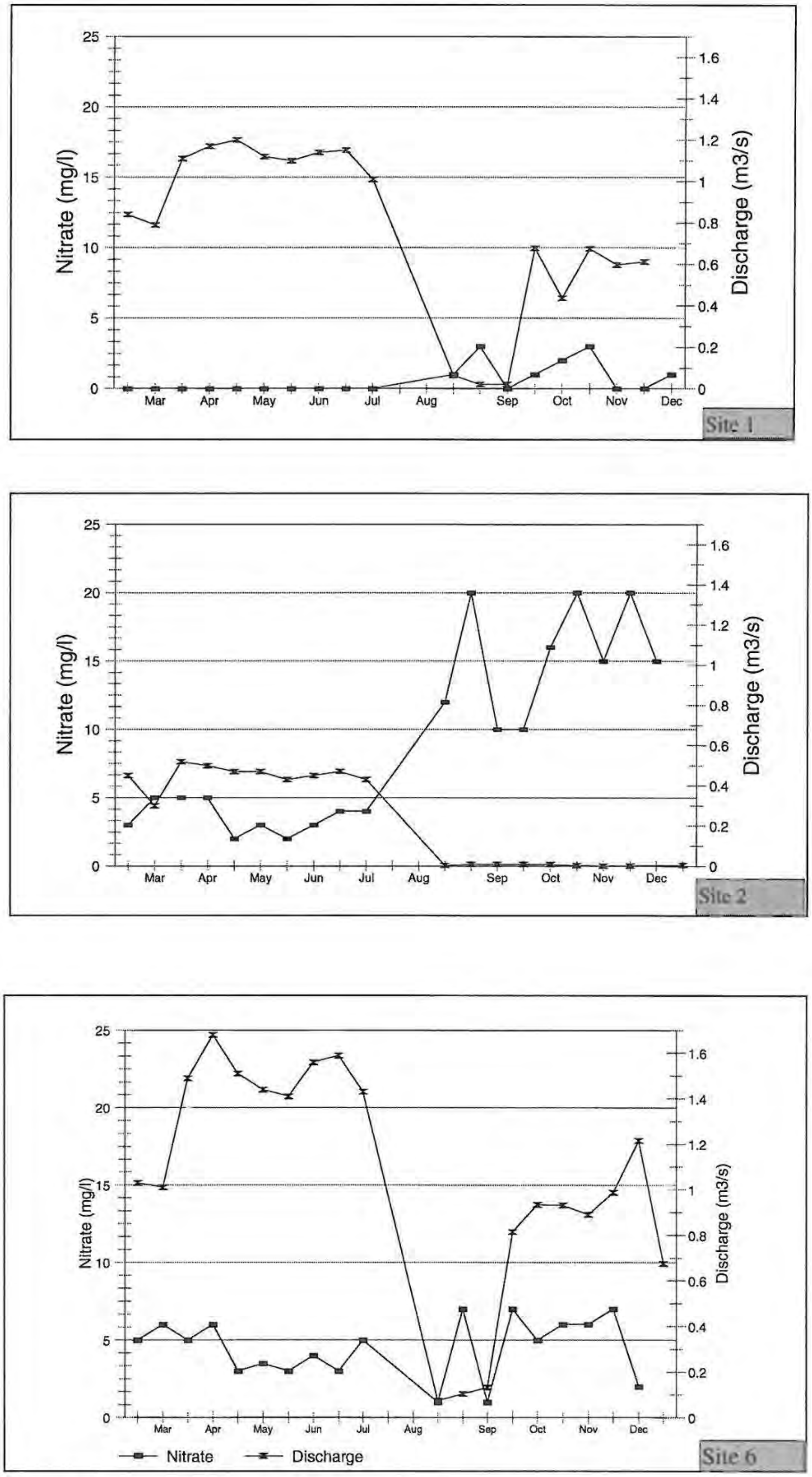

Figure 39: Nitrate temporal trends in the upper Kat River

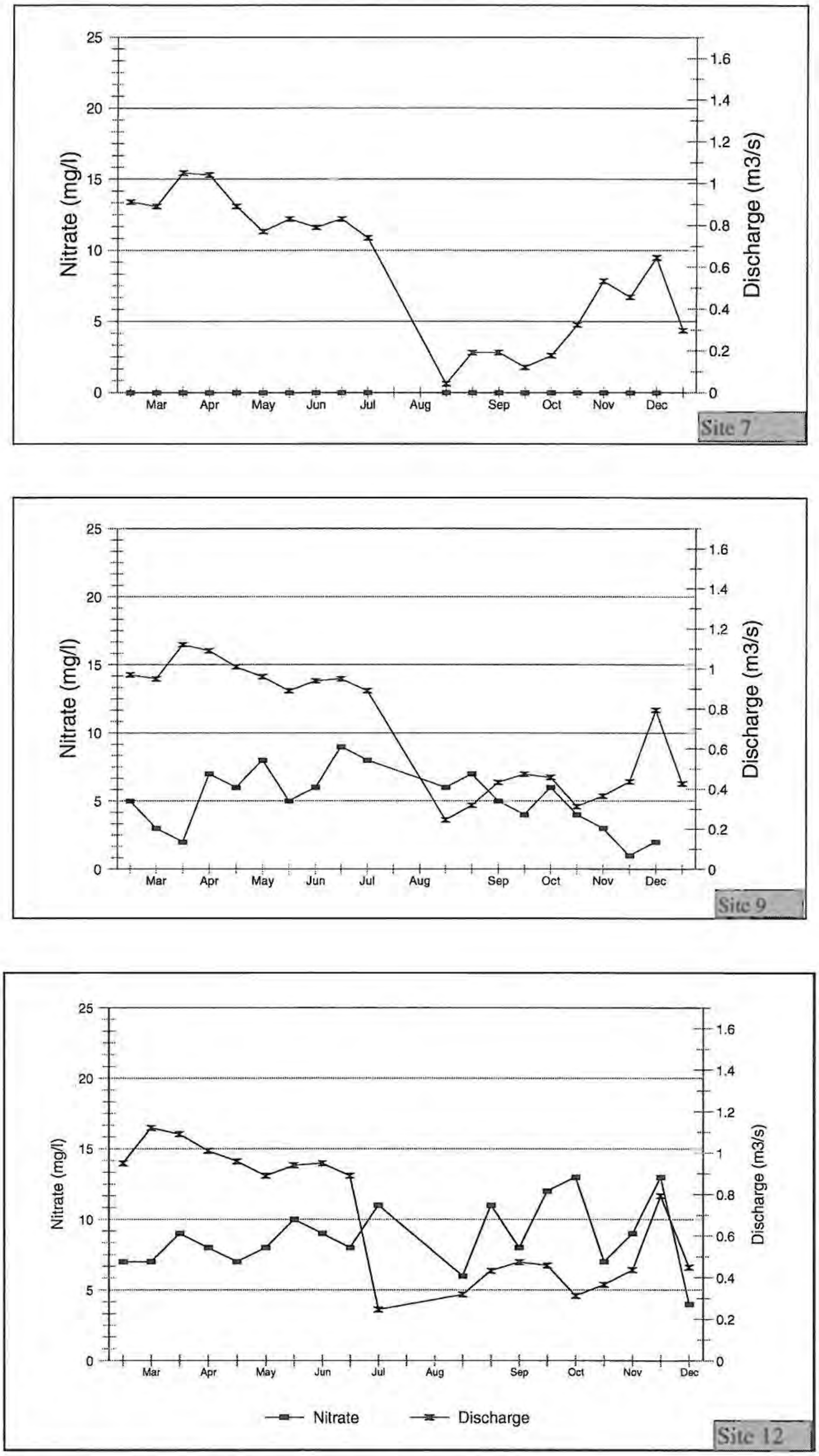

Figure 40: Temporal nitrate trends in the Balfour River

passing through site 3 per second is 2426.6 mg and 3009.6 mg during the wet and , dry periods period respectively. Thus, it is observable that river water passing through site 3 have on average 583 mg more nitrate load during dry than wet period. Nitrate was not found at sites 5 and 7.

The single most contributor of nitrate between Sites 1 and 6 is Site 2 in both high and low flow periods. Hence, nitrate loads were more than 2500 at Site 3 compares to 0 at Site 1 during the wet period. During the dry period as well, nitrate loads rise from 448 in Site 1 and 4117 in Site 3 as a consequence of the nitrate contributions from Site 2. Organic pollution from the grazing animals, application of nitrogenous fertilisers on crops, pit latrines and a septic tank are the major sources of nitrate in Site 2. As a result of dilution by zero-nitrate Fairbairn River water, nitrate loads drop from 4398 mg/l in Site 4 to 900 mg/l in Site 6.

4.2.10 Ammonium

4.2.10.1 Spatial variation

Figure 38 and Appendix 17 demonstrate the variation of ammonium over the upper Kat River catchment. From this diagram, it is evident that the Kat River is more enriched with ammonium than the Balfour River. This is evidenced by the fact that amonium was observed in most sites in the Kat River (Site 1, 2, 3 and 4). In particular, it is apparent that the Hertog stream in which Site 2 is located had the highest concentrations of ammonium. For example, ammonium concentrations at Site 2 varied between 0 and 9 mg/l. In the Kat River itself however, the highest ammonium concentration observed was 5mg/l in Site 4. In the Balfour River and tributaries, ammonium was only observed at Site 11. In Sites 6, 7, 8, 9, 10, and 12 no ammonium was found during the analysis.

4.2.10.2 Temporal variation

In Figures 42 and 43, the temporal variation of ammonium is illustrated. It has been noted that whilst no ammonium was found in any Site during the water quality analysis conducted between March 15th and

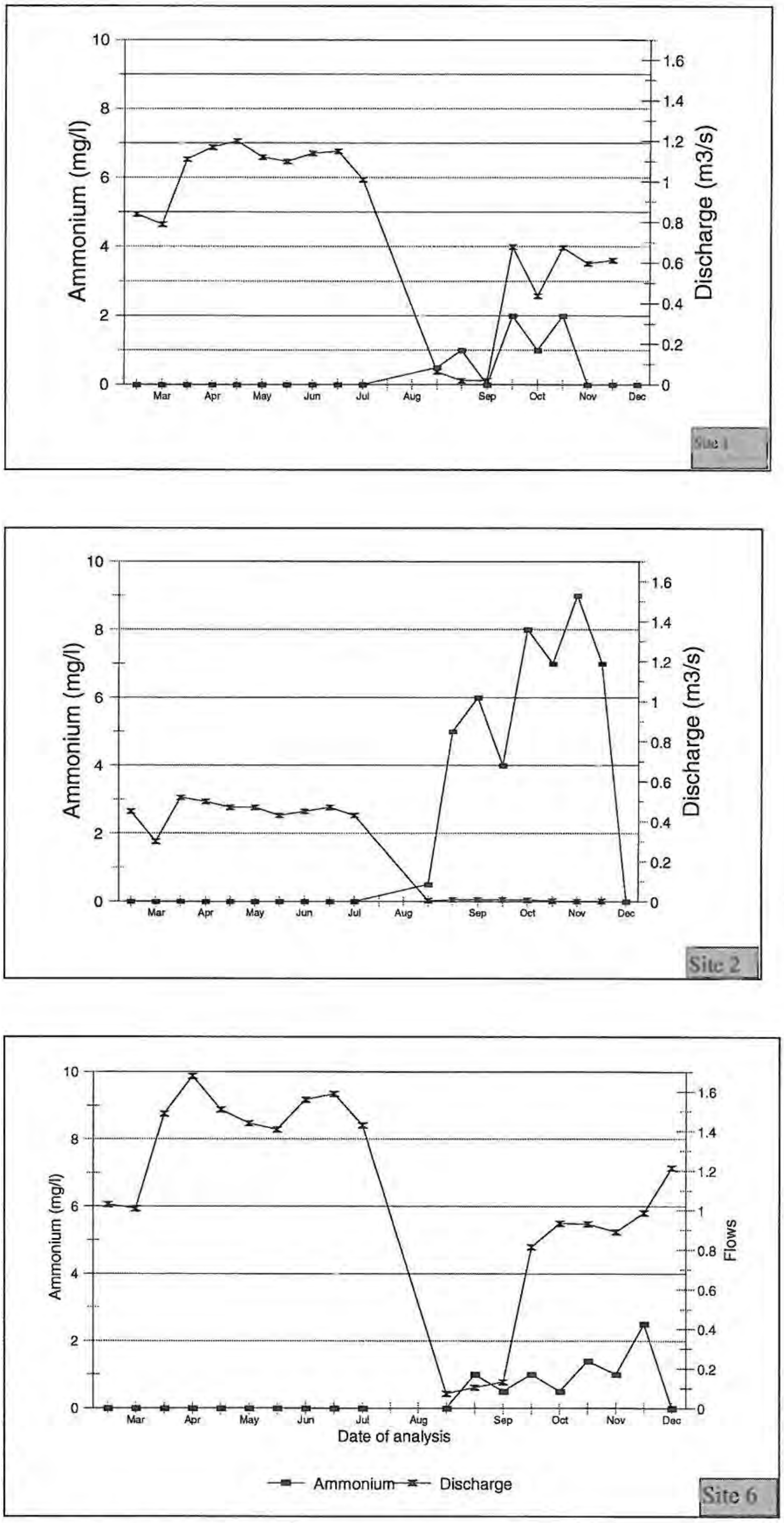

Figure 41: Ammonium in the upper Kat River

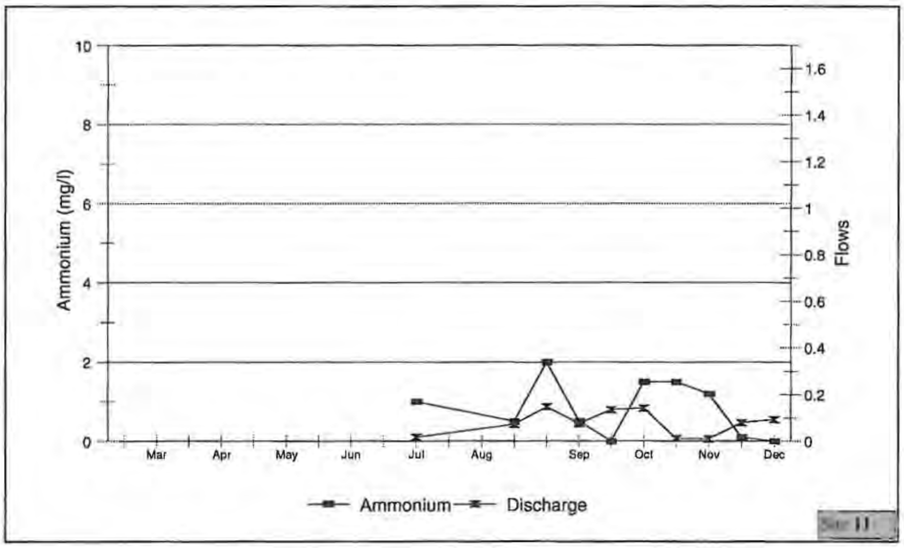

Figure 42: Ammonium in the Balfour River

July 21st (high flow period), in 6 of the 12 Sites ammonium was found when analysis was done during the dry low flow period (September 2nd – December 16th). It would therefore appear that the source of ammonium in many parts of the catchment is the groundwater, which the main source of flow for many stream during low flow conditions. This is not surprising, particularly if one considers that groundwater in most parts of the catchment, particularly around Hertzog stream, is heavily polluted (Section 4.3.12) and well loaded with nitrates. Bleuten (1989) points out that the processes of nitrification and oxidation are central in a relationship between nitrates and ammonium that makes them to be readily convertible to each other. Therefore, where nitrates are found, ammonium is likely to be found as well as a consequence of the interaction between the two.

4.2.11 **Faecal coliforms**

4.2.11.1 Spatial variation

Figures 38 and 44 and Appendix 18 illustrate the variation of the faecal coliform over the upper Kat River catchment. A gradual increase in faecal coliform count was observed between sites 1, 3, and 4. It is observable from the results of the study that faecal coliforms count is extremely high in the upper Kat River. Results of the study show that the number of faecal coliforms in the water of the Kat River increases on average by 33.2 percent from site 1 to site 4. A reduction in the number of organisms per 100ml of river water of 35 percent is observable between sites 4 and 6 as a result of the Fairbairn River input.

At Balfour, there is also a marked increase in the number of bacteria downstream. Between sites 7 and 9, the number of bacteria in river water increases by about 214 percent. Another increase of 92.4 percent is observed between sites 9 and 12. In total, between site 7 and 12, the number of the faecal coliform bacteria per 100 ml of river water increases by 503 percent from 117 to 706 organisms per

100 ml of water. It is evident from the Figure 37 that sites 2, 3, and 4 have the highest number of bacteria per 100 ml of water. In particular, site 2 has an average of 1167 organisms per 100 ml of water. It is also noticeable from results of the study that sites 5 and 7 have the lowest number of faecal coliform bacteria per 100 ml of water.

4.2.11.2 The temporal variation and the bacteria loads

Due to logistical constraints wet season faecal coliform results are not available. Hence, no comparison can be made. For the same reason, comparing dry and wet season loads of the faecal coliform bacteria is not possible. The dry season trends of faecal coliform bacteria are nonetheless presented in Figures 45 and 46. The loads are presented in Tables 6and 7. It is noticeable that all site in the main Balfour and Kat Rivers have higher loads of the faecal coliforms than the tributaries. An increasing trend in faecal coliforms downstream in the Kat River shows that there is some faecal pollution happening. This might be from the grazing livestock or pit latrines used by the communities. Human faeces, which also be having a considerable contribution, is also not a rare sight along the banks of the river. An increase of 2250198 organisms that observable between Site 7 and 12 in the Balfour River is a consequence of faecal pollution from the grazing animals as well as pit latrines used by communities in the Balfour village.

4.2.12 Potassium

4.2.12.1 Spatial variation

Appendix 19 illustrate potassium trends in the upper Kat River area. At the Kat River, a downstream increasing trend in potassium concentration is observed between sites 1 and 4. For example, potassium concentration increases by more than 190 percent between sites 1 and 4. A slight drop in potassium concentration was observable from site 4 to 6. In sites 2, 8 and 9 potassium concentrations are higher compared to other sites. In sites 5 and 7, no potassium was observed.

4.2.12.2 Temporal variation and loads

Due to logistical constraints, wet season potassium concentration results are not available. Thus, no comparison can be made. For the same reason, comparing dry and wet season loads of potassium is not possible.

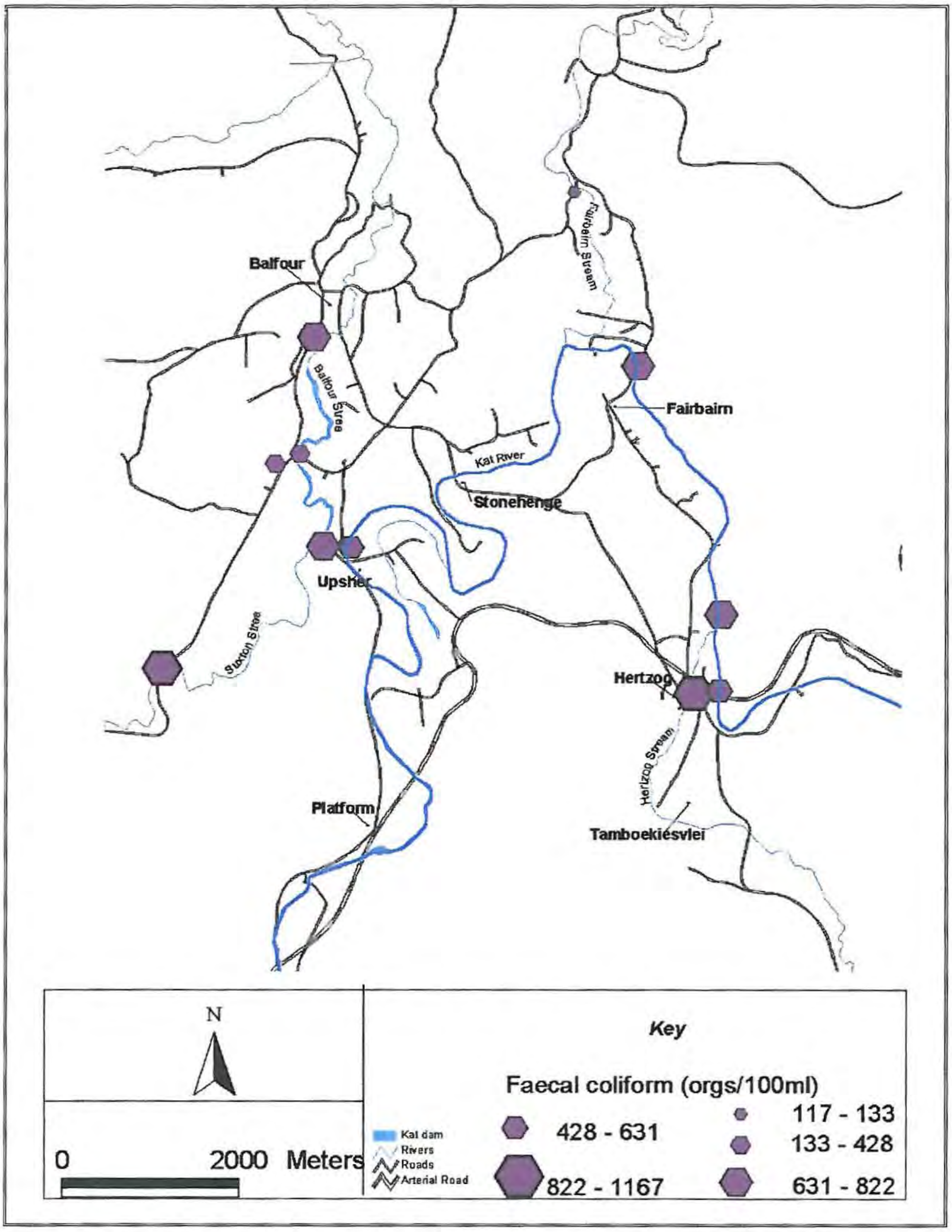

Figure 43: Faecal coliforms spatial dynamics in the upper Kat River

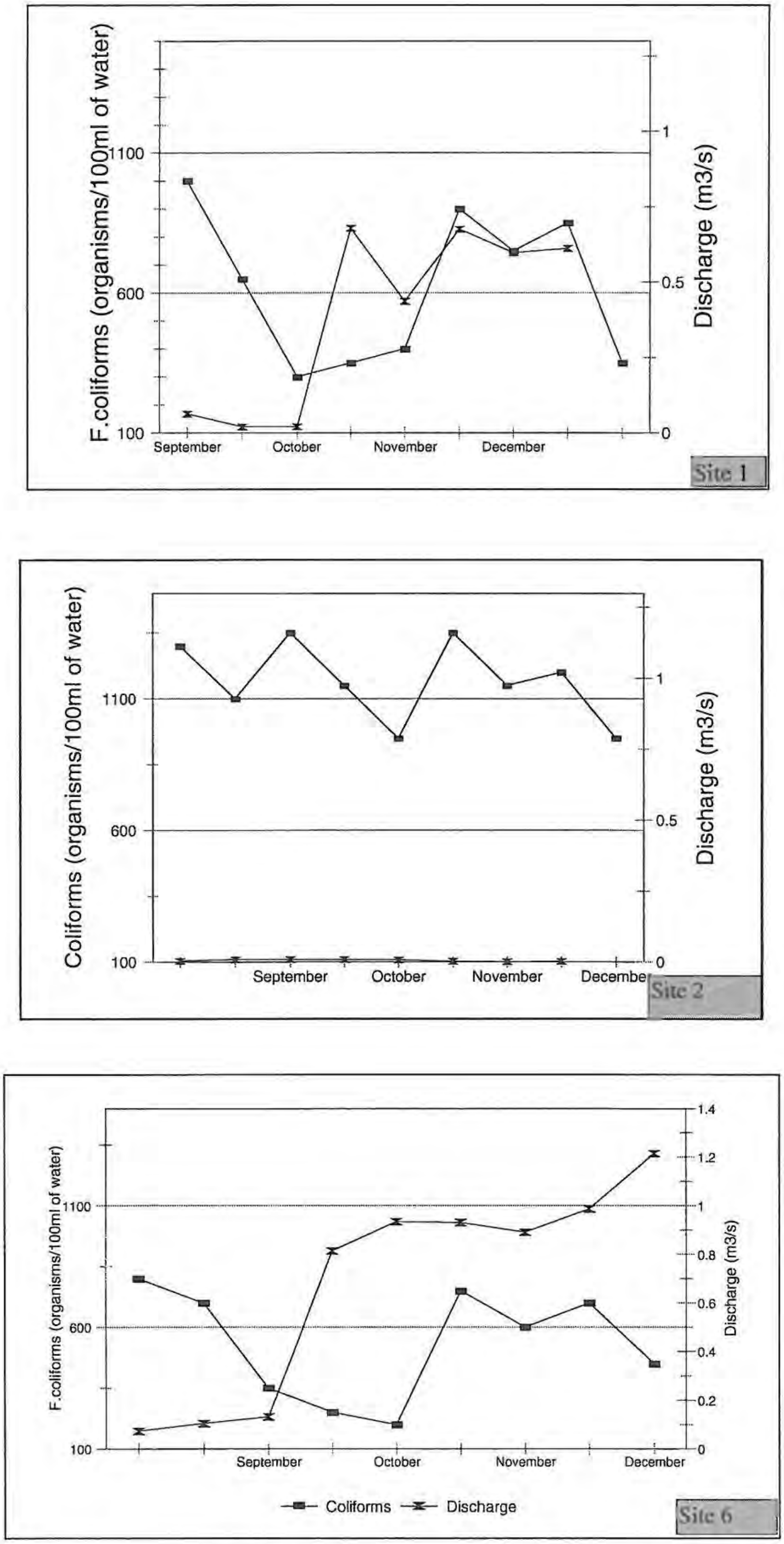

Figure 44: Temporal faecal coliform trends in the upper Kat River

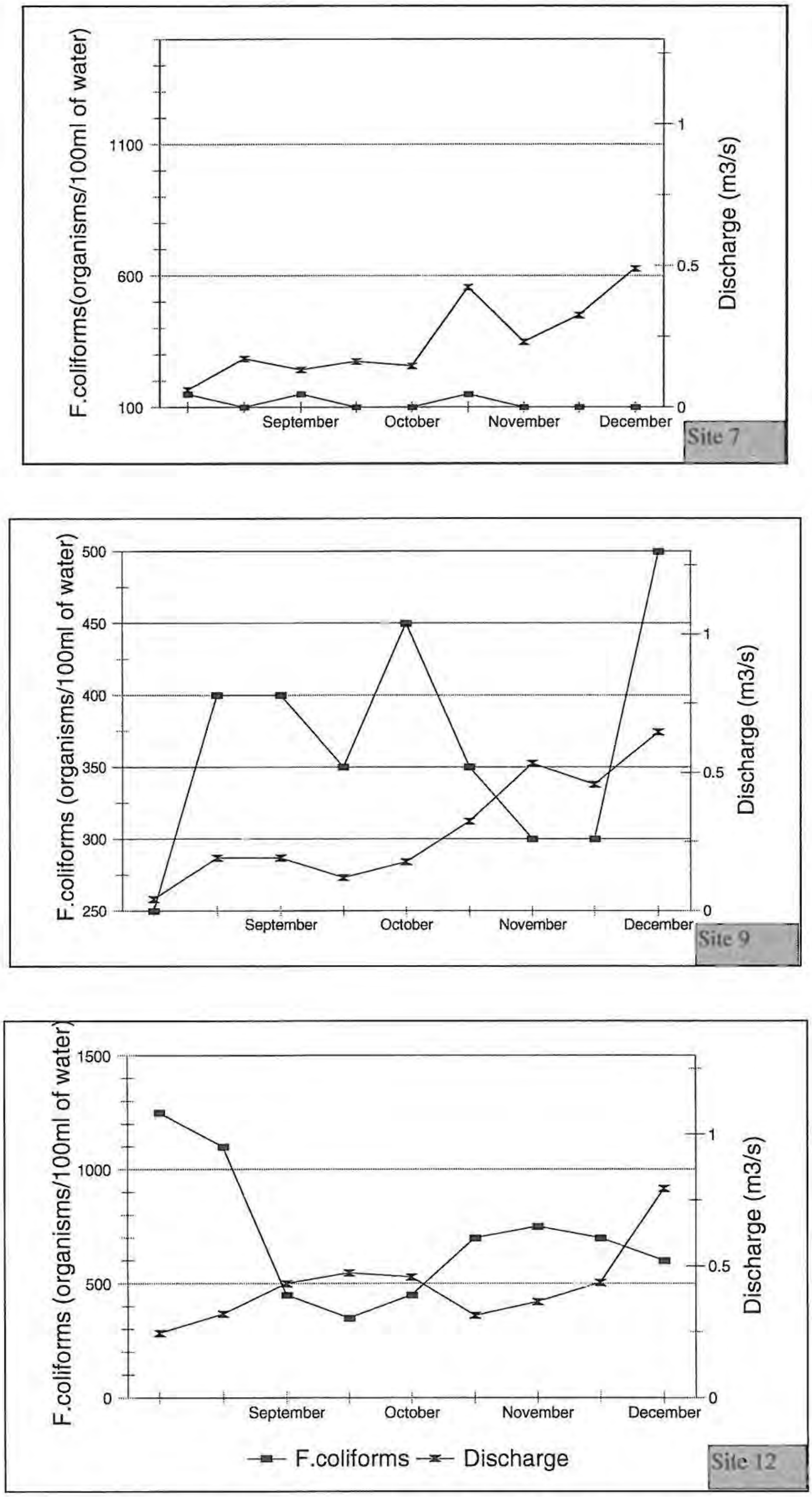

Figure 45: Temporal coliforms temporal dynamics in the Balfour River

4.3.12 Quality of groundwater in the upper Kat River area

It is evident that groundwater is heavily polluted in most parts of the catchment. This is evidenced by the results obtained during the walk up several streams of the catchment. For example, a water-quality-survey-walk up the Hertzog stream revealed that the stream is mostly dependent on groundwater in a form of a series of springs for its flow (Table 8). For example, the most spring water has been observed to be having electrical conductivity exceeding 1000 mS/m and nitrate concentrations were in excess of 20mg/l in at least two springs and more than 50mg/l in one of the wells utilized by the community of Tambokeisvlei for domestic purposes. Results obtained during the water quality discussion workshop (Appendix 20) confirmed that groundwater in the area is polluted. Also, in the tap water at Balfour (which DWAF confirmed that it is being extracted from the groundwater), nitrate concentrations exceeding 50mg/l were continuously recorded.

By implication, the areas of the catchment whose groundwater is polluted will be impacted upon more. This situation is more evident during the dry season when the flows are low and the main source of the flow is groundwater. Also, this situation would be more pronounced on catchment streams that rely mostly on groundwater for their flows as evidenced in Hertzog stream.

Table 8: Results of the upstream walk along the Hertzog stream

Variable	Bridge	Weir	Up the weir 1	Up the weir 2	Spring 1	Up the spring	Spring 2	Spring 3	Salty well	Sweet well
pH	8.6	8.7	8.4	7.4	7	8.2	7.8	7.9	8.8	7.8
EC	1246	1175	1326	1310	1090	1240	1210	640	1230	523
Nitate	5	10	> 10	> 20	> 20	14	> 20	14	> 50	> 20

Chapter 5

Water Quality Discussion

This chapter aims to discuss both the spatial and temporal trends of selected water quality variables in the upper Kat River area. The impact of these pollutants on human health and welfare will be determined by measuring them against the Department of Water Affairs and Forestry water quality guidelines.

5.1 The spatial dynamics of water quality variables

From results of the study, a spatial change in concentrations and loads of several water quality variables was noticeable. The results showed greater concentrations of water quality variables in some parts of the catchment than in others. It has been established that the major reason for this difference in spatial concentrations of pollutants is that major sources of pollutants were often different throughout the study area. Also, where sources of pollutants were identified to be similar, the impact was often different mainly because of one factor or combination of the following circumstantial factors:

- The source of pollution is more intense in some parts of the catchment than others. The obvious consequence of this is that areas where the source of pollutants is more intense will be highly impacted upon than other areas of the catchment.

- The flows are higher in major rivers than the tributaries. Thus, major rivers in the area have greater dilution capabilities than the tributaries. This means that these rivers have a greater capability for self-purification. Hence, most loads of pollutants are higher in the main Kat River than the tributaries, yet concentrations are much lower in the Kat River.

- As stated in Section 4.3.12 of Chapter 4, groundwater is profoundly polluted almost throughout the catchment Table 8. This situation was more pronounced and evident in those streams in the catchment whose flow was mainly groundwater. In contrast, in the Kat River which had the storm flows, the impact of polluted groundwater was less evident.

- It has been observed that agricultural practices, particularly crop farming, covered a broader area in the past than it did during the duration of the study. For example, the Tamboekeisvlei has pointed to a piece of land that was productively used for cropping, but which at the time of the study lied unutilised because a farmer upstream of Hertzog stream has built a dam that blocks the flow of water in the stream. Likewise, it is reported that most land along the Balfour River area was once used for tobacco farming. The apartheid government policies however forced White farmers out of the area. Although some of this land at Balfour village is still used for crop farming, most agricultural land has since been consumed by the rapidly expanding Balfour settlement. At Buxton village as well, the once productive cropland now lies unutilized.

The impact of this more extensive agricultural practice on water quality may still be felt in most parts of the catchment to this day. This may be one of the explanations for the level of groundwater pollution in the area. Moreover, as a consequence, new pollutants may be introduced into the catchment from the new land-uses and the resulting activities.

- The results of the study indicate that the most common form of sanitation is the pit latrine. A study by Pretorius (2000) in Botshabelo has indicated that microbial water pollution by pit latrines can be significant. The findings of Pretorius (2000)'s study indicate that the level of microbes in water infected by pollutants from the pit latrines might approach levels found in raw sewage.

One village indicated that they used septic tank. Jensen and Gerston (1986) have noted that although septic tank systems may be safe and effective, when these are used in rural areas, the chances of critical surface and groundwater pollution as a result of the system failure are high. The consequences of surface and groundwater contamination by discharges from the septic tank include repulsive odours, high levels of phosphate and nitrates and a number of pathogens (Jensen and Gerston, 1986), a phenomenon that has been observed in the upper Kat River area.

It has also been noted that some parts of the catchment are without any form of sanitation and are thus using the veld. During the rainy period, the overland flows carry the human faecal waste into the stream. Leeming *et al.*, (1997) indicates that the consequences of this kind of input of pollution include elevated levels of nitrate, phosphate and disease-causing organisms. Payment (1999) has reminded us that water-borne diseases are still major causes of death in areas lacking modern sanitation and water treatment.

- Whilst grazing has been noted throughout the catchment, it has been noticed that it is more intense along the banks of some parts of the catchment. It would be expected that, amongst others, such intense areas of grazing be the major source of animal excreta. Amongst others, US EPA (1997) identified such areas as the major contributors of bacteria and nutrients into surface and groundwater. Synge *et al.* (2000) associated the 1999 outbreak of water-borne VTEC 0157 in the Scottish highlands with grazing sheep. Synge *et al.* (2001) later warned of the risk related with the use of untreated water from open land where animals graze.

- The present agricultural system is more intense than the past as a result of the HARCOP cooperate influences. Hence, present day crop farming activities in the area are more heavily reliant on agro-chemicals and irrigation than ever before. More often, runoff picks up and transports these chemicals and other agricultural pollutants and deposits them into surface water bodies and groundwater (US EPA, 1997). US EPA (1997) listed the following potential water pollutants from agricultural land: excess fertilizers, herbicides, insecticides, sediment from improperly managed crop land, salt from irrigation practices, bacteria and nutrients from livestock wastes. Most of these agro-chemicals are critically harmful both to humans and aquatic life. For example, Larson *et al.*, (1997) has indicated that pesticides are carcinogenic to humans. Besides being carcinogenic, US EPA (1989) adds the following health effects associated with pesticides: genetic mutation, diarrhoea, nausea, vomiting, abdominal pain, profuse salivation and sweating, blurred vision, skin and eye irritation, upper respiratory tract distress, edema of the lungs, acute gastro-intestinal distress, headache, dizziness, drowsiness and seizure.

- In the study area there are five settlements, four of which are completely rural and one which is semi-urban. No settlement has a waste collection service. Hence, rivers are more polluted by domestic waste along these settlements. Consequently, signs of domestic waste are apparent along the riverbanks where the river passes through a settlement.

  Specifically, in all five villages, it has been established that in-stream washing is practised in some parts of the river. Thus, there is a direct input of detergents into the river. The impact of detergents on aquatic organisms is documented in chapter 3.

5.2 Temporal variation of the water quality variables

Results of the study indicate that water quality variable levels varied over time. For example, there is a noticeable change on the levels of water quality variables throughout the study Site between low and high flow periods. An obvious explanation would be to implicate groundwater as the source of pollutants because the concentrations are high at the period when the main source of the flow is groundwater. Because most of the flows during the wet period are derived from the runoff, groundwater input is then proportionally lesser, hence its lower impact. Also because the flows are higher during the high-flow period, the mixing capabilities are higher.

Loads pollutants are however higher during the high than the low-flow period, thereby casting doubts on the above explanation. Loads seem to suggest that the dilution capabilities of the stream are the main effect.

5.3 The impact of water quality variables on health and welfare of the user communities

In this section, water quality results of the study are measured against the World Health Organisation (WHO, 1998) and Department of Water Affairs and Forestry's (DWAF, 1999) water quality guidelines for domestic uses. The exercise of comparing the water quality for each Site in the study area was carried out to determine the fitness of water in the area for use in domestic applications. Tables 9 – 20 present minimum, maximum and mean Site-to-Site water quality results measured against WHO (1998) and DWAF (1999)'s water quality specifications. The following discussion serves to explain the contents of these tables.

- Site 1 (upper Kat River)

Table 9 gives an indication of the quality of water in Site 1 as measured against DWAF and WHO's water quality guidelines for domestic purposes. The electrical conductivity, pH, total hardness, nitrate, and potassium on this Site are at excellent levels. A variation of the quality of water as influenced by nitrite is noticeable at this Site. Despite that, even when it is at its highest, nitrite concentration (2 mg^{-1}) is still within the WHO's limit for insignificant risk on water users.

It also appears that the maximum concentrations of chloride (423 mg^{-1}) and ammonium (2) at this Site are marginal. The South African National Department of Health and Population Development in Aucump and Vivier (1990) and WHO (2001) are in agreement that chloride above 250 mg^{-1} not only impact on the odour but will also give water a salty taste. WHO (2001) states that concentrations of ammonium above 1.5 mg^{-1} would have a noticeable impact on the aesthetic quality of water, specifically on odour and taste. DWAF (2000) also highlights the following health and welfare concerns associated with the use of water with chloride concentrations between 200 mg^{-1} and 600 mg^{-1}:

Legend	Ideal	Good	Marginal	Poor	Very poor	Guideline not available

Table 11 Water quality condition at Site 1

Water quality variable	Units of measurement	Site	WHO acceptable guidelines		DWAF acceptable guidelines		Minimum at the stream source	Maximum at the stream source	Mean at the stream source	Water quality classification
			Maximum limit for no risk	Maximum limit for insignificant risk	Maximum limit for no risk	Maximum limit for insignificant risk				
Electrical conductivity (TDS)	mS/m (mg^{-1})	1	600	1200	450	1000	73	422	171	
Turbidity	nephelometric turbidity units (NTUs)	1	0	5	0-1	1-5	99	234	162	
pH	pH units	1	6.5 – 9.5	9.6 & 6.4	6 / 9	5.5 / 9.5	7.6	8.6	7.96	
Total hardness	mg^{-1} $CaCo_3$	1	100	200	200	300	1	13	7	
Chloride	mg^{-1}	1	200	300	250	600	73	423	172	
Nitrate	mg^{-1}	1	6	50 (acute effect)	6	10	0	3	0.56	
Nitrite	mg^{-1}	1	0.2	3 (chronic effect)	6	10	0	2	0.342	
Ammonium	mg^{-1}	1	0	1.5	1	2	0	2	0.4	
Potassium	mg^{-1}	1	Not available	Not available	200	400	0	4	1.4	
Phosphate	mg^{-1}	1	Not available	Not available	Not available	Not available	0	2	0.16	No guideline available
Faecal coliform	Counts/100 ml	1	0	0	0	1	300	1000	617	

- A distinctly salty taste is noticeable.
- Water with marginal levels of chloride may result to the moderate corrosion of iron.
- Health risk to sensitive individuals is increased either by the consumption of or eating food prepared from water with marginal concentration of chloride.

Agro-chemical and irrigation dependent intensive crop farming and grazing have been identified as the main source of chloride and other salts and nutrients like ammonium and nitrate in the study area.

What has been observed to be critical at this Site, however are the very poor turbidity levels and very high faecal coliform count. Both WHO (2001) and DWAF (2000) indicate that turbidity levels should not exceed 5 NTUs. Even the minimum concentrations at this Site (99 NTUs) are about 20 times more than specified limits. The Kat River dam just upstream of this Site is responsible for high turbidity levels not only in this Site but also other Sites that are in the Kat River, that is, Sites 3, 4, and 6.

DWAF (2000) lists the following health effects associated with consumption and use of water with high turbidity:

- Serious health effects are common in all users as a result of the likely presence of micro organisms associated with the sediment, particularly clay.
- Water's appearance increasingly becomes muddy, hence critical effects on aesthetic quality of water.
- Secondary health effects are likely to result from the food prepared from water with that high turbidity.
- Water with high turbidity is also not suitable for laundry as it stains clothes.

WHO (2001), DWAF (2000), and DWAF (1993) indicate that there should not be any faecal coliform bacteria in drinking water. They also note it takes only just over 10 organisms per 100ml of drinking water to cause clinical infections, even with once off consumption. The minimum number of bacteria observed at this Site per 100ml of water is 300.

According to DWAF (2000) consequences of the domestic use of water with high faecal coliform count are that :

- Serious health effects, particularly gastro-intestinal diseases may result from the consumption of and eating food prepared with such water.
- Chances of infection are high when bathing and doing laundry with water of that quality.

Faecal coliforms are described by DWAF (2000:50) as the *"indicators of the presence of faecal pollution in water ....."*. Around this Site , it has been established that there are many sources of faecal pollution. These include animal excreta from cattle and other domestic animals such as goats, pigs, sheep, and horses grazing along and drinking from the river, and human faeces which is a common sight, not only at this Site but also throughout the catchment.

- Site 2

From Table 10, it could be observed that pH and total hardness values and nitrite and potassium concentrations at this Site fall within DWAF and WHO's acceptable threshold for no risk. It is however noticeable that the total dissolved salts (TDS), nitrate and ammonium sometimes reach health threatening concentrations. DWAF gives 1000 mg/l of TDS as the maximum limit for insignificant risk. At times, however, the concentration at this Site exceeds this limit by far. For example, the maximum concentration of TDS at this Site was 1365 mg/l. This is about 40 percent more than the stipulated limit of insignificant risk and more than double DWAF's required maximum limit for no risk (450 mg/l). It would seem logical to conclude that the salt content in the water of this Site is extremely high. Besides the evidence of extremely high total dissolved salts, chloride concentrations (also 1365 mg^{-1}) in this Site are a compelling substantiation of very high salt contents. According to DWAF (2000), domestic use of this water can lead to:

- the possibility of overloading of salts to sensitive users,
- tastiness in water is certainly noticeably salty,
- nausea and vomiting a possible consequence of consumption of this water,
- there is an extremely high risk of dehydration in infants,
- water with this concentration of salts is very corrosive.

Poor levels of nitrate and ammonium were also noted at this Site. Maximum nitrate levels (20 mg/l) at this Site were more than 300 percent greater than the required maximum limit for no risk (6 mg/l), exactly 200 percent more than the specified maximum limit for insignificant risk. DWAF (1993) and DWAF (2000) note the following health and welfare concerns associated with household use of water with high concentrations of nitrate:

- increased risks of methaemoglobinaemia in infants,
- possible chronic risks in some babies may result as a consequence of drinking and eating food prepared in water with high nitrate concentrations,

WHO (2001) states that ammonium concentration should not exceed 1.5 mg/l in water to be used for domestic applications. Table 10 illustrates that ammonium in water at Site 2 occasionally reached unacceptable concentrations. For example, the highest ammonium concentration recorded at Site 4

Legend	Ideal	Good	Marginal	Poor	Very poor	Guideline not available

Table 12 **Water quality condition at Site 2**

Water quality variable	Units of measurement	Site	WHO acceptable guidelines		DWAF acceptable guidelines		Minimum at the stream source	Maximum at the stream source	Mean at the stream source	Water quality classification
			Maximum limit for no risk	Maximum limit for insignificant risk	Maximum limit for no risk	Maximum limit for insignificant risk				
Electrical conductivity (TDS)	mS/m (mg^{-l})	2	600	1200	450	1000	241	1365	569	
Turbidity	nephelometric turbidity units (NTUs)	2	0	5	0-1	1-5	0.5	21	6	
pH	pH units	2	6.5 – 9.5	9.6 & 6.4	6 / 9	5.5 / 9.5	6.6	9.4	7.9	
Total hardness	mg^{-l} $CaCo_3$	2	100	200	200	300	7	40	21	
Chloride	mg^{-l}	2	200	300	250	600	241	1365	569	
Nitrate	mg^{-l}	2	6	50 (acute effect)	6	10	2	20	9	
Nitrite	mg^{-l}	2	0.2	3 (chronic effect)	6	10	0	0	0	
Ammonium	mg^{-l}	2	0	1.5	1	2	0	4	0.95	
Potassium	mg^{-l}	2	Not available	Not available	200	400	0	14	10.1	
Phosphate	mg^{-l}	2	Not available	Not available	Not available	Not available	0	4	0.58	
Faecal coliform	Counts/100 ml	2	0	0	0	1	950	1350	1167	

mg/l. This is over 260 percent more than the acceptable maximum limit of ammonium in water used for domestic purposes. As stated earlier in this discussion, high ammonium concentrations affect the taste and also introduce an unpleasant smell into water.

The faecal coliform count was also extremely high at this Site. The minimum and maximum number of organisms per 100 ml of water recorded in this Site ranged between 950 and 1350 respectively. This is indisputable evidence that water in this area is being faecally polluted. An old septic tank, pit latrines, agro-chemicals and irrigation-dependent intensive crop farming, heavily polluted groundwater and intensive grazing upstream of Site 2 have been identified as the major sources of pollution. These sources of pollution introduce faecal coliform bacteria, salts, nitrate, and ammonium into the Hertzog stream. The impact of the faecal coliform bacteria on human health and welfare is dealt with under Site 1 discussion above.

- Site 3

It is evident from Table 11 that total hardness, pH, nitrite and potassium in water at this Site is of an ideal level. The total dissolved salts concentration is seen to be at a good level. The chloride concentration is at the marginal level. The side effect on human health and welfare of using water with marginal levels of chloride is given under Site 1 above. It would appear that nitrate levels in this Site are mostly of acceptable level, but occasionally, reach marginal levels. For example, the maximum concentration of nitrate measured at this Site was 20 percent more than the DWAF (1993)'s acceptable guideline for insignificant risk and 200 percent more than WHO (2001) and DWAF (2000)'s maximum limit for no risk. The health and welfare effect of nitrate on human has been documented under Site 2 above.

At low concentration, ammonium at this Site is of ideal concentration, but it would seem that at times, it becomes extremely high. For example, the maximum recorded ammonium concentration at Site 3 is 5 mg^{-1}. Considering that WHO (2001), DWAF (2000), DWAF (1993), and the South African national Department of Health and Population Development in Aucamp and Vivier (1990) all agree that there should not be any ammonium in water used for domestic applications, the maximum concentration of ammonium found at this Site is totally unacceptable., The impact of ammonium on health and welfare of the water users is discussed under Site 2 above.

Turbidity levels at this Site have been found to be extremely high, particularly if one considers that the minimum and maximum turbidity levels recorded at this Site were 59 and 186 NTUs respectively. These levels of turbidity are 11.8 (for minimum turbidity recorded) and 37.2 (for maximum turbidity recorded) times higher than the guideline limit given by DWAF and WHO organisation for

Legend	Ideal	Good	Marginal	Poor	Very poor	Guideline not available

Table 13 Water quality condition at Site 3

Water quality variable	Units of measurement	Site	WHO acceptable guidelines		DWAF acceptable guidelines		Minimum at the stream source	Maximum at the stream source	Mean at the stream source	Water quality classification
			Maximum limit for no risk	Maximum limit for insignificant risk	Maximum limit for no risk	Maximum limit for insignificant risk				
Electrical conductivity (TDS)	mS/m (mg^{-l})	3	600	1200	450	1000	81	488	221	
Turbidity	nephelometric turbidity units (NTUs)	3	0	5	0-1	1-5	59	186	127	
pH	pH units	3	6.5 – 9.5	9.6 & 6.4	6 / 9	5.5 / 9.5	7.6	8.5	8.1	
Total hardness	mg^{-l} CaCo$_3$	3	100	200	200	300	2	19	9	
Chloride	mg^{-l}	3	200	300	250	600	81	488	221	
Nitrate	mg^{-l}	3	6	50 (acute effect)	6	10	1	12	5	
Nitrite	mg^{-l}	3	0.2	3 (chronic effect)	6	10	0	0	0	
Ammonium	mg^{-l}	3	0	1.5	1	2	0	5	0.95	
Potassium	mg^{-l}	3	Not available	Not available	200	400	0	5	2.7	
Phosphate	mg^{-l}	3	Not available	Not available	Not available	Not available	0	5	0.74	
Faecal coliform	Counts/100 ml	3	0	0	0	1	350	1100	756	

insignificant risk (5 NTUs). In the discussion section on Site 1, the effects of using water with extremely high turbidity on domestic applications are highlighted.

Table 11 indicates that the faecal coliform count in this Site is extremely high. This is so if one considers that the minimum count of organisms per 100ml of water is 350 while the maximum was about 1100 organisms. WHO (2001) agrees with the South African National Department of Health and Population Development in Aucamp and Vivier (1990), DWAF (1993) and DWAF (2000) in that there should not be any bacteria in water used for domestic purposes. The discussion sections on Site 1 and 2 highlight all the health and welfare effects of using water for domestic purposes with that high bacteria count.

Because this Site is below the confluence of the Kat River with Hertzog stream, it has been noted that one of the greatest contributors of pollutants into this Site is the Hertzog stream which is heavily polluted (Site 2). The intensive agriculture practised in the area has also been noted as the likely source of salts, nutrients and other pollutants, particularly because it is heavily dependent on irrigation and agro-chemicals. These pollutants may be getting into the river via overland flow from precipitation and irrigation created runoff, groundwater, particularly during dry conditions when the flow of the river is principally maintained by the groundwater input. The widespread use of pit latrines by the Hertzog community might also be adding some pollutants, including nitrates, salts, ammonium, and pathogens into the stream via groundwater and overland flow, particularly when the said latrines overflow.

The Kat River dam creates very turbulent flows, thereby increasing the river's ability to erode and transport greater loads of sediment and other materials, and hence leading to the high turbidity readings recorded at this Site. Also, the fact that this Site is below the confluence of the Kat River with Hertzog stream means that flows are evidently higher at this Site than Site 1. This increase in volume of flow also impact on the stream's eroding and transportation capacities. This would then obviously increase the amount of material transported by the river, and hence high turbidity levels. The high nutrient and sediment content in the river may have an indirect impact on the levels of turbidity at this Site, particularly at times when the flow of the river is not very fast. These conditions would encourage the growth of algae and other aquatic plants in the river. These would certainly increase the turbidity in the water. Another possible explanation of the extreme turbidity levels in the Kat River is that, bottom feeding fish in the Kat River Dam might be playing a critical role in stirring up the bottom sediments, which are later released from the dam (Andrew, T. pers comm., South African Institute for Aquatic Biodiversity). In fact, this explanation holds more truth than the others as there is very little sediment below the dam itself.

Legend	Ideal	Good	Marginal	Poor	Very poor	Guideline not available

Table 14 Water quality condition at Site 4

Water quality variable	Units of measurement	Site	WHO acceptable guidelines		DWAF acceptable guidelines		Minimum at the stream source	Maximum at the stream source	Mean at the stream source	Water quality classification
			Maximum limit for no risk	Maximum limit for insignificant risk	Maximum limit for no risk	Maximum limit for insignificant risk				
Electrical conductivity (TDS)	mS/m (mg^{-l})	4	600	1200	450	1000	89	787	243	
Turbidity	nephelometric turbidity units (NTUs)	4	0	5	0-1	1-5	48	177	129	
pH	pH units	4	6.5 – 9.5	9.6 & 6.4	6 / 9	5.5 / 9.5	7.7	9.1	8.3	
Total hardness	mg^{-l} $CaCo_3$	4	100	200	200	300	2	14	9	
Chloride	mg^{-l}	4	200	300	250	600	89	787	243	
Nitrate	mg^{-l}	4	6	50 (acute effect)	6	10	2	15	6	
Nitrite	mg^{-l}	4	0.2	3 (chronic effect)	6	10	0	0	0	
Ammonium	mg^{-l}	4	0	1.5	1	2	0	2	0.24	
Potassium	mg^{-l}	4	Not available	Not available	200	400	2	7	4.1	
Phosphate	mg^{-l}	4	Not available	Not available	Not available	Not available	0	2	0.32	
Faecal coliform	Counts/100 ml	4	0	0	0	1	400	1150	822	

- Site 4

It is observable from Table 12 that TDS, pH, total hardness, nitrite, ammonium, and potassium are all found on ideal or at least good levels in water at this Site. Thus, an improvement in water quality between the previous Site and this one, particularly in ammonium, is noticeable, although insignificant increases in TDS, chloride, and nitrate are also apparent.

Chloride and nitrate were found at marginal concentrations in water at this Site. Turbidity and faecal coliform counts in this Site were found to be extremely high. The effects of all of these on human health and welfare are presented in sections 1 and 2 above.

The sources of salts and nutrients identified at this Site include intensive agro-chemical and irrigation agriculture practised around the Site, domestic animals grazing along the banks of and drinking from the river. The pollutants from these sources get into the stream via natural runoff, irrigation-resultant overland flow, irrigation and rain water dissolving these and transporting them into the groundwater, which is the main source of river flow during dry periods, and the direct input of these into the river. For example, when cattle drink from the river, they may urinate or deposit some excretions directly into the river. The identified likely sources of pathogens into the river include pit latrines that are used widely throughout the area around the Site, domestic animals that have been spotted around the Site, and human faecal matter that could be seen along the banks of the river. These pathogens and other pollutants then get into the river via natural runoff, overland flow and groundwater.

- Site 5

From Table 13 it is observed that TDS, pH, total hardness, chloride, nitrate, nitrite, ammonium, and potassium readings recorded are of excellent quality. Only two variables had readings that caused concern, these are turbidity and faecal coliform count. Although Table 17 shows that these were lower than in many parts of the catchment, but they were still high enough to cause a water quality concern. The impact of the faecal coliform bacteria and high turbidity levels on human health and welfare is evaluated in the Site 1 discussion above.

Fairbairn stream, where Site 5, is located in a sediment-rich environment. Thus, sediment is readily available to be transported by the stream. Hence water in this Site is highly turbid. The main source of pathogens into the stream has been identified as the grazing wild and domestic animals. Grazing is quite intensive in this part of the catchment as there is a livestock farmer in the area around the Site.

Legend	Ideal	Good	Marginal	Poor	Very poor	Guideline not available

Table 15 Water quality condition at Site 5

Water quality variable	Units of measurement	Site	WHO acceptable guidelines		DWAF acceptable guidelines		Minimum at the stream source	Maximum at the stream source	Mean at the stream source	Water quality classification
			Maximum limit for no risk	Maximum limit for insignificant risk	Maximum limit for no risk	Maximum limit for insignificant risk				
Electrical conductivity (TDS)	mS/m (mg$^{-l)}$	5	600	1200	450	1000	91	226	147	
Turbidity	nephelometric turbidity units (NTUs)	5	0	5	0-1	1-5	8	60	24	
pH	pH units	5	6.5 – 9.5	9.6 & 6.4	6 / 9	5.5 / 9.5	6.9	8.3	7.7	
Total hardness	mg^{-l} $CaCo_3$	5	100	200	200	300	1	12	7	
Chloride	mg^{-l}	5	200	300	250	600	91	226	147	
Nitrate	mg^{-l}	5	6	50 (acute effect)	6	10	0	0	0	
Nitrite	mg^{-l}	5	0.2	3 (chronic effect)	6	10	0	0	0	
Ammonium	mg^{-l}	5	0	1.5	1	2	0	0	0	
Potassium	mg^{-l}	5	Not available	Not available	200	400	0	0	0	
Phosphate	mg^{-l}	5	Not available	Not available	Not available	Not available	0	0	0	
Faecal coliform	Counts/100 ml	5	0	0	0	1	100	200	133	

- Site 6

An improvement in the quality of water in form of reduced water quality concentrations is noticeable at this Site compared to the one just upstream (Site 4). The main cause for this is that between these two Sites there is a confluence with Fairbairn river whose water is noticeably less polluted (Site 5) than the Kat River, hence the mixing and dilution effects which improve the quality of water at this Site in the Kat River.

From Table 14, it is noticeable that TDS, pH, total hardness, nitrate, nitrite, ammonium and potassium levels in water at this Site are at acceptable levels as they at least fall within WHO (2001) and DWAF (2000)'s maximum respective limits for insignificant risk. At 631 mg/l, the maximum chloride concentrations recorded at this Site are more than double the WHO recommended limit of 300 mg/l. It is also noticeable from the table that turbidity and faecal coliform count are not acceptable. If one considers that minimum and maximum turbidity readings recorded in this Site are 49 and 177 NTUs respectively against the maximum of 5 NTUs permitted in water used for domestic applications (Aucump and Vivier, 1990; DWAF, 1993; DWAF, 2000 and WHO, 2001), turbidity is totally unacceptable in this Site. With faecal coliform bacteria ranging between 200 and 800, one can conclude that this level of bacteria in water is totally not at an unacceptable level for water being used for domestic purposes, particularly if one considers that both WHO (2001) and DWAF (2000) are specifying that there should not be any bacteria in that water. The impact of chloride, turbidity and high number of bacteria in water on health and welfare of human health and welfare are discussed under Sites 1 and 2. It has been established that salts and some nutrients are introduced into river water by human activities like intensive agro-chemical dependent agriculture that is prevalent just upstream of the Site. These may be getting into the fluvial environment through groundwater, overland flows and natural runoff. Turbidity in this Site is still the effect of the turbid water coming out of the Kat River Dam. Also the fact that water volume has increased since the upstream Site as a result of the confluence with the Fairbairn River has increased the river's potential to transport more sediment and other materials.

It would seem logical to conclude that most of the faecal coliform bacteria found at this Site are those being transported by the flow to this Site. This thinking is mainly motivated by the fact that there are fewer activities noted that would introduce the coliforms into the river between this Site and the one upstream (Site 4) and also a noticeable reduction in a number of organisms per 100ml of water between this Site and Site 4. For example, the minimum and maximum numbers of faecal coliforms per 100ml of water are 400 and 1150 at Site 4 respectively compared to 200 and 800 respectively at this Site. The noted impacting human activities include the impact of fewer domestic animals grazing along and drinking from the river and pit latrines from the very small village of Stonehenge.

Legend	Ideal	Good	Marginal	Poor	Very poor	Guideline not available

Table 16 Water quality condition at Site 6

Water quality variable	Units of measurement	Site	WHO acceptable guidelines		DWAF acceptable guidelines		Minimum at the stream source	Maximum at the stream source	Mean at the stream source	Water quality classification
			Maximum limit for no risk	Maximum limit for insignificant risk	Maximum limit for no risk	Maximum limit for insignificant risk				
Electrical conductivity (TDS)	mS/m (mg^{-1})	6	600	1200	450	1000	104	631	198	
Turbidity	nephelometric turbidity units (NTUs)	6	0	5	0-1	1-5	49	177	128	
pH	pH units	6	6.5 – 9.5	9.6 & 6.4	6 / 9	5.5 / 9.5	7.6	8.6	8.2	
Total hardness	mg^{-1} CaCo$_3$	6	100	200	200	300	1	17	8	
Chloride	mg^{-1}	6	200	300	250	600	104	631	198	
Nitrate	mg^{-1}	6	6	50 (acute effect)	6	10	1	7	4.6	
Nitrite	mg^{-1}	6	0.2	3 (chronic effect)	6	10	0	0	0	
Ammonium	mg^{-1}	6	0	1.5	1	2	0	0	0	
Potassium	mg^{-1}	6	Not available	Not available	200	400	0	3.1	2.2	
Phosphate	mg^{-1}	6	Not available	Not available	Not available	Not available	0	3	0.94	
Faecal coliform	Counts/100 ml	6	0	0	0	1	200	800	533	

Legend	Ideal	Good	Marginal	Poor	Very poor	Guideline not available

Table 17 **Water quality condition at Site 7**

Water quality variable	Units of measurement	Site	WHO acceptable guidelines		DWAF acceptable guidelines		Minimum at the stream source	Maximum at the stream source	Mean at the stream source	Water quality classification
			Maximum limit for no risk	Maximum limit for insignificant risk	Maximum limit for no risk	Maximum limit for insignificant risk				
Electrical conductivity (TDS)	mS/m (mg^{-l})	7	600	1200	450	1000	98	241	161	
Turbidity	nephelometric turbidity units (NTUs)	7	0	5	0-1	1-5	2	97	26	
pH	pH units	7	6.5 – 9.5	9.6 & 6.4	6 / 9	5.5 / 9.5	7.6	8.5	8.1	
Total hardness	mg^{-l} CaCo$_3$	7	100	200	200	300	1	23	11	
Chloride	mg^{-l}	7	200	300	250	600	98	241	161	
Nitrate	mg^{-l}	7	6	50 (acute effect)	6	10	0	0	0	
Nitrite	mg^{-l}	7	0.2	3 (chronic effect)	6	10	0	0	0	
Ammonium	mg^{-l}	7	0	1.5	1	2	0	0	0	
Potassium	mg^{-l}	7	Not available	Not available	200	400	0	0	0	
Phosphate	mg^{-l}	7	Not available	Not available	Not available	Not available	0	2	0.26	
Faecal coliform	Counts/100 ml	7	0	0	0	1	100	150	117	

- Site 7

Table 15 illustrates that most water quality variables are found in excellent levels in this Site. The variables are TDS, pH, total hardness, chloride, nitrate, nitrite, ammonium and potassium. Only the maximum value of turbidity has been found to be exceeding the maximum guidelines for insignificant risk (WHO, 2001 and DWAF, 2000). Although the minimum and the maximum faecal coliform count recorded at this Site are still of unacceptable quality, they are the lowest observed in the catchment.

The results of the study show that turbidity is highest in this Site during the wet season, when flows are high. This is a consequence of the stream flow's increased ability to erode and transport more sediment and other material. The noted likely sources of pathogens in this Site include domestic animals that have often been spotted on the banks of the river. Human faeces in the floodplain of the river is not an uncommon sight. These pollutants may be swept into the river channel by the natural runoff and overland flow.

- Site 8

Water quality variables whose concentrations and levels were ideal and good for use in domestic applications in water at this Site are: TDS, pH, total hardness, nitrate, nitrite, ammonium, and potassium. Table 16 shows that the maximum turbidity observed was at marginal levels, hence of concern. From the table it can be seen that the maximum concentration of chloride (695mg/l) in this Site is more than double the WHO (2001)'s maximum limit for insignificant risk (300 mg/l). Faecal coliform count in Site 8 was found to be high, as it ranged between 400 and 800 bacteria count per 100ml of water. The impact of high level of turbidity, chloride, faecal coliforms on human health and welfare are discussed under Site 1 and above.

Livestock and intensive crop farming happening up-stream of Site 8 contribute a number of pollutants into the stream, including sediment, salts, and pathogens; these are therefore found at high levels and concentrations in water of this Site. It is speculated that these pollutants get into the flow mainly through the natural surface flow. The overland flow and groundwater are also thought to introduce pollutants into the stream.

- Site 9

From Table 17, it could be seen that most water quality variables in the water of this Site are ideal to good. These variables are TDS, pH, total hardness, nitrate, nitrite, ammonium, and potassium. When measured against DWAF (1993) and DWAF (2000) guidelines, maximum chloride concentration (423

Legend	Ideal	Good	Marginal	Poor	Very poor	Guideline not available

Table 18 Water quality condition at Site 8

Water quality variable	Units of measurement	Site	WHO acceptable guidelines		DWAF acceptable guidelines		Minimum at the stream source	Maximum at the stream source	Mean at the stream source	Water quality classification
			Maximum limit for no risk	Maximum limit for insignificant risk	Maximum limit for no risk	Maximum limit for insignificant risk				
Electrical conductivity (TDS)	mS/m (mg^{-l})	8	600	1200	450	1000	403	695	514	
Turbidity	nephelometric turbidity units (NTUs)	8	0	5	0-1	1-5	5	19	9	
pH	pH units	8	6.5 – 9.5	9.6 & 6.4	6 / 9	5.5 / 9.5	7.6	8.9	8.5	
Total hardness	mg^{-l} $CaCo_3$	8	100	200	200	300	4	36	23	
Chloride	mg^{-l}	8	200	300	250	600	403	695	514	
Nitrate	mg^{-l}	8	6	50 (acute effect)	6	10	1	9	4.2	
Nitrite	mg^{-l}	8	0.2	3 (chronic effect)	6	10	0	0	0	
Ammonium	mg^{-l}	8	0	1.5	1	2	0	0	0	
Potassium	mg^{-l}	8	Not available	Not available	200	400	0	20	10.9	
Phosphate	mg^{-l}	8	Not available	Not available	Not available	Not available	0	4	0.32	
Faecal coliform	Counts/100 ml	8	0	0	0	1	400	800	631	

Legend	Ideal	Good	Marginal	Poor	Very poor	Guideline not available

Table 19 Water quality condition at Site 9

Water quality variable	Units of measurement	Site	WHO acceptable guidelines		DWAF acceptable guidelines		Minimum at the stream source	Maximum at the stream source	Mean at the stream source	Water quality classification
			Maximum limit for no risk	Maximum limit for insignificant risk	Maximum limit for no risk	Maximum limit for insignificant risk				
Electrical conductivity (TDS)	mS/m (mg^{-l})	9	600	1200	450	1000	114	423	329	
Turbidity	nephelometric turbidity units (NTUs)	9	0	5	0-1	1-5	2	77	31	
pH	pH units	9	6.5 – 9.5	9.6 & 6.4	6 / 9	5.5 / 9.5	7.9	8.5	8.3	
Total hardness	mg^{-l} $CaCo_3$	9	100	200	200	300	3	34	17	
Chloride	mg^{-l}	9	200	300	250	600	114	423	328	
Nitrate	mg^{-l}	9	6	50 (acute effect)	6	10	1	9	5.3	
Nitrite	mg^{-l}	9	0.2	3 (chronic effect)	6	10	0	0	0	
Ammonium	mg^{-l}	9	0	1.5	1	2	0	0	0	
Potassium	mg^{-l}	9	Not available	Not available	200	400	0	15	6.2	
Phosphate	mg^{-l}	9	Not available	Not available	Not available	Not available	0	4	0.37	
Faecal coliform	Counts/100 ml	9	0	0	0	1	250	500	367	

mg/l) in Site 9 is below the maximum limit for insignificant risk (600 mg/l) by 177mg/l. The same maximum chloride concentration (423 mg/l) however exceeds the WHO (2001)'s maximum limit for insignificant risk (300 mg/l) by 123 mg/l.

The occasionally high turbidity levels and high number of faecal coliform bacteria in water are the main water quality problems at Site 9. For example, it could be observed from Table 21 that maximum turbidity reading recorded at this Site (77 NTUs) is more than 15 times the acceptable level for insignificant risk (5 NTUs). The count of faecal coliform bacteria in this Site varied between 250 and 500 organisms per 100ml of water at Site 9. The impact on human health and welfare of turbidity, chloride, and faecal coliform presence in water used for domestic applications is discussed under Sites 1 and 2 above.

Balfour village, grazing animals and the confluence of Balfour River with a more polluted stream on which Site 8 is located have been identified as the three main sources of pollutants of water at this Site. Site 9 is located just below Balfour village and any pollution from the village will manifest itself at this Site. Balfour community contributes a number of pollutants to Balfour River, including salts, some nutrients and sediment from agricultural land, and nitrate. Pit latrines that are widely used in the village are known to contribute nutrients and pathogens. Grazing animals also contribute nutrients and pathogens into the water of the Balfour River.

Pollutants from these sources are likely to reach the stream either as a natural runoff sweeping through the agricultural land carrying along any pollutants, including salts, into the Balfour River or through groundwater. Groundwater also makes a significant contribution to the degradation of the water of the Balfour River. Groundwater around the Balfour village area has been found to be highly polluted (workshop report- Appendix 20). In particular, nitrate was found at alarming concentrations (+ 50 mg/l) in groundwater of the Balfour village. It is therefore speculated that groundwater contributes nitrates and other nutrients into the Balfour River. Also, because the pit latrine sanitation system is widespread in Balfour village, it is thought that the pathogens migrate from these pit latrines into groundwater. It is therefore assumed that groundwater also transports these pathogens into the river.

- Site 10

It can be observed from Table 18 that TDS, pH, total hardness, nitrite, and potassium levels in water of this Site are ideal to good. It is also noticeable from Table 22 that chloride and ammonium concentrations reach concerning levels. The proof of this is that the maximum concentrations of chloride and ammonium are orders of magnitude above the respective WHO (2001) and DWAF (2000)'s maximum limit for insignificant risk. Maximum concentration of chloride

Legend	Ideal	Good	Marginal	Poor	Very poor	Guideline not available

Table 20 Water quality condition at Site 10

Water quality variable	Units of measurement	Site	WHO acceptable guidelines		DWAF acceptable guidelines		Minimum at the stream source	Maximum at the stream source	Mean at the stream source	Water quality classification
			Maximum limit for no risk	Maximum limit for insignificant risk	Maximum limit for no risk	Maximum limit for insignificant risk				
Electrical conductivity (TDS)	mS/m (mg^{-l})	10	600	1200	450	1000	447	715	545	
Turbidity	nephelometric turbidity units (NTUs)	10	0	5	0-1	1-5	2	59	15	
pH	pH units	10	6.5 – 9.5	9.6 & 6.4	6 / 9	5.5 / 9.5	7.7	8.9	8.5	
Total hardness	mg^{-l} $CaCo_3$	10	100	200	200	300	3	35	24	
Chloride	mg^{-l}	10	200	300	250	600	448	715	545	
Nitrate	mg^{-l}	10	6	50 (acute effect)	6	10	1	9	4	
Nitrite	mg^{-l}	10	0.2	3 (chronic effect)	6	10	0	0	0	
Ammonium	mg^{-l}	10	0	1.5	1	2	0	9	2.4	
Potassium	mg^{-l}	10	Not available	Not available	200	400	0	9	4.7	
Phosphate	mg^{-l}	10	Not available	Not available	Not available	Not available	0	9	1,894737	
Faecal coliform	Counts/100 ml	10	0	0	0	1	250	650	428	

recorded at this Site (715 mg^{-l}) is about 238 percent more than the WHO (2001)'s maximum limit for insignificant risk (300 mg^{-l}). Maximum concentration of ammonium (9 mg^{-l}) at Site 10 is 6 and 4.5 times more than WHO (2001) and DWAF (2000)'s respective maximum limits for insignificant risk.

Maximum turbidity levels and the number of faecal coliform bacteria in water at this Site are also concerning. For example, it can be observed from Table 22 that maximum turbidity (59 NTUs) observed at this Site is almost twelve times more than the stipulated maximum limit (5 NTUs) for insignificant risk. The number of faecal coliform bacteria per 100ml in water of this Site ranged between 250 and 650 organisms. Considering that WHO (2001), DWAF (2000), DWAF (1993) and the South African National Department of Health and Population Development in Aucamp and Vivier (1990) all stipulate that there should be no faecal coliform in water used for domestic purposes, even the minimum number of organisms per 100ml of water (250 organisms per 100ml of water) recorded in this Site is undoubtedly extremely high and totally unacceptable. The impact of chloride, ammonium, turbidity and faecal coliform in health and welfare of the water-user communities is given under Site 1 and 2 above.

Intensive grazing happening upstream of this Site is the main source of pollutants. Grazing animals are a source of a number of pollutants which include pathogens, organic and inorganic pollutants like nitrate, nitrite and ammonium, and the microbiological agents. These reach the stream flows though pathways like natural runoff and seepage into the groundwater which is the main source of flow of most rivers during the dry periods.

- Site 11

At this Site, TDS, pH, total hardness, nitrite, ammonium and potassium have been found in acceptable quantities in water. Chloride, and nitrate concentrations, turbidity levels and the number of faecal coliform bacteria per 100ml of water are all of concern. Table 19 shows that the maximum chloride concentrations (715 mg/l) observed in this Site are more than double the maximum limit for insignificant risk (300 mg/l) specified by the WHO (2001). Table 19 displays that nitrate concentrations at this Site are always above the maximum limit for insignificant risk specified (10 mg/l) by DWAF (2000), DWAF (1993) and the South African National Department of Health and Population Development in DWAF (1993). This is evidenced by the fact that even the minimum nitrate concentration recorded in this Site (11 mg^{-l}) exceeds the specified limit by 10 percent. The maximum turbidity level (36 NTUs) observed in this Site exceeds the specified maximum turbidity limit for insignificant risk (5 NTUs) by more than six times (WHO, 2001 and DWAF, 2000). It is also observable from Table 19 that numbers of faecal coliform bacteria per 100ml of water are extremely high as they range between 550 and 1300 organisms. Under Site 1 and 2 above,

Legend	Ideal	Good	Marginal	Poor	Very poor	Guideline not available

Table 21 Water quality condition at Site 11

Water quality variable	Units of measurement	Site	WHO acceptable guidelines		DWAF acceptable guidelines		Minimum at the stream source	Maximum at the stream source	Mean at the stream source	Water quality classification
			Maximum limit for no risk	Maximum limit for insignificant risk	Maximum limit for no risk	Maximum limit for insignificant risk				
Electrical conductivity (TDS)	mS/m (mg^{-l})	11	600	1200	450	1000	160	715	537	
Turbidity	nephelometric turbidity units (NTUs)	11	0	5	0-1	1-5	2	36	24	
pH	pH units	11	6.5 – 9.5	9.6 & 6.4	6 / 9	5.5 / 9.5	7.8	8.7	8.4	
Total hardness	mg^{-l} $CaCo_3$	11	100	200	200	300	4	20	13	
Chloride	mg^{-l}	11	200	300	250	600	160	715	537	
Nitrate	mg^{-l}	11	6	50 (acute effect)	6	10	11	25	17	
Nitrite	mg^{-l}	11	0.2	3 (chronic effect)	6	10	0	0	0	
Ammonium	mg^{-l}	11	0	1.5	1	2	0	0	0	
Potassium	mg^{-l}	11	Not available	Not available	200	400	0	5	2.6	
Phosphate	mg^{-l}	11	Not available	Not available	Not available	Not available	0	0	0	
Faecal coliform	Counts/100 ml	11	0	0	0	1	550	1300	950	

a discussion on the impact of these water pollutants in health and welfare of those using the water for domestic purposes is given.

Intensive agricultural practices upstream of the Site have been noted as the main contributors of pollutants into the river. Intensive livestock farming is one of the main practices in the area upstream of the Site. Commercial forestry is the other noted likely contributor of pollutants into the river.

It is likely that the crop farming practised in the study area contributes pollutants such as salts, sediment, nitrates and other nutrients into the river. Intensive livestock farming might be contributing sediment, salts, nutrients and disease-causing micro-organisms. Commercial forestry might be introducing a number of pollutants into the river system, with the most prominent being salts and acidic compound, depending on the tree species in use. Surface flow and groundwater are the main agents that transport the pollutants into the river.

- Site 12

It is noticeable from Table 19 that TDS, pH, total hardness, and nitrite levels of water in this Site are ideal and good. Although mostly good, it has been observed that the concentrations of chloride, nitrate and ammonium and the level of turbidity can be of concern, especially when high. This is confirmed by the fact that the maximum concentrations of these, with the exception of turbidity, are marginal. The maximum levels of turbidity at this Site (87 NTUs) are more than 16 times higher than the maximum turbidity limit for insignificant risk (5 NTUs) specified by both WHO (2001) and DWAF (2000). The greatest concern in respect of water quality at this Site, however, should be the extremely high number of faecal coliform bacteria per 100ml of water. Table 20 shows that the faecal coliform bacteria at this Site vary between 350 and 1250 organisms per 100ml of water. The impact of turbidity, chloride, nitrate, ammonium, and faecal coliforms on human health and welfare is discussed under Sites 1 and 2 above.

From Table 20 an increase in most water quality variables between Site 9 (upstream of this Site in Balfour River) and this Site is apparent. Some noted increases including TDS, turbidity, total hardness, chloride, nitrate, ammonium, and faecal coliform bacteria are massive between the two Sites. For example, the mean number of faecal coliform bacteria increases by about 92 percent from 367 to 706 organisms per 100ml of water between the two Sites.

It could be observed that land between the two Sites is being utilised for grazing. It is apparent that the two tributaries of the Balfour River below Site 9 contribute considerably to the pollutants at this Site. From the above observation and discussion, it would seem logical to conclude that the two tributaries contribute salts, some hard water, chloride, nutrients, specifically nitrate and

Legend	Ideal	Good	Marginal	Poor	Very poor	Guideline not available

Table 22 Water quality condition at Site 12

Water quality variable	Units of measurement	Site	WHO acceptable guidelines		DWAF acceptable guidelines		Minimum at the stream source	Maximum at the stream source	Mean at the stream source	Water quality classification
			Maximum limit for no risk	Maximum limit for insignificant risk	Maximum limit for no risk	Maximum limit for insignificant risk				
Electrical conductivity (TDS)	mS/m (mg^{-1})	12	600	1200	450	1000	127	566	394	
Turbidity	nephelometric turbidity units (NTUs)	12	0	5	0-1	1-5	2	87	39	
pH	pH units	12	6.5 – 9.5	9.6 & 6.4	6 / 9	5.5 / 9.5	7.6	8.7	8.1	
Total hardness	mg^{-1} $CaCo_3$	12	100	200	200	300	2	55	22	
Chloride	mg^{-1}	12	200	300	250	600	127	566	394	
Nitrate	mg^{-1}	12	6	50 (acute effect)	6	10	6	13	9	
Nitrite	mg^{-1}	12	0.2	3 (chronic effect)	6	10	0	0	0	
Ammonium	mg^{-1}	12	0	1.5	1	2	0	2	0.83	
Potassium	mg^{-1}	12	Not available	Not available	200	400	0	7	4.1	
Phosphate	mg^{-1}	12	Not available	Not available	Not available	Not available	0	0	0	
Faecal coliform	Counts/100 ml	12	0	0	0	1	350	1250	706	

Ammonium, as well as pathogens. The additional volume of the flow arises as the two tributaries pour their entire flows into Balfour River, which leads to a greater flow volume in the Balfour River. This is capable of eroding and transporting more material. The additional transported load increases the turbidity levels of the
water.

Chapter 6
Concluding discussion

6.1 Introduction

Many authors, such as O'Keefe *et al.*, (1996), Herold and Bailey (1996), Pearce and Schumann (1997), Kruger (1992), Pieterse and van Vuuren (1997), Davies and Day (1998), Conrad *et al.*, (1999), Pretorius (2000) and others have made commendable strides towards a better understanding of urban water quality. Few however have done substantial work in rural areas. Thus, rural water quality remains less understood in South Africa. This is despite a wide acceptannce that most rural people in South Africa still do not have access to safe and clean drinking water (DWAF, 2000).

Calls from the United Nations Conference on Environment and Development (UNCED) through the Chapter 18 of Agenda 21 (UNCED, 2001) that water quality in rural areas needs to be monitored and understood have also seemingly done little to encourage the aquatic scientists to study rural water quality impacts. One can hope that the work of DWAF (2000) showing that South Africa is facing a crisis on water quality will be enough to attract the attention of the water quality scientists to the realisation that despite the fact that they have always been neglected, people in rural areas are the ones who are largely affected by the pollution of water, as they have to consume the very water they pollute. The 2000 catastrophic outbreak of cholera in many rural parts of the country that claimed 239 lives by the 13th of November 2001, which was blamed on the unavailability of clean and safe drinking water to the affected communities may hopefully be enough to make aquatic scientists realise that water quality studies in rural areas may mean a difference between life and death.

It is that realisation that led this study to be conducted in a rural setting. This study has helped in establishing a relationship between the daily livelihoods of rural communities and the quality of their water. Also, the study has contributed to the better understanding of the impact of poor water quality on human health in these areas. Thus, the study has made a contribution to the better understanding of the water quality challenges encountered by the rural communities in South Africa.

Many studies that have been conducted in the past, whether on water quality or on the social effects, tend to be more specialised in nature. For example, many water quality-monitoring programmes in the country, including those conducted by DWAF, are strictly concerning themselves with the water chemistry part. These studies tend to disregard the interaction there is between the natural water resource and the users of that resource. In this study, it has been recognised that a resource and its users have close relations. This interrelationship manifests itself clearly in that when the one is altered, the other will certainly be affected. For example, if water quality degrades, human health will be severely affected by the waterborne diseases.

It is for that reason that, whilst a water quality monitoring programme was a major part of this study, the social side has not been neglected. Thus, in this study, a relationship between human activities and the quality of water was recognised. Communities in the study area were a crucial part of the study. An interaction with them was given a high value. Hence, the results of the study were shared with the communities in a water quality workshop (Appendix 20). One other primary purpose of the workshop was to make recommendations with the communities on how to improve the quality of their water. By involving them, it was hoped that any development concerning water in the area will be community rather than government driven.

One of the recommendations from the water quality workshop was that, on its position as the sole guardian of water resources in this country, DWAF should be called upon in a meeting with community representatives where communities would express their concerns with regard to the quality of water in the area. Hence, the water quality workshop report, with summarised findings of the study, was sent to several sections of DWAF as a way of involving them. Thus, the results of this have not only been useful to the affected parties, but also to the government. Results of this study may be useful to service providers as well. For example, a realisation that groundwater in the area is heavily polluted should immediately be considered if an agent will be providing the communities with safe and clean drinking water.

The findings of this study should also be useful to the Water User Association (WUA) in the area by demonstrating to them areas that are most affected by the poor water quality. WUA is a body that has been established in the area to oversee the sustainable use of water resources. Present and future studies undertaken in the area are also likely to benefit from the study's findings. For example, at present, a study determining the present Reserve class of the Kat River is being undertaken. Without knowing the quality of water resources, the determination of the Reserve class is impossible. Hence, the findings of this study are perceived as crucial in this regard.

6.2 Project review

This thesis has been generally aimed at examining the impact of land use and related activities of Black village communities on the quality of surface water in the upper Kat River catchment. It aims to contribute to the understanding of water quality problems faced by the rural communities in underdeveloped parts of the globe. The contribution made by the project towards better understanding rural water quality problems was deemed necessary following a realisation that there is relatively more water quality work documented on urban than rural areas. Hence, underdeveloped Black of rural communities in the upper Kat River area were studied towards accomplishing this purpose of the study.

Literature on the impact of several rural land-use and related activities is documented in section 2.1.1 of Chapter 2. Amongst others, this section demonstrates the impact of rural land-uses like crop farming, grazing, and settlements. The impact of land-use related activities like irrigation of crops and applying agro-chemicals are also documented. All major land-use in the study area was mapped and the study area's land-use map was produced using GIS. This land-use map is presented in Chapter 2 (Figure 2). Major land-use categories identified in the study area include settlements, crop farming, grazing and commercial forestry.

Chapter 3 focuses on washing practices in the area as one kind of land-use related activity. This chapter reports on work motivated by an international detergent manufacturing company interested in identifying the risk posed by the direct as opposed to the via-the sewage works, input of detergents to aquatic systems. The results reported in chapter 3 were part of a wider study on the impacts of direct in-stream washing. The wider study included washing habits (chapter 3) as well as toxicity testing (Mkize, 2000 and Muller, 2000) of the riverine organisms from the Kat River.

The washing study provided quantified data on washing powder loads. This information enabled the experimental in-stream measurement of MBAS (Muller, 2000). The wet testing of the response of organisms to Omo® (Muller, 2000) washing powder followed.

A pilot study aiming to study the impact on water quality resulting from the direct input of raw detergents into surface water bodies was also carried out as part of chapter 3. This impact was examined through the experimentation with the three most popular brands of detergents used in the area and a pilot study in which the in-stream washing practices were studied. Results from the two exercises illustrate that the input of raw untreated detergents into the surface water body impact negatively on the quality of water.

The quality of water in the study area's main rivers and their tributaries was monitored fortnightly (21 measures) measuring 11 water quality variables. These water quality variables were observed in twelve sampling sites throughout the catchment. This water quality monitoring programme illustrated the spatial and temporal patterns related to land-use activities in the catchment. Results of the water quality in the area were measured against WHO (2001), DWAF (1993) and DWAF (2000) water quality guidelines of water used for domestic purposes to determine the water's suitability for use in domestic applications. In most sites, it was observed that water was not fit for human consumption.

6.3 Reviewing the aims and objectives of the study

The general conclusion from this study is that land use and related activities of the rural communities in the upper Kat River have considerable influence on the water quality of the upper Kat River catchment. The following section outlines how each objective of the study was achieved.

Two rural communities and one semi-rural community were selected in the upper Kat River area, five additional villages in the middle and upper Kat River area were selected for the study of washing sites. A total of eight communities were involved in the study.

Land-use was identified via the orthophoto and topographic maps of the study area. A number of field visits were also conducted to confirm, identify and map major land-use and related activities. Particular attention was paid to identifying and studying washing sites. The community delegates in a workshop conducted in the area to report back the water quality findings of the study, were also requested to map all major land-use in their respective villages. When the informal and formal interviews were conducted in the study area, some major land-use related activities were identified by the communities. From all these activities, GIS map showing all major land-use and the one showing the distribution of washing sites in the area was produced.

Major land-use and related activities identified include settlements, cropland, grazing land, commercial citrus farming and commercial forestry. The extensive literature documented on rural land-use and related activities revealed that the uses of land and related activities in the area have been proven elsewhere to be having a considerable effect on the quality of water of the surface water bodies. The water quality problems that were noted to result from the rural land-use and related activities include:

- the nutrient enrichment of surface water bodies leading to the eutrophication effect and health problems on those consuming the water, particularly infants and sensitive groups,
- pathogens being introduced into the aquatic systems thereby causing serious health problems like cholera outbreak on the communities consuming the polluted water.

The study of the washing practices demonstrated that the in-stream washing activity, which is widely practised throughout the study area, has a significant effect on the quality of river water, though temporary in the immediate vicinity of the washing site. An analysis of the selected chemical properties of the three most popular detergent brands in the area revealed an increase in the salt and nutrient concentrations with the increase in quantities of detergent in sample water. In-stream washing practice in the study area resulted in an increase in salt content and elevation in nutrients concentrations.

The determination of the water quality trends also served to assess the potential health, safety and welfare problems posed by the deteriorating quality of water to the surrounding communities. During the interviews, it was noted that most communities in the area lack basic services like clean piped water supply, sanitation and waste collection. Faecal coliform bacteria and the elevated levels of nitrate were cited in most parts of the catchment as the problems threatening the water users.

The upper Kat River catchment is so profoundly affected by the land-use and related activities of the communities in the area such that, in some parts of the catchment, particularly in smaller tributaries with low flows, water was determined not to be healthy for domestic use. In particular, the unacceptable high number of faecal coliforms throughout the study area, high turbidity in the Kat River, nitrate and ammonium in some site are the main cause of concern. Regardless of this, it has been noted that nearby communities carry on using this water for domestic purposes. These communities are thus exposing themselves to the hazard of water-borne infections.

A workshop was held with concerned communities in the area. The workshop's purpose was threefold: first was to communicate with communities about water quality, by showing the analyses of the samples of water from their respective water sources, using simple equipment to make water quality results meaningful; second was to share this project's water quality results to give them a full picture of quality of water of their water resources; third was to make recommendations on how to cope best with water of this quality and what is to be done to reverse the continuing deterioration of their water resources and also to improve the quality of their water in the area. From the workshop some resolutions were taken which would improve the quality of water, health and welfare of the water user communities as well as the livelihood and well being of aquatic ecosystems.

The aims and objectives of this study (chapter 1, section 1.6) have been achieved, and it has been demonstrated that the Black rural communities' land-use and related activities are impacting on water quality.

6.4 Lessons learnt in the Kat River area

One major lesson learnt was that water quality issues in the area are somewhat complicated as there is no single but many diffuse sources of pollution. For example, many land-uses contribute to the deteriorating quality of water in the upper Kat River area. The contribution of land-uses like crop farming, grazing, settlements, pit latrines etc. is observable. Also contributing to the deterioration of the quality of water in the area are a number of land-use related activities which include in-stream washing practice, use of the agro-chemicals in crop farming and irrigation.

It has been observed that although Balfour and Tamboekeisvlei villages have access to piped water, the quality of their water is worse than the upper Kat and Balfour Rivers water. It has been established that their water is drawn from the groundwater sources and is provided to them without prior treatment. From this, it could be inferred that:

- having access to piped water does not guarantee that the quality of that water is better than unpiped water source unless water has gone through treatment processes before being delivered to the end users.
- groundwater in the area is heavily polluted. (Workshop report in Appendix 20)

Results of the study area also show some natural sources of pollution. For example, it was realised that all tributaries of the Balfour River had high salinity levels compared to other parts of the catchment. Underlying rock (geology) was implicated for this pollution.

It has also been observed that in-stream washing is widely practised throughout the Kat River area. This is not surprising if one considers long distances community members have to travel to access water. It was however interesting to realise that the Balfour community that has piped water in the neighbourhood, prefers to do their laundry in the river.

A number of explanations were given as to why Balfour community members prefer in-stream washing practices. These explanations included that doing laundry by the river has a socialising aspect attached. During the questionnaire survey conducted in the area, Balfour community members complained that one uses larger quantities of detergents when doing laundry using tap water compared to when using river water.

This led to a suspicion that tap water used by the people at Balfour was harder compared to the Balfour River water. The suspicion led to a series of water quality tests in which the presence or absence of a number of water quality variables was examined in the Balfour tap water. From the water quality tests it was realised that Bafour tap water was indeed extremely hard compared to the Balfour River water. Also, high nitrate concentrations, sometimes exceeding 50mg/l were detected in Balfour tap water.

The other lesson learnt in the Kat River area is that the value of involving communities in one's study is immense. In particular, the Kat River communities' involvement has become indispensable because of their extensive knowledge, and the previous experience they had about interacting with their environment (Motteux, 2001). Thus, the communities have displayed a full understanding of how they affect the environment and in return, how the environment affects their daily livelihood. Their contributions have been fundamental to understanding certain issues in the environment. Communities' explanations of environmental issues might not necessarily have any scientific foundation, but their explanations are still valuable because:

- such an explanation exposes the researcher to alternative perceptions and thoughts regarding environmental impacts. This stimulates critical thinking about issues at hand;
- understanding communities' perceptions has assisted in attaining a sense of reasoning behind some actions communities take whether to improve, maintain or degrade their environment;
- being aware of the feelings and perceptions of the communities has helped in developing better working relations with them;

- listening to and understanding the communities' perceptions results in mutual trust developing easily and communication within the communities became easy and effective.

Because they were involved throughout the study, communities felt a sense of ownership of any work done during the duration of this thesis. It has been realised also that because communities were aware of and involved in the study, any work done was conducted without any fear that one was intruding. Hence, a sense of safety was felt throughout this study.

6.5 The South African situation (South African National Water Act No. 36 of 1998) (NWA)

The country's past racial discrimination system resulted in major imbalances in the availability of clean and safe water, because most people in the country were ignored. A consequence of such imbalances is that most Non-White people in South Africa are still without clean water. Whilst redressing the results of past racial and gender discrimination, the country's democratic government welcomes any initiative that will help towards this venture. The NWA in DWAF, (1998) specifies that "Monitoring, recording, assessing and disseminating information on water resources is critically important for achieving the objects of the Act".

One of the primary purposes of this study was to identify sources of water pollution. This would help in water pollution prevention studies and hence on the sustainability of water resources for the benefit of all water uses. It is recognised in the NWA in DWAF, (1998) that it is crucial to protect the quality of water resources to warrant the sustainability of the nation's water resources. To achieve this aim, water quality studies like this should be welcome as one cannot protect the quality of water if one does not know the quality.

The NWA in DWAF, (1998) recognises the priority rights of water for:

- basic human needs Reserve which makes provision for the necessary needs of individuals catered for the water resource.
- ecological Reserve which ensures that the aquatic ecosystems of a resource are provided with the water they require to sustain themselves.

Both the ecological and basic human needs Reserves are given priority status in the NWA in DWAF, (1998). The Reserve provides for the necessary water quality and quantity for basic needs and ecosystem function. Implementation of the Reserve depends on knowing what the present state of quality and quantity of water of the water resource. Hence, this study has been crucial in assisting in the process of Reserve assessment in the Kat River.

The information contained in this thesis has been important in developing a catchment management strategy, for a number of reasons, including the following:

- it can be used to estimate the present and future water needs in the area.
- it gives the present state of quality and quantity of water available, therefore.
- the objectives of water quality required can be set through the classification system.
- it helps the Catchment Management Agency in identifying water uses in the area and hence, who the stakeholders are.

By providing a land-use map of land-use activities in the area, the study has generally helped in giving the researcher a broader knowledge of various water uses and hence various sources of water pollution and the stakeholders.

6.6 Recommendations on how to improve water quality or mitigate the impacts of poor water quality on health

Community delegates on a water quality workshop (Appendix 20) made the following recommendations on ways of addressing water quality challenges in the area:

- Community delegates committed themselves to minimising the activities that impact on the river water quality.
- Communities indicated that fencing along the river would go a long way towards keeping domestic animals away from the river.
- They also requested an intervention of the Department of Water Affairs and Forestry to help them get safe drinking water in the form of treated piped water.
- It was also hoped that when the Kat River Water Users Association was operational, better strategies of managing the river would be in place, and that water quality may improve.

List of references

Abel, P.D. (1974). Toxicity of synthetic detergents to fish and aquatic invertebrates. *Journal of. Fish Biology*. Vol.6 pp 279

Aggarwal, K.K. (2001). *Water borne diseases*. Heart Care Foundation. Washington.

Ahel, M. and Giger, W. (1985). Determination of alkyphenols and alkyphenol mono and diethoxylates in environmental samples by high perfomance liquid chromatography. *Anal Chemistry*, **51**, pp 1577-1583.

Alexander, M. (1995). How toxic are toxic chemicals on soil. *Environmental Science Technology*. Vol.29. pp 2713-2717.

Al-Layla, M.A. and Al-Rizzo, H.M. (1989). A water quality model for the Tigris River downstream of Sadam Dam, Araq. *Hydrological Sciences Journal*, Vol. 34, No. 6, pp 687-704.

American Public Health Association (1989). *Centers for Disease Control and Prevention*.– APHA, Washington, DC.

Anderson, D.D. and Darcup, J.A. (1976). Water quality modeling of a deep reservoir. *Journal of Water Quality Pollution Control Federation*. **48** (1), pp134-146.

Andrews, T. (2002). Personal communication. Deputy Director – South African Institute for Aquatic Biodiversity, Rhodes University, Grahamstown, South Africa.

Ankley, G.T. and Burkhand, L.D. (1992). Identification of surfactants as toxicants in a primary effluent. *Environ. Toxicol. Chem*. **11**, pp 1235-1248.

ASCE/AWWA. (1990). *Water Treatment Plant Design*, (2nd ed.). Kemmer - Nalco Water Handbook. McGraw Hill.

Atkinson, J. (1971). *A handbook for interviewers*. Office of Population Census Surveys, M136.HMSO. London.

Aucump P.J, and Vivier, F. S.. (1990). Water quality criteria in South Africa. *Technology SA*, June 1990.

Baird, C. (1995) *Environmental Chemistry*. W.H. Freeman and Company, New York.

Baird, S. (2000). *Presentation to the Centre for Aquatic Toxicology, Institute for Water Research. Rhodes University, Eastern Cape* - South Africa.

Banks, R.B. (1976). Distribution of BOD and CO in rivers and lakes. *Journal of Environmental Engineering Division-ASCE*. **102** (EE 2), 265-280.

Barratt, N. (1998). *Integrating community knowledge and scientific findings: a study of soils in the Kat River Valley*. Rhodes University, Grahamstown.

Bath, A.J. (1989). *Phosphorus transport in the Berg River, Western Cape*. Department of Water Affairs, Cape Town, South Africa.

Benefield, L.D., Judkins, J.F. and Weand, B.L. (1982). *Process chemistry for Water and Wastewater treatment*. Prentice-Hall Inc. Englewood Cliffs, New Jersey, USA.

Bleuten, W. (1989). Differences between the actual and natural water quality in a small drainage area with a high level of groundwater discharge. *Hydrological Sciences Journal*, Vol. 34, No. 6, pp575-588.

Boyd, CE. (1982). Water Quality management for pond fish culture. *Deveopment in aquaculture and fisheries sciences, Vol. 9*. Elsevier Science Publishers. The Netherlands.

Brown, D.; De Henau, H.; Garrigan, J.T.; Gerike, P.; Holt, M.; Keck, E.; Matthijs, E. and Waters, J. (1986). Removal of Nonionics in a Sewage Treatment Plant. *Tenside Deteregents Surfactants*. Vol. 23,issue 4. pp190-195

Brownawell, B.J, Chen, H., Zhang, W. and Westall, J.C. (1991). Ardsorbtion of surfactants. In Barker, R. (ed). *Organic Substances in Sediments and Water.* Lewis, Chelsea, MI, USA. Pp 127-147.

Buikema A.L.; Lee, D.R.. and Cairns, J. Jr. (1976). A screening bioassay using Daphnia pulex for refinery wastes discharged into freshwater. *Journal of Testing and Evaluation.* Vol. 4, pp 119.

Bulusu, K.R. and Pande, S.P. (1990). Nitrates – a serious threat to groundwater pollution. *Bhu-Jal News*, **5**, pp 39-43.

Cabridene, R. and Lundahl, P. (1976). Incidents. *Technical Science.* Vol. 71. pp 219-222.

Cairns, J., Beamer, T., Churchill, S. and Ruthven J. (1971). Response of Protozoans to Detergent-Enzymes. *Hydrobiologia* - Vol. 38, No. 2. Dr.W.Junk n.v.Publishers. The Hague. The Netherlands.

Calvo, J.C (1990). Water resources development in Costa Rica 1970-2000. *hydrological Sciences-Journal*, Vol. 35, No. 3, pp184-196.

Canadian Guidelines (1987). *Canadian Water Quality Guidelines.* Prepared by the Task on Water Quality Guidelines on the Canadian Council of Resource and Environmental Engineers. Canada.

Cano, M.L., and Dorn, P.B. (1996). Sorption of an alcohol ethoxylate surfactant to natural sediments. *Environmental Toxicology and Chemistry vol.15.* Pergamon Press Ltd. U.S.A.

Canton, J.H and Adema, D.M.M. (1978). Reproducibility of short-term and reproduction toxicity experiments with *Daphnia magna* and comparison of the sensitivity of *Daphnia magna* with *Daphnia pulex* and *Daphnia cuculatta* in short term experiments. *Hydrobiologia.* Vol.59.

Children's Water Fund-Project of Children's Hunger Relief Fund. (2001). *Clean water saves live.* Santa Rosa. Canada.

Chourasia, L.P. and Tellam, J.H. (1992). Determination of the effect of surface water irrigation on the groundwater chemistry of hard rock terrain in central India. *Hydrological Sciences Journal*, Vol. 37, No. 4, pp313-328.

Chutter, F.M. (1998). *Research on the Rapid Biological Assessment of Water Quality Impacts in Streams and Rivers.* WRC Report No. 422/1/98.

Cloete, T.E. and Venter, S.N. (2001). Cholera outbreak in South Africa part of an ongoing global pandemic. *SA Waterbulletin. Water Research Commission.* Pretoria.

Combrink, S.A.J. (1997). A pilot study of the minibus operations within the Sebokeng-Evaton and Vereeniging-Vanderbijlpark region – An attempt at introducing students from traditionally deprived backgrounds to the realm of initiating and conducting a research project. *Vista Occasional Papers.* Vol. 5, No. 1, November 1997, pp70-77.

Conrad, J.E.; Colvin, C.; Sililo, O.; Gorgens, A.; Weaver, J.; and Reinhardt, C. (1999): *Assessment of the Impact of Agricultural Practices on the Quality of Groundwater Resources in South Africa*, WRC Report No 641/1/99, Pretoria.

Cordery, I. (1977). Quality Characteristics of Urban Storm Water in Sydney, Australia. *Water Resources Jounal.* Vol. 13, No. 1. pp 197-201.

Corum, J. and Everett, D. (2001). People joining together to enable all people of the world to have safe drinking water – using Polio Plus as a model. *Pure water for the World.*

Crabtree, R.W., Cluckie, I.K., and Forster, C.F. (1986). A comparison of two water quality problems. *Water Resources*, pp 53-61.

Craun, G .F. (1986). Waterborne Diseases in the United States. *CRC Press Inc. Boca Raton.* Florida. USA.

Crescenzi, C.; Di Corcia, A.; Passariello, G.; Samperi, R. and Turnes-Carou, M.L. (1995). Determination of non-ionic pplyethoxylate surfactants in environmental waters by liquid chromatography/electrospray mass spectronomy. *Anal Chemistry* no. 67. pp 1797-1804.

Cuello, C., Correa, P. and Haenszel, W. (1976). Gastric cancer in Columbia. I. Cancer risk and suspect environmental agents. *Journal of National Cancer Institute*, **57**, pp 1015-1020.

Dallas, H.F., Day, J.A., and Reynolds, E.G. (1994). *The effects of water quality variables on riverine biotas :* Report to the Water Research Commission, Report No. 351/1/94. South Africa.

Dallas, H.F., and Day, J.A.. (1993). *The effect of the water quality variables on riverine ecosystems: A review.* Prepared for the Water Research Commission by the Freshwater research Unit. University of Cape Town. Rondebosch.

Davies, B.; and Day, J. (1998): *Vanishing Waters*, University of Cape Town Press, Rondebosch, Cape Town, South Africa pp166-241.

Department of Water Affairs and Forestry (2000) *Water for all – Meeting basic water and sanitation needs*. Government Printer. Pretoria.

Department of Water Affairs and Forestry (1999). *Quality of domestic water supplies, Vol. 1: assessment guide.* Government Printer. Cape Town.

Department of Water Affairs and Forestry (1999). *The South African Water Act 54 of 1956.* Government Printer. Cape Town, South Africa.

Department of Water Affairs and Forestry (1998). *Republic of South Africa's National Water Act No 36 of 1998.* Government Printer. Pretoria.

Department of Water Affairs and Forestry (1997). *White paper on a national water policy for South African Department of Water Affairs and Forestry.* Pretoria, South Africa. Government Printer. Pretoria.

Department of Water Affairs and Forestry. (1996). *South African Water Quality Guidelines: Volume 1, Domestic Use. CSIR Environmental services.* The Government Printer. Pretoria.

Department of Water Affairs and Forestry (1995) *You and your water rights: South African Law Review- a call for public response*. Government Printer. Pretoria.

Department of Water Affairs and Forestry. (1995). *South African Water Quality Management Series: Procedures to assess effluent discharge impacts.* Water Research Commission Report no.TT64/94. The Government Printer. Pretoria

Department of Water Affairs and Forestry (1994). *Water Supply and Sanitation Policy (White Paper): Water- an indivisible national asset.* Government Printer. Cape Town, South Africa.

Department of Water Affairs and Forestry. (1993). *South African Water Quality Guidelines: Volume 1, Domestic Use. CSIR Environmental services.* The Government Printer. Pretoria.

Department of Water Affairs and Forestry. (1993). *South African Water Quality Guidelines - vol. 4: Agricultural Use.* CSIR Environmntal Services. Pretoria. South Africa.

Ditoro, D.M., Dodge, L.J. and Hand, V.C. (1990). A model for anionic surfactant sorption. *Environ. Sci. Technology*, **24**, pp 1013-1020.

Ditoro, D.M. (1985). A particle interaction model of reversible organic chemical sorption. *Chemosphere*, **14**, pp1503-1538.

Dixon, C.J. and Leach, B. (1978). *Questionnaires and Interviews in Geographical Research.* CATMOG.

Dorn. P.B.; Salanito, J.P.; Evans, S.H., and Kravetz, L. (1993). Assessing the aquatic hazard of some branched and linear non-ionic surfactants by biodegradation and toxicity. *Environmental Toxicology and Chemistry*. Vol. 12, pp 1751-1762. Pergamon Press Ltd. U.S.A.

EduGreen (2001). *Health impacts of water pollution: Water-borne Disease.* In: http://www.edugreen.teri.res.in/explore/water/health.htm.

Edwards, D.A., Liu, Z. and Luthy, R.G. (1994). Surfactant solubilization of organic compounds in soil/aqueous systems. *Journal of Environment Engineering*, **120**, pp5-22.

Eisler, R. (1965). Some effects of synthetic detergents on estuarine fish. *Trans. Am. Fish. Society.* Vol. 94.

Eketeh O. J.; Udoh A.; Idiong , F. and Etim , M. (1998) supporting scientific, educational, agricultural and environmental research programs that will enhance and promote the quality of life of all people. *AKWA IBOM STATE ASSOCIATION OF NIGERIA (USA), INC.*

Ellis, J. and McCalla, T. (1978). Fate of pathogens in soils receiving animal wastes – A review. *Trans. Am. Soc. Agric. Eng*, Vol. 21, No. 2, pp 309-313.

Falkenmark, M. (1997). Society's interaction with the water cycle: a conceptual framework for a more holistic approach. *Hydrological Sciences Journal*, Vol. 42, No. 4, pp 451-466.

Feijtel, T.C.J., Struijs, J. and Mathijs, E. (1999). Exposure modelling of detergent surfactants - prediction of 90^{th} percentile concentrations in the Netherlands. *Environmental Toxicology and Chemistry vol.18.* Pergamon Press Ltd. U.S.A.

Fendinger, N.J., Begley, W.M., McAvoy, D.C. and Eckhoff, W.S. (1995). Measurement of alkyl ethoxylate surfactants in natural waters. *Environmental Science Technology*, **29**, pp 856-863.

Gammeter, S. and Frutiger, A. (1990). Short term toxicity of ammonia and low oxygen to benthic macro-invertebrates of running waters and conclusions for wet weather water pollution measures. *Water Science and Technology,* Vol. 22.

Geological Map of Southern Africa, (1970)

Gerike, P., Wrinkler, K., Schneider, W., and Jakob, W. (1990). Water analysis in the Rhine Basin. *Henkel-Referate excerpts of Henkel Research Papers. Issue no.26* pp 11-17.

Gilbert, P.A. and Pettigrew, R.(1984). Surfactants and the Environment. *International Journal of Cosmetic Science.* Vol. 6. No. 4 pp 149-158.

Gilli, G., Carrao, G. and Favilli, S. (1984). Concentrations of nitrate in drinking water and incidence of gastric carcinomas: first descriptive study of the Piemonte Region, Italy. *Sci. Total Environ.* **34**, pp 35-48.

Giolando, S.T.; Rapaport, R.A.; Larson, R.J.; Federle, T.W.; Stalmans, M. and Masscheleyn, P. (1994). Environmental Safety Assessment of DEEDMAC: A New Boidegradable Cationic Surfactant for Use in Fabric Softners. *Chemosphere.*

Goldstein, J. (1990). *Demanding Clean Food and Water.* Plenum. New York.

Goudie, A. (1981): *The Human Impact - Man's Role in Environmental Change*, pp140 - 186, Basil Blackwell, Oxford, Great Britain.

Grabow, W.O.K., Taylor, M.B. and Wolfaardt, M. (1986). *Research on Human Viruses in Diffuse Effluents and Related Water Environments.* WRC Report 496/1/96. Pretoria.

Greenberg, A.E., Trussel, R.R., Clesceri, L.S. and Franson, M.A.H. (1985). *Standard Methods for the examination of Water and Wastewater*(16^{th} ed.). American Public Health Association, American Water Works Association and Water Pollution Control Federation. Washington, DC. USA.

Guhl, W. (1992). Detergent Science. *Journal Seifen.* Ole, Fette. Wasche. Germany.

Gwinn, R.P., Swanson, C.E. and Goetz, P.W. (1986). *The New Encyclopaedia Britannica, Vol. 4 (15^{th} ed.)*, pp 39. London.

Gwinn, R.P., Swanson, C.E. and Goetz, P.W. (1986). *The New Encyclopaedia Britannica, Vol. 21 (15^{th} ed.)*, pp 360-365. London.

Hamilton, A.P. and Shedlock, J.R. (1992). Are fertilisers and pesticides in the groundwater? A case study of the Dalmarva Peninsula, Delaware, Maryland, Virginia. *USGS Circular 1080*, pp 1-16.

Hand, V.C., Rapaport, R.A., and Wendt, R.H. (1990). Adsorption of dodeclytrimethylammonim chloride (C_{12}TMAC) to river sediment. *Environment Toxicology Chemistry*. **9**, 467-471.

Handa, B.K. (1989). *Water analysis, aims, objectives and interpretation.* Water Resarch Centre, Chandigarh, India.

Harms, H. and Zehnder, A.J.B. (1995). Bioavailability of sorbed 3-chlorodibenzofuran. *Applied Environmental Microbiology*. Vol. 61. pp27-33.

Hart, B.T., Angehrn-Bettinazzi, C., Campbell, I.C., and Jones, M.J. (1992). Australian water quality guidelines. *Australian and New Zealand and Conservation Council.*

Hatzinger, P.B. and Alexander, M. (1995). Effect of aging of chemicals in soil on their biodegradability and extractability. *Environmental Science Technology*. Vol. 29. pp 537-545.

Henderson, C., Pickering, Q,H. and Cohen, I.M.(1959). The toxicity of synthetic detergents and soaps to fish. *Sewage Industrial Wastes*, 295.

Herbet, D.W.M.; Elkins, G.H.J.; Mann, H.T. and Hemens, J. (1957). Toxicity of synthetic detergents to rainbow trout. *Water Waste Treatment Journal.* Vol 6 p394.

Herold, C.E. and Bailey, A.K. (1996). *Long Term Salt Balance of the Vaalharts Irrigation Scheme*. WRC Report No. 420/1/96.

Hoffman, F.A. and Bishop, J.W. (1994). Impacts of a Phosphate Detergent ban on concentrations of Phosphorus in the James River, Virginia. *Water Research Issue*. Vol. 28. No. 5. pp1239-1240.

Hokanson, J.E.F. and Smith, L.L. (1971). Some factors influencing the toxicity of LAS to the bluegill fish. *Trans. Am. Fish. Society*, issue 100. pp1

Hughes, E.O.; Gorham, P.R. and Zehnder, A. (1958). Toxicity of an unialgal culture of *Microcytis euruginosa*. *Microbiology*. Canada. Pp 225-236.

Jain, C.K., Bhatia, K.K.S. and Seth, S.M. (1998). Assessment of point and non-point sources of pollution using a chemical mass balance approach. *Hydrological Sciences Journal*, Vo. 43, No. 3, pp379-390.

Japanese Ministry of International Trade and Industry (1981). *Annual Report from Chemical Industry Statistics Division.* Tokyo, Japan.

Jennings, G.D. and Sneed, R.E. (1996) Water quality and waste management – nitrate in drinking water. *North Carolina Cooperative Extension Service*, publication number AG 473-4. North Carolina.

Jensen, R. and Gerston, J. (1986). How Safe Are Septic Tanks. *Texas Water Resources Institute*. Summer 1986 Vol. 12, No. 2, Texas Water Resources. Texas.

Jobling, S. and Sumpter, J.P. (1993). Detergent components in sewage effluent are weakly oestreginic: An in vitro study using rainbow trout (*Onchorhynchus mykiss*) hepatocytes. *Aquatic Toxicology*. **27**, 361-372.

Joint Research Centre. (1989). Scientific Assessment of the EC Standards for Drinking Water. EUR 12427 EN. *Commission of the European Communities*, Brussels-Luxemborg.

Karickhoff, S.W. (1984). Organic pollutant sorption in aquatic systems. *Journal of Hydraulic Engeneering*. **110**, 707-735.

Kempster, P.L. and van Vliet, H.R. (1991). Water Quality Fitness for Use Curves for Domestic Water. Draft internal report. *Hydrological Research Institute*. DWAF. Pretoria.

Kempster, P.L. and Smith, R. (1985). Proposed Aesthetic/Physical or Inorganic Drinking Water Criteria for the Republic of South Africa. Research Report no.628. *National Institute for Water Research*. CSIR. Pretoria.

Kikuchi, K. (1979). Toxic effects of synthetic LAS detergent on the colonial green algae, Pleodorina californica. *Kawasaki med.* Vol. 5 pp 175-169.

Klimas, A. and Paukstys, B. (1993). Nitrate contamination of groundwater in the Republic of Lithuania. *NGU Bulletin*, **424**, pp 75-85.

Kolpin, D.W., Burkart, M.R. and Thurman, E.M. (1994). Herbicides and nitrate in near-surface aquifers in the mid continental United States, 1991. *USGS Water Supply Pap.* 2413, pp 34.

Kondo, K. (1980). Trend and future of detergent. *Journal of Water Waste*. Vol. 24. pp 397-407

Kondratas, A.R.. and Mikalauska, V.V. (1973). An example of regional groundwater contamination. *Nedra*. Moscow, pp 280.

Kravetz, L., Chung, H., Guin, K.F., Shebs, W.T. and Smith, L.S. (1984). Primary and ultimate biodegradation of an alcohol ethoxylate and a nonylphenol ethoxylate under average winter conditions in the United States. *TensideDetergents*, **21**, pp 1-6.

Kruger, H. (1992). Chemistry and our endangered environment. *Spectrum,* October 1992. pp 59-62.

Kundzewicz, Z.W. (1997). Water resources for sustainable development. *Hydrological Sciences Journal*, Vol. 42, No. 4, pp 467-480.

Larson, S.J.; Capel, P.D. and Majewski, M.S. (1997). *Pesticides in Surface Waters: Distribution, Trends and Governing Factors*. Chelsea, Michigan: Ann Arbor Press pp 373.

Leeming, R.; Bate, N.; Hewlett, R. and Nichols, P.D. (1997). Discriminating faecal pollution: a case stuffy of stormwater entering Port Phillip Bay, Australia. *Environment Protection Authority*. Melbourne. Australia. pp 11-18.

Lewis, M.A. (1992). The effects of mixtures and other environmental modifying factors on the toxicities of surfactants to freshwater and marine life. *Water Research*. Vol. 26. pp1013 – 1023.

Lewis, W.M. and Morris, D.P. (1986).Toxicity of nitrite to fish: a review. *Trans. Am. Fish. Soc.*

Liu, Z.; Edwards, D.A. and Luthy, R.G. (1992). Sorption of non-ionic surfactants onto soil. *Water Resources*. Vol.26. pp147-158.

Lord, D.A. and Mackay, H.M. (1993). *The effect of runoff on the Water Quality of the Swartkops Estuary*. WRC Report No. 324/1/93. Pretoria.

Lornezen, B.R. and Chen, C.W. (1977). Discussion of nitrification. *Journal of Water Pollution Federation*, Vol. 49, No. 5, pp 615-617.

Lunkad, S.K. (1994). rising nitrate levels in groundwater and increasing N fertiliser consumption. *Bhu-Jal News*, **9**, pp 4-9.

Madsen, T. and Kristensen, P. (1996). Effects of bacterial inoculation and nonionic surfactants on degradation of polycyclic aromatic hydrocarbons in soil. *Environmental Toxicology and Chemistry vol.16.* Pergamon Press Ltd. U.S.A.

Magni, P. and Motteux N. (2000). *Analysis of the detailed questionnaire for the kat River Valley Project - an unpublished report.* Geography Department, Rhodes University, Grahamstown.

Mahro, B. and Kastner, M. (1993). Mechanisms of microbial degradation of polycyclic aromatic hrdrocarbon (PAH) in solid compos mixtures. In Arendt, F.; Annokkee, G.J.; Bosman, R. and van der Brink, W.J. (eds). *Contaminated Soil'93.* Vol. 2. Kluwer, Dodrecht. The Netherlands. Pp 1249-1256.

Maki, A.W. and Bishop, W.E. (1979). *Acute toxicity Studies of Surfactants to Daphnia magna and Daphnia pulex.* The Proctor and Gamble Company, New York, U.S.A. 599-611.

Malik, S. and Banergi, S. (1981). Nitrate pollution of groundwater as a result of agriculture development in Indo-Ganga plain, India. In: *Proceedings of the International Symposium on Quality of groundwater*, Netherlands.

Manickavasagan, J. (1996). Rural Water Supply Project for Clean Water and Sanitation Services in 900 Nepali villages. *World Bank: Global Development Gateway Report.* Washington, DC. USA.

Matthijs, E., Debaere, G., Itrich, N., Masscheleyn, P., Rittiers, A., Stalmans, M., and Ferdele, T. (1995). The fate of detergent surfactants in sewer systems. *Water science and technology.* Vol.31. Issue no.7. IAWQ. Great Britain.

Mawdsley, J.L., Badgett, R.D., Merry, R.J., Pain, B.F. and Theodorou, M.K. (1995). Pathogens in livestock waste, their potential for movement soil and environmental pollution. *Applied Soil Ecology*, Vol. 2, No. 1, pp 1-15.

McCall, P.J.; Vrona, S.A. and Kelly, S.S. (1981). Fate of uniformly carbon-14 ring labelled 2,4,5-trichlorophenoxyacetic acid and 2,4-dichlorophenoxyacetic acid. *Journal of Agricultural Food Chemistry.* Vol. 29. pp 100-107.

McCarty, P.L. and Semprini, L (1993). Engineering and hydrogeological problems associated with *in situ* treatment. *Hydrological Sciences Journal,* Vol. 38, No. 4, pp362-372.

McCormick, P.V., Cairns, J., Belanger, S.E., and Smith, E.P. (1991). *Response of protisan assemblages to a model toxicant, the surfactant C12-TMAC (dodecyl trimethyl ammonium chloride), in laboratory streams.* Elsevier Science Publishers. Blachsburg,VA, U.S.A.

McMahon, P.B. and Bohlke, J.K (1996). Denitrification and mixing in a steam-aquifer system: effects on nitrate loading to surface water. *Journal of Hydrology*, **186**, pp 105-128.

Mehta, B.C., Singh, R.V., Srivatsava, N and Das, S. (1990). impact of fertiliser use on groundwater quality in parts of Genjam District, Orissa. *Bhu-Jal News*, **5**, pp 44-48.

Miller, G.T. (1994). *Living in the environment: Principles, Connections, and Solutions, 8th ed.* Wadsworth Publishing Company. Belmont, California.

Mkize, N. (2000). *The effects of detergents on mayfly nymphs.* Unpublished BSc Honours Project. Department of Entomology and Institute for Water Research, Rhodes University, Grahamston.

Moreno, A.; Ferrer, J. and Berna, J.L. (1990). Biodegradation of LAS in a Sewer System. *Tenside Detergents Surfactants.* Vol. 27. No. 5. pp312-315

Motteux, N. (2001). *The development and co-ordination of catchment fora through the empowerment of rural communities*. WRC project No. K5/1014 pp21-32.

Motteux, N. (2000). *An assessment of integrated community based approaches to the sustainable management of riparian zones in the Eastern Cape - unpublished PhD thesis*. Rhodes University, Grahamstown.

Motteux, N. (1999). *The Kat River Valley Eastern Cape, South Africa - biomonitoring report*. Rhodes University, Geography Department. Grahamstown.

Muller, W.J.M., Palmer, C.G. and Scherman. P.A. (2001). *Scoping Study: Effects of detergents on South African streams-a Project undertaken for Unilever, UK*. Centre for Aquatic Toxicology, Institute for Water Research, Rhodes University, Grahamstown, South Africa.

Muller, W.J.M. (2000). *Effects of detergents on South African streams*. Unilever project, draft final report.

Nel, E. and Motteux, N. (1999). *Local Government and Institutional Arrangements for Local Economic Development: the Case of Seymour - Unpublished Report*. Rhodes University. Grahamstown.

Nel, E.L. and Hill, T. (1996). Rural development in Hertzog, Eastern Cape: Successful local development? *Development Southern Africa*, Vol. 16, No. 6 pp 861-870.

Nkayi, N. (2000). Personal communication. Leader - Hertzog Agricultural Cooperative and Concillor - Balfour and Seymour Transitional Local Council.

Noam, J. (1985). *Effect of raw sewage from Mosul on Tigris River*. Msc theses, College of Engineering, Mosul University, Iraq.

O'Connor, D.J. and Connoly, J. (1980). The effect of concentration of adsorbing solids on the partition coefficient. *Water Resources.* **14**, 1517-1523.

O'Keeffe, J.H., van Ginkel, C.E., Hughes, D.A., Hill, T.R. and Ashton, P.J. (1996). *A situation analysis of Water Quality in the Catchment of the Buffalo River, Eastern Cape, with Special Emphasis on the Impacts of Low Cost, High Density Urban Development on Water Quality.* Vol. 1. WRC Report No. 405/1/96.

Owen, O.S. and Chiras, D.D. (1995). *Natural Resource Conservation Management for a Sustainable Future.* Prentice Hall. New Jersey.

Park, K.S.; Sims, R.C.; Dupoint, R.R.; Doucette, W.J. and Matthews, J.E. (1990). Fate of PAH compounds in two soil types: influence of volatilisation, abiotic loss and biological activity. *Environment Toxicological Chemistry.* Vol. 9. pp 187-195.

Payment, P. (1999). *Canadian Journal of Microbiology.* 45 (8): 709.

Pearce, M.W. and Schumann, E.H. (1997). *The effect of Land Use on Gamtoos Estuary Water Quality.* WRC Report No. 503/1/97. Pretoria.

Pieterse, A.J.H. and van Vuuren, S.J. (1997). *An Investigation into Phytoplankton Blooms in the Vaal River and the Environmental Variables Responsible for their Development and Decline.* WRC Report No. 359/1/97. Pretoria.

Pieterse, M.J. (1989). Drinking water criteria with special reference to the South African experience. *Water SA* 15(3).

Pillay, M. (1994). *Detergent phosphorus in South Africa: Impact on eutrophication with specific reference to the Umgeni Catchment* – unpublished Master of Science thesis. University of Natal.

Poremba, K.; Gunkel, W.; Lang, S. and Wagner, F. (1991). Marine biosurfactants,III. Toxicity testing with marine microorganisms. *Z. Naturforsch. Sect.. C.* Vol. 46. pp 210-216.

Pratt, J.R., Bowers, N.J. and Cairns, J. Jr. (1990). Effect of sediment on estimates of diquat toxicity on laboratory microcosms. *Water Resources*, **24**, pp 51-57.

Pretorius, L. (2000): How does different levels of sanitation affect the surface water quality in a developing community, *South African Water Bulletin, vol 23 no.3, May June 2000.*

Rand Water Board and Delta Environmental Centre Report. (2000). *Water pollution and your Health.* Government Printer. Pretoria.

Rand Water Board. (1992). Potable Water Quality Guidelines. *Draft proposals for comment. Johannesburg*. South Africa.

Rao, N.S. (1998). Impact of clayey soils on nitrate pollution in the groundwater of the lower Vamsadhara River basin, India. *Hydrological Sciences Journal*, Vol, 43, No. 5, pp 701-714.

Reddy, K., Khaleel, R. and Overcash, M. (1981). Behaviour and transport of microbial pathogens and indicator organisms in soils treated with organic wastes. *Journal of Environmental Quality*, Vol. 10, No. 3, pp 255-266.

Reinhard, M., Goodman, N. and Mortelmans, K.E. (1982). Occurrence of brominated alkylphenol polyethoxy carboxylates in mutagenic wastewater concentrates. *Environ. Sci. Technol*, **16**, pp 351-362.

Retuna, C., Vasseur, P. and Cabridene, R. (1989). Performances of the three bacterial assays in toxicity assessement. *Hydrobiolgia*, **188/189**, pp 149-153.

Reynolds, B., Hornung, M. and Hughes, S. (1986). Chemistry of streams draining grassland and forest catchments at Plynlimon, mid-Wales. *Hydrological Sciences Journal*. Vol. 34, No. 6, pp 667-686.

Rhoades, J.D.; Kandiah, A. and Mashali, A.M. (1992). The use of saline waters for crop production - FAO irrigation and drainage. *Food and Agriculture Organisation of the United Nations*. Rome. Italy.

Ribosa, I., Garcia, M.T., Sanchez, L. and Gonzalez, J.J. (1993). *Photobacterium phosphoreum* test data of non-ionic surfactants. *Toxicological Environmental Chemistry*, **39**, pp 237-241.

Roberts, L. (2000). Personal communication. Leader – Kat Ricer Cooperate Commercial Citrus Farmers, Fort Beaufort, South Africa.

Rosen, M.J. (1978). *Surfactants and Interfacial Phenomena*. John Wiley and Sons, New York, USA.

Rowntree, K. (ed.). (1995) *Tugela River IFR workshop: starter document*. Department of Water Affairs Report.

Rublee, P.A. (1992). Community structure and bottom-up regulation of heterotrophic microplankton in artic LTER lakes. *Hydrobiologia*. Vol. 240. pp133-141.

Sandery, M., Stinear, T. and Kaucner, C. (1996). Detection of pathogenic *Yersinia enterocolitica* in environmental waters by PCR. *Journal of Applied Bacteriology*, Vol. 80 No. 3, pp 327-332.

Sankaranarayana, G., Sudursan, V. and Narsimulu, C. (1989). Nitrate pollution in the groundwater of Sangareddy Area, AP, India. In: *Proceedings of the International Workshop on Appropriate Methodologies of Groundwater Resources in Developing Countries*, Vol. 2, IBH-Oxford, New Delhi.

Scamehorn, J.F., Schechter, R.S. and Wade, W.H. (1982). Adsorption of surfactants on mineral oxide surfaces from aqueous solutions I: Isometrically pure anionic surfactants. *Journal of Colloid Interface Science*, **85**, pp463-478.

Scholefield, K., Searger, J., and Merriman, R.P. (1990). The impact of intensive dairy farming activities on water quality: the eastern Cleddau catchment study. *Joint Institute for Water environmental management*, Vol.4.

Schoombie, S.W., Cloot, A., and le Roux, G. (1997). *A Dynamic Model for Algal Growth in the Vaal River*. WRC Report No. 536/1/97.

Schroder, F.R. (1995). Monitoring of detergent ingredients. *Henkel-Referate excerpts of Henkel Research Papers.* Volume 31.

Sehgal, V.K., Sahgal, R.K. and Kakar, Y.P. (1989). Nitrate pollution of groundwater in Lucknow Area, UP. In: *Proceedings of the International Workshop on Appropriate Methodologies of Groundwater Resources in Developing Countries*, Vol. 2, IBH-Oxford, New Delhi.

Shaw, E.M. (1983). *Hydrology in practice.* Van Nostrand Reinhold. Berkshire.

Shepherd, J. (1978). An introduction to survey analysis. *CATMOG Geo Abstracts.* Norwisch.

Sherman, H.M. (1998): *The assessment of groundwater quality in rural communities: two case studies from KwaZulu-Natal* (unpublished thesis), University of Natal

Sherrard, K.B., Marriot, P.J., McCormick, M.J., and Millington, K. (1996). A limitation of the Microtox Test for toxicity measurements of nonionic surfactants. *Environmental Toxicology and Chemistry vol.15.* Pergamon Press Ltd. U.S.A.

South African Bureau of Standards. (1984). *Specification for Water for Domestic Supplies.* South African Standard 241-1984.

Stalmans, M.; Matthijs, E.; Weeg, E. and Morris, S. (1993). *The Environmental Properties of Glucose Amide, a New Nonionic Surfactant.* SOFW. Issue 119. pp 794-808

Stoner, J.H. and Gee, A.S. (1985). Effects of forestry on water quality and fish in Welsh rivers and lakes. *Journal of Instn. Wat. Engrs. Scient.* **39**, pp 27-45.

Sudo, R. (1982). Outline of researches and development on the gray water treatment. *Journal of Water Waste.* Vol. 24 pp 397-407.

Synge, B.A.; Licence, K.; Oates, K. and Thomson-Carter, F. (2000). Water-borne outbreak of Escherichia coli 0157 associated with grazing sheep. *Ministry of Agriculture, Fisheries and Food.* United Kingdom.

Synge, B.A.; Oates, K. Licence, K.; Reid, M.S. and Thomson-Carter, F.M. (2001). Water-borne outbreak of VTEC 0157 associated with grazing sheep. *Ministry of Agriculture, Fisheries and Food.* United Kingdom.

Szesztay, K. (1994). The role of water in the landscape ecology and in crop production. *Periodical Polytechnica Ser. Civ. Engineering*, Vol. 38, No. 3, pp 315-331.

TEGEWA. (1994). *Communique, 15.09.1994.*

The Council of the South African Bureau of Standards (2001). Pretoria. South Africa.

Tolls, J., Haller, M., Labee, E., Verweij, M. and Sijm, T.H.M.D. (1999). Experimental determination of bioconcentation of the nonionic surfactant alcohol ethoxylate. *Environmental Toxicology and Chemistry vol.19.* Pergamon Press Ltd. U.S.A.

Townsend, J. (1977). Perceived worlds of the colonists of tropical rainforest. *Transactions of the Institute of British Geographers, 2(4), 430 -458.* London.

Tshwete, L.E. (2000). *An investigation into the effects of detergents on riverine macro-invertebrates* (unpublished BSc Honours project). Geography Department, Rhodes University, Grahamstown. South Africa.

Ukeles, R. (1965). Inhibition of unicellular algae by synthetic surface-active agents. *Journal of Phycol.* Vo. 1. pp 97-102.

United Nations Conference on Environment and Development (UNCED). (1992). Agenda 21- Chapter 18. *In United Nations Sustainable Development*, 20001.

United Nations Food and Agriculture Organisation (FAO), (1996). *Water-borne diseases.* Rome, Italy.

United States Environmental Protection Agency. (1997). What is Nonpoint Source Pollution? Questions and answers. *Environmental Protection Agency's Office of Wetlands, Oceans, & Watersheds.* Washington.

United States Environmental Protection Agency. (1997). *EPA Labcert Bulletin.* October 1997.

United States Environmental Protection Agency. (1989). Pesticides Fact Book. *US EPA.* Washington, D.C.

United States Environmental Protection Agency. (1986). Quality Criteria for Water 1986. EPA 440/5-86-001. *US EPA.* Washington DC.

United States Environmental Protection Agency. (1986). Pesticides Fact Book. *US EPA.* Washington, D.C.

United States Environmental Protection Agency (1983). Chesapeake Bay Program, Annapolis, Md. Chesapeake Bay Program Technical Studies: A synthesis. *U.S EPA*, Washington, DC.

Valoras, N., Letey, J. and Osborn, J.F. (1969). Adsorbtion on nonionic surfactants by soil materials. *Soil Science Society of Amsterdam.* **33**, 345-348.

Velz, C.J. (1970). *Applied Stream Sanitation*, (1st ed.). John Wiley and Sons Inc., New York, USA.

Versteeg, D.J., Stanton, D.T., Pence, M.A., and Cowan, C. (1996). Effects of surfactants on Rotifer, Brachionus Calyciflorus, in a chronic toxicity test and in the development of QSARS. *Environmental Toxicology and Chemistry vol.16.* Pergamon Press Ltd. U.S.A.

Walker, M.J.; Montemagno, C.D.; and Jenkins, M.B. (1998): Source water assessment and non-point sources of acutely toxic contaminants: A review of research related to survival and transport of *Cryptosporidium parvum, Water Resources Research,* Vol. 34, No.12 pp 3383 - 3392, December 1998.

Wallace, R.L. and Snell, T.W. (1991). *Rotifera.* In Thorpe, J.H and Covich, A.P. (eds.). ecology and Classification of North American Freshwater Invertebrates. Academic. New York. USA. Pp 187-248.

Walter, M.F., Bubenzer, G.D. and Converse, J.C. (1975). predicting verical movement of manurial nitrogen in soil. *Trans. Am. Soc. Agric. Engrs.* **18**, pp 100-105.

Water Research Commission. (1999). *Quality of domestic water supplies, Vol. 1, Second Print: Assessment Guide.* Water Research Commission No. TT 101/98.

Water Research Commission. (1998). *Steering Committee Meeting for the Development of a Guide to assess Non-Point Source pollution of surface water resources in South Africa.* File No. K5/696/0/1. Pretoria, South Africa.

Water Research Commission. (1997). *Surface Water Resources of South Africa : Eastern Cape.* The Government Printer. Cape Town, South Africa.

Wild, H.E. and Crocket, C.P. (1971). Factors affecting nitrification kinetics. *Journal of Water Pollution Control Federation.* **43** (9), pp 516-525.

Williams, K.A.; Green, D.W.J.; and Pascode, D. (1986). Studies on the acute toxicity of pollutants to freshwater macro-invertebrates. *Archive Hydrobiology, vol 106.*
Woltering, D.M. and Bishop, W.E. (1989). Evaluating the environmental safety of detergent chemicals: a case study of cationic surfactants. In : Paustenbach, D.J. (ed.). (1989) *The risk assessment of and human health hazards.* John Willey and Sons. New York, pp 345-389.

World Health Organisation. (2001). Disease Outbreaks Reported - Cholera in South Africa - Update 19. In: http://www.who.int/disease-outbreak-news/n2001/march/28march2001.html 15th September 2001, World Health Organisation, Geneva.

World Health Organisation. (1998). *Water and Sanitation: Fact sheet n° °112.* World Health Organisation, Geneva.

World Health Organisation (1998). *Quality of domestic water supplies, Vol. 1: Assessment Guide.* Water Research Commssion No. TT 101/98.

World Health Organisation (1992). Guidelines for drinking Water Quality. *World Health Organisation,* Geneva.

World Health Organisation. (1984). *Guidelines for drinking water quality.* World Health Organisation. Geneva.

World Health Organisation (1984). Guidelines for drinking Water Quality, Vol. 3: Drinking Water Quality Control in Small Community Supplies. *World Health Organisation*, Geneva.

Xu, G., Song, P. and Reed, P.I. (1992). The relationship between gastric muscol changes and nitrate intake via drinking water in a high risk population for gastric cancer in Moping County, China. *European Journal of Cancer Prev.* **1**, 437-443.

Yamagishi, T., Hashimoto, S., and Otsuki, A. (1998). Tentative identification of persistent poly (glycidyl) monofluorooctylphenyl ether nonionic surfactant in river waters and effluent from a secondary wastewater treatment plant. *Environmental Toxicology and Chemistry vol.17.* Pergamon Press Ltd. U.S.A.

Yamane, A.N.; Okada, M. and Sudo, R. (1984). The growth inhibition of planktonicalgae due to surfactants used in washing agents. *Water Resources*, vol.18, no. 9, pp1101-1105

Appendix 1: Nature of Basic Services in the Balfour village

Questions	Responses:			
	Category			
	Mean no. of respondents			
	Range of respondents			
	Median			
ages of the respondents (years)	**10 - 25**	**26-35**	**36-45**	**>46**
	34	18	7	41
	72	*36*	*18*	*80*
	19	*9*	*0*	*21*
	32	17	7.5	35.5
number of family members	**<3**	**4**	**5**	**>6**
	16	10	12	62
	37	*20*	*25*	*85*
	0	*0*	*0*	*46*
	14	11	12.5	63
source of income	**selling agri. produce**	**working**	**other**	
	10	39	51	
	48	*66*	*70*	
	0	*24*	*26*	
	4.5	34.5	52.5	
number of people working in the family	**0**	**1**	**2**	**>3**
	45	32	15	8
	79	*45*	*24*	*21*
	25	*17*	*4*	*0*
	42.5	31	13	11

total family income (Rands per month)	**540-**	**541-1000**	**>1001**	
	63	21	16	
	100	*42*	*52*	
	26	*0*	*0*	
	62.5	19.5	15	
number of taps (per community)	**0**	**1 - 2**	**>3**	
	68	0	32	
	100	*0*	*100*	
	0	*0*	*0*	
	100	0	0	
kind of toilet used by the family	**buckets**	**pit**	**flushed**	**veld**
	0	70	0	30
	0	*100*	*0*	*80*
	0	*20*	*0*	*0*
	0	74.5	0	25.5
kind of toilets mostly used in the village	**buckets**	**pit**	**flushed**	**veld**
	0	64	0	36
	0	*100*	*0*	*100*
	0	*0*	*0*	*0*
	0	74	0	26
waste collection frequency per month	**0**	**1**	**2**	**3**
	100	0	0	0
	100	*0*	*0*	*0*
	100	*0*	*0*	*0*
	100	0	0	0

Appendix 2: Nature of Basic services in all villages studied

Questions	Responses: Category / Mean no. of respondents / *Range of respondents* / Median			
ages of the respondents (years)	**10 - 25**	**26-35**	**36-45**	**>46**
	34	18	7	41
	72	*36*	*18*	*80*
	19	*9*	*0*	*21*
	32	17	7.5	35.5
number of family members	**<3**	**4**	**5**	**>6**
	16	10	12	62
	37	*20*	*25*	*85*
	0	*0*	*0*	*46*
	14	11	12.5	63
source of income	**selling agri. produce**	**working**	**other**	
	10	39	51	
	48	*66*	*70*	
	0	*24*	*26*	
	4.5	34.5	52.5	
number of people working in the family	**0**	**1**	**2**	**>3**
	45	32	15	8
	79	*45*	*24*	*21*
	25	*17*	*4*	*0*
	42.5	31	13	11

total family income (Rands per month)	**540-**	**541-1000**	**>1001**	
	63	21	16	
	100	*42*	*52*	
	26	*0*	*0*	
	62.5	19.5	15	
number of taps (per community)	**0**	**1 - 2**	**>3**	
	68	0	32	
	100	*0*	*100*	
	0	*0*	*0*	
	100	0	0	
kind of toilet used by the family	**buckets**	**pit**	**flushed**	**veld**
	0	70	0	30
	0	*100*	*0*	*80*
	0	*20*	*0*	*0*
	0	74.5	0	25.5
kind of toilets mostly used in the village	**buckets**	**pit**	**flushed**	**veld**
	0	64	0	36
	0	*100*	*0*	*100*
	0	*0*	*0*	*0*
	0	74	0	26
waste collection frequency per month	**0**	**1**	**2**	**3**
	100	0	0	0
	100	*0*	*0*	*0*
	100	*0*	*0*	*0*
	100	0	0	0

Appendix 3: Describing the washing practices at Balfour

Questions	Responses:	Category / Mean no. of respondents		
ages of the respondents (years)	10 - 25	26-35	36-45	>46
	72	10	8	10
number of family members	<3	4	5	>6
	24	14	16	46
source of income	selling agri. produce	working	other	
	2	66	32	
number of people working in the family	0	1	2	>4
	34	42	18	14
total family income (Rands per month)	<540	541-1000	>1001	
	26	22	52	
laundry frequency (per week)	1	2	3	>4
	28	40	18	14
laundry frequency at home (per week)	0	1 - 2	3	other
	22	52	16	0
laundry frequency at the river (per week)	0	1 - 2	3	>4
	70	14	2	0
family member doing washing	mother	children	father	other
	32	64	4	
types of detergents used.	omo	surf	sunlight	other
	90	6	4	0
frequency of detergent purchase (per month)	1	2	3	
	80	12	8	
detergent use (kg/village/month)	omo	surf	sunlight	other
	169	146	164	0
number of taps (per community)	0	36556	>3	

	40	4	56	0
number of people doing washing per time	1	36647	36804	other
	35	45	20	
reason/s for doing washing in groups	safety	social	other	
	40	60	0	
most common washing day in the village	Saturday	Sunday	Friday	other
	100	0	0	0
most common washing place in the village	river	home	taps	other
	72	14	14	0
other things washed by the river besides clothes	humans	motor-cars	blankets	other
	56	44	0	0
kind of toilet used by the family	buckets	pit	flushed	veld
	0	70	0	30
kind of toilets mostly used in the village	buckets	pit	flushed	veld
	0	66	0	44
waste collection frequency per month	0	1	2	3
	100	0	0	0

Appendix 4: Washing practices in all villages

Questions	Responses			
	Category			
	Mean no. of respondents			
	Range of respondents			
	Median			
laundry frequency (per week)	1	2	3	>4
	24	44	16	16
	47	*70*	*32*	*35*
	5	*24*	*5*	*0*
	22	41	15.5	14
laundry frequency at home (per week)	0	1 - 2	3	other
	38	40	11	11
	74	*72*	*28*	*43*
	0	*16*	*3*	*0*
	25	35	6	12.5
laundry frequency at the river (per week)	0	1 - 2	3	4
	79	11	5	5
	100	*35*	*17*	*13*
	35	*0*	*0*	*0*
	81.5	9.5	5	0
family member doing washing	mother	children	father	other
	44	55	1	0
	56	*65*	*5*	*0*
	32	*40*	*0*	*0*
	43.5	54	0	0
types of detergents used	omo	surf	sunlight	other
	64	19	17	0
	90	*35*	*46*	*0*
	27	*5*	*4*	*0*

	66.5	18.5	15	0
frequency of detergent purchase (per month)	1	2	3	>4
	67	21	12	0
	81	*47*	*27*	*15*
	32	*9*	*0*	*0*
	70	15.5	9.5	0
detergent use (kg/village/month)	omo	surf	sunlight	other
	136 .12	99.62	71.25	0
	169	*146*	*164*	*0*
	75	*6*	*54*	*0*
	149	75	85	0
number of people doing washing per time	1	2 - 5	6 - 10	other
	45	20	35	
	75	*57*	*50*	
	30	*16*	*0*	*0*
	43	31	6.6	0
reason/s for doing washing in groups	safety	social	other	
	28	69	3	
	45	*100*	*20*	
	0	*55*	*0*	
	33	65	0	
most popular washing day in the village	Saturday	Sunday	Friday	other
	96	0	4	0
	100	*0*	*14*	*0*
	100	*0*	*0*	*0*
	100	0	0	0
most popular washing place in the village	river	home	taps	dams
	48	37	3	12
	92	*100*	*14*	*100*
	0	*0*	*0*	*0*

	56.5	24.5	0	0
other things washed by the river besides clothes	humans	motor-cars	blankets	other
	60	35	5	0
	100	*65*	*40*	*0*
	35	*0*	*0*	*0*
	56	44	0	0

Appendix 5: A comparison of tap water chemistry with 5g, 10g and 15g of Omo and Surf washing powder and a Sunlight bar soap

Element (units)	Tap water	Omo washing powder			Surf washing powder			Sunlight bar soap		
		5g	10g	15g	5g	10g	15g	5g	10g	15g
Hardness (mmol/l)	1.2									
Conductivity (mS/cm)	0.37	3.8	6.3	8.1	4.2	6	9	74.7	117.9	158.2
Turbidity (NTUs)	2.19	56	145	262	118	207	323	567	824	989
pH	8.4	10.3	10.4	10.5	10.2	10.7	10.9	10.7	10.9	11.3
Ammonium (mg/l)	0.45	0.45	0.45	0.45	0.5	1.7	2	0.45	0.45	0.45
Nitrate (mg/l)	0.7	1	1.5	2	0.7	0.7	0.7	0.7	0.7	0.7
Nitrite (mg/l)	0.035	0.045	0.05	0.1	0.035	0.035	0.035	0.035	0.035	0.035
Phosphate (mg/l)	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
Chloride (mg/l)	70	110	140	195	100	150	210	150	290	340

Appendix 6: Situation analysis in 3 washing sites studied

sample site no.	no. of people doing washing per washing day	total weight of dirty laundry (g)	types of detergents used	total amount of detergent used in grams per washing day (g)	average amount of detergent used per 1000g of dirty laundry (g)	average amount of detergent used by 1 person per washing day (g)
1	10	30, 000	omo, surf,sunlight	998	33.2	99.8
4	7	27, 450	omo, and sunlight	970	35.3	138.6
9	11	37, 020	omo, surf,sunlight	1, 845	49.8	167.7

Appendix 7: Studying the washing practices at Hertzog (1)

washing site no.	element	general water quality	on site analysis after contact with detergent	situation in 100m away from the site	situation in 1km from the washing site
1	hardness (mmol/l)	0.9375mmol/l			
	EC (mS/m)	13	27	19	15
	turbidity (NTUs)	128	180	163	142
	pH	7.9	9.2	8.9	8.3
	ammonium (mg/l)	0	0.45	0.3	0
	nitrate (mg/l)	1	3	1.5	1.3
	nitrite (mg/l)	0	0.035	0.025	0.12
	phosphate	0	0	0	0
	chloride	30	125	90	70

Appendix 8: Studying the washing practices at Fairbairn (4)

washing site no.	element	general water quality	on site analysis after contact with detergent	situation in 100m away from the site	situation in 1km from the washing site
4	hardness (mmol/l)	0.999mmol/l			
	EC (mS/m)	21	72	45	23
	turbidity (NTUs)	27	69	49	32
	pH	7.9	9.4	8.2	8
	ammonium (mg/l)	0	0.5	0.35	0.01
	nitrate (mg/l)	6	10	8.5	7
	nitrite (mg/l)	0	0.035	0.01	0.001
	phosphate	0	0	0	0
	chloride	29	175	100	80

Appendix 9: Studying the washing practices at Balfour (9)

washing site no.	element	general water quality	on site analysis after contact with detergent	situation in 100m away from the site	situation in 1km from the washing site
9	hardness (mmol/l)	1.5375mmol/l			
	EC (mS/m)	21	51	48	33
	turbidity (NTUs)	19	47	35	24
	pH	7.9	9	8.7	8.2
	ammonium (mg/l)	0	0	0	0
	nitrate (mg/l)	0	1	0.6	0.3
	nitrite (mg/l)	0	0.035	0.025	0.015
	phosphate	0	0	0	0
	chloride	49	140	95	83

Appendix 10: Discharge (m^3/s)in the upper Kat River catchment

	Site											
Date	1	2	3	4	5	6	7	8	9	10	11	12
MARCH	.840	.450	.980	1.000	.470	1.030	.870	.017	.910	.015		.970
	.790	.300	.930	.980	.430	1.010	.850	.012	.890	.011		.950
APRIL	1.110	.520	1.150	1.220	.510	1.490	1.010	.024	1.050	.017		1.120
	1.170	.500	1.230	1.390	.470	1.680	1.000	.021	1.040	.028		1.090
MAY	1.200	.470	1.210	1.090	.400	1.510	.780	.032	.890	.019		1.010
	1.120	.470	1.120	1.290	.370	1.440	.670	.022	.770	.017		.960
JUNE	1.100	.430	1.090	1.220	.340	1.410	.700	.019	.830	.015		.890
	1.140	.450	1.130	1.350	.420	1.560	.770	.023	.790	.020		.940
JULY	1.150	.470	1.160	1.370	.430	1.590	.800	.025	.830	.025		.950
	1.010	.430	1.030	1.290	.410	1.430	.730	.019	.740	.023	.017	.890
SEPT	.064	.004	.060	.060	.058	.074	.061		.042		.072	.245
	.021	.009	.024	.048	.018	.105	.171	.005	.191	.010	.148	.318
	.021	.009	.044	.060	.123	.132	.132	.003	.192	.021	.076	.433
OCT	.679	.009	.712	.732	.231	.815	.162	.001	.121	.012	.135	.474
	.437	.008	.723	.763	.211	.935	.145	.004	.177	.011	.142	.458
NOV	.675	.003	.700	.735	.432	.931	.423	.003	.324	.010	.013	.312
	.598	.002	.626	.655	.305	.891	.231	.011	.533	.011	.010	.365
DEC	.612	.002	.679	.765	.323	.988	.325	.001	.457	.012	.080	.436
	.330	.006	.146	.592	.564	1.216	.489	.018	.646	.011	.093	.794

Descriptive Statistics (DISCHARGE)										
			Confid.	Confid.	Lower	Upper	Quartile			
Site	Valid N	Std.Dev	Mean	-95.000%	+95.000%	Median	Quartile	Quartile	Range	Range
1	19	.740333	.543007	.937658	.790000	.436678	1.120000	1.179370	.683322	.409402
2	19	.239072	.127627	.350517	.300000	.006000	.470000	.518463	.464000	.231221
3	19	.775997	.572445	.979548	.930000	.625700	1.130000	1.205663	.504300	.422320
4	19	.874188	.658693	1.089683	.980000	.654700	1.290000	1.342400	.635300	.447100
5	19	.342905	.269875	.415934	.400000	.230564	.432340	.545150	.201776	.151518
6	19	1.064984	.821158	1.308810	1.030000	.890700	1.490000	1.606500	.599300	.505879
7	19	.543141	.387259	.699023	.670000	.171188	.800000	.949410	.628813	.323417
8	18	.014450	.009668	.019232	.017300	.003700	.022000	.030881	.018300	.009617
9	19	.601113	.440111	.762115	.740000	.191700	.890000	1.008000	.698300	.334040
10	18	.016028	.013252	.018803	.015000	.011213	.020000	.017897	.008787	.005581
11	10	.078587	.040875	.116300	.077700	.017462	.135000	.137370	.117538	.052718
12	19	.715996	.568295	.863696	.890000	.432600	.960000	.874848	.527400	.306442

Appendix 11: Turbidity (NTUs) in the upper Kat River area

	Site											
Date	1	2	3	4	5	6	7	8	9	10	11	12
MARCH	140.000	.630	134.000	136.000	20.000	138.000	21.000	8.000	19.000	8.000		29.000
	154.900	.660	131.000	134.000	22.500	137.000	22.000	8.000	17.000	8.300		29.700
APRIL	153.000	.570	145.000	167.000	20.300	170.000	21.000	8.000	23.000	8.000		26.000
	167.000	.490	151.000	169.000	21.000	173.000	19.000	6.000	21.000	6.000		27.000
MAY	155.700	.450	150.000	166.000	17.000	170.000	17.000	6.000	20.000	5.900		23.900
	198.300	.480	130.000	168.000	22.000	171.000	19.000	7.000	24.000	6.700		25.000
JUNE	147.700	.500	135.000	166.000	18.100	169.000	20.000	7.000	25.000	6.300		27.000
	194.300	.530	145.000	169.000	18.300	175.000	19.000	6.000	24.000	6.100		25.800
JULY	187.000	.550	146.000	170.000	17.400	177.000	19.000	6.000	23.000	6.000		25.000
	174.000	.570	149.000	163.000	18.600	169.000	17.000	5.000	21.000	5.000	2.310	27.000
SEPT	98.900	5.800	61.700	48.300	8.300	64.600	2.300	2.400	1.500	32.400	2.300	67.000
	125.000	21.000	111.000	99.780	47.000	97.300	97.000	19.000	65.000	59.000	20.800	79.000
	149.000	18.700	59.800	55.100	59.800	48.600	10.500	5.900	13.200	7.400	35.700	2.900
OCT	135.000	8.900	105.000	99.780	34.800	97.300	55.000	13.300	77.300	43.000	34.700	87.000
	145.000	7.400	107.000	78.000	35.000	57.000	20.000	10.700	65.900	27.000	12.200	73
NOV	197.000	7.800	139.300	117.800	30.000	93.000	65.000	10.000	72.900	23.000	35.000	54.800
	177.000	6.400	127.000	97.000	15.800	77.500	17.000	11.300	45.000	35.000	23.900	83.000
DEC	154.000	9.800	107.000	89.000	20.000	74.600	15.000	9.000	20.000	15.000	27.000	77.000
	234.000	16.600	186.000	177.000	13.300	169.700	11.200	7.800	15.900	6.300	15.300	23.600

Descriptive Statistics (turbidity)										
			Confid.	Confid.	Lower	Upper	Quartile			
Site	Valid N	Mean	-95.000%	+95.000%	Median	Quartile	Quartile	Range	Range	Std.Dev.
1	19	162.4632	147.5441	177.3822	154.9000	145.0000	187.0000	135.1000	42.00000	30.95346
2	19	5.6753	2.4167	8.9338	.6600	.5300	8.9000	20.5500	8.37000	6.76069
3	19	127.3579	112.6832	142.0326	134.0000	107.0000	146.0000	126.2000	39.00000	30.44648
4	19	129.9874	109.3090	150.6657	136.0000	97.0000	168.0000	128.7000	71.00000	42.90250
5	19	24.1684	18.1980	30.1388	20.0000	17.4000	30.0000	51.5000	12.60000	12.38709
6	19	127.8211	104.7702	150.8719	138.0000	77.5000	170.0000	128.4000	92.50000	47.82491
7	19	25.6316	14.7828	36.4803	19.0000	17.0000	21.0000	94.7000	4.00000	22.50852
8	18	8.5556	6.8577	10.2534	7.9000	6.0000	10.0000	14.0000	4.00000	3.41420
9	19	31.2947	20.5927	41.9968	23.0000	19.0000	45.0000	74.9000	26.00000	22.20419
10	19	14.9211	7.4239	22.4182	7.4000	6.0000	23.0000	57.5000	17.00000	15.55469
11	10	23.8310	14.9802	32.6818	25.4500	20.8000	34.7000	33.3900	13.90000	12.37260
12	19	39.1053	26.3907	51.8199	27.0000	25.0000	67.0000	84.7000	42.00000	26.37969

Appendix 12: pH in the upper Kat River area

Date	1	2	3	4	5	6	7	8	9	10	11	12
MARCH	8.100	7.300	8.300	9.000	7.700	8.400	8.100	8.400	8.300	8.800		8.200
	8.300	7.400	8.500	9.100	7.800	8.600	8.200	8.600	8.500	8.900		8.000
APRIL	8.100	7.100	8.300	8.400	7.600	8.400	8.000	8.300	8.500	8.600		7.800
	8.100	7.100	8.300	8.400	7.600	8.400	8.000	8.300	8.500	8.600		7.800
MAY	7.900	6.600	7.900	8.000	6.900	8.000	7.800	8.000	8.100	8.000		7.600
	8.000	6.800	8.100	8.300	7.100	8.300	7.900	8.300	8.100	8.700		7.700
JUNE	8.000	7.100	8.000	8.300	7.100	8.100	8.000	8.100	8.300	8.300		7.900
	8.000	7.100	8.000	8.300	7.100	8.100	8.000	8.100	8.300	8.300		7.900
JULY	8.000	7.100	8.200	8.000	7.300	8.300	8.100	8.300	8.400	8.500		7.700
	7.800	7.300	8.400	8.300	7.500	8.400	8.200	8.500	8.500	8.600	8.700	7.900
SEPT	7.600	8.400	7.700	7.800	8.300	7.600	8.100		8.100	8.100	8.400	8.000
	7.900	8.900	8.200	8.100	7.900	8.000	8.200	8.900	8.300	8.500	8.400	8.500
	8.600	9.000	8.200	8.300	8.200	8.400	8.500	8.400	8.300	8.900	8.700	8.300
OCT	7.900	8.900	8.000	8.000	8.000	8.300	8.200	8.900	8.400	8.500	8.200	8.500
	7.800	9.100	8.200	8.100	7.800	8.300	8.300	8.700	8.300	8.600	8.500	8.700
NOV	7.700	9.400	7.900	7.900	7.900	8.000	8.100	8.700	8.300	8.700	8.700	8.500
	7.600	9.000	8.000	8.600	7.800	8.200	8.000	8.500	8.100	8.900	8.300	8.700
DEC	8.000	8.900	8.300	8.400	8.000	8.300	8.300	8.900	8.400	8.300	8.300	8.000
	7.800	8.000	7.600	7.700	8.100	8.000	7.600	7.600	7.900	7.700	7.800	7.600

Descriptive Statistics (pH)

			Confid.	Confid.	Lower	Upper	Quartile			
Site	Valid N	Std.Dev	Mean	-95.000%	+95.000%	Median	Quartile	Quartile	Range	Range
1	19	7.963158	7.843780	8.082535	7.900000	7.800000	8.100000	1.000000	.300000	.247679
2	19	7.900000	7.426934	8.373066	7.400000	7.100000	8.900000	2.800000	1.800000	.981495
3	19	8.131579	8.013460	8.249698	8.200000	8.000000	8.300000	.900000	.300000	.245068
4	19	8.268421	8.093121	8.443721	8.300000	8.000000	8.400000	1.400000	.400000	.363704
5	19	7.678947	7.490501	7.867394	7.800000	7.400000	8.000000	1.400000	.600000	.390980
6	19	8.231579	8.119055	8.344102	8.300000	8.000000	8.400000	1.000000	.400000	.233459
7	19	8.073684	7.973554	8.173814	8.100000	8.000000	8.200000	.900000	.200000	.207745
8	18	8.450000	8.283532	8.616468	8.450000	8.300000	8.700000	1.300000	.400000	.334752
9	19	8.284211	8.206720	8.361701	8.300000	8.100000	8.400000	.600000	.300000	.160773
10	18	8.536842	8.376816	8.696868	8.600000	8.300000	8.800000	1.200000	.500000	.332015
11	10	8.400000	8.200496	8.599504	8.400000	8.300000	8.700000	.900000	.400000	.278887
12	19	8.063158	7.886277	8.240039	8.000000	7.800000	8.500000	1.100000	.700000	.366986

Appendix 13: Chloride (mg/l) in the upper Kat River catchment

Date	1	2	3	4	5	6	7	8	9	10	11	12
MARCH	32	190	46	80	55	60	47	119	55	120		75
	35	200	50	89	60	65	50	120	67	125		80
APRIL	31	186	41	47	60	59	45	120	70	123		78
	29	155	41	49	30	55	48	118	72	121		55
MAY	25	100	30	35	25	40	35	75	65	65		20
	29	200	38	49	47	47	49	80	71	90		35
JUNE	28	105	40	53	40	53	33	75	59	120		29
	30	150	35	46	40	55	40	105	63	90		60
JULY	30	145	34	39	35	51	48	105	67	87		58
	33	170	37	49	40	59	53	110	72	96	75	63
SEPT	26	150	140	80	45	50	45		45	250	100	60
	49	135	80	70	35	45	23	90	47	90	80	65
	35	195	50	45	40	35	30	125	45	150	50	50
OCT	40	135	60	70	30	45	23	90	56	105	95	65
	45	270	55	60	45	40	25	75	49	125	110	55
NOV	45	300	65	70	30	35	30	85	50	130	105	65
	40	215	30	35	25	30	25	75	45	155	60	72
DEC	20	190	45	55	35	40	20	90	35	95	75	45
	25	75	40	45	25	35	25	75	30	70	50	30

Descriptive Statistics (chloride)										
			Confid.	Confid.	Lower	Upper	Quartile			
Site	Valid N	Std.Dev	Mean	-95.000%	+95.000%	Median	Quartile	Quartile	Range	Range
1	19	33.0000	29.2735	36.7265	31.0000	28.0000	40.0000	29.0000	12.00000	7.73161
2	19	171.8947	145.3521	198.4374	170.0000	135.0000	200.0000	225.0000	65.00000	55.06955
3	19	50.3684	38.2683	62.4685	41.0000	37.0000	55.0000	110.0000	18.00000	25.10469
4	19	56.1053	48.4037	63.8068	49.0000	45.0000	70.0000	54.0000	25.00000	15.97879
5	19	39.0526	33.7765	44.3288	40.0000	30.0000	45.0000	35.0000	15.00000	10.94671
6	19	47.3158	42.4373	52.1943	47.0000	40.0000	55.0000	35.0000	15.00000	10.12177
7	19	36.5263	31.1080	41.9446	35.0000	25.0000	48.0000	33.0000	23.00000	11.24163
8	18	96.2222	86.8385	105.6059	90.0000	75.0000	118.0000	50.0000	43.00000	18.86969
9	19	55.9474	49.7656	62.1291	56.0000	45.0000	67.0000	42.0000	22.00000	12.82564
10	18	116.1579	96.5979	135.7179	120.0000	90.0000	125.0000	185.0000	35.00000	40.58224
11	10	80.0000	64.1829	95.8171	77.5000	60.0000	100.0000	60.0000	40.00000	22.11083
12	19	55.7895	47.5149	64.0641	60.0000	45.0000	65.0000	60.0000	20.00000	17.16773

Appendix 14: Total Dissolved Salts (mg/l) in the upper Kat River catchment

Date	1	2	3	4	5	6	7	8	9	10	11	12
MARCH	124	331	137.150	260.000	169.000	214.500	214.500	487.500	357.500	578.500		357.500
	125	344	141.050	292.500	182.000	240.500	234.000	507.000	325.000	598.000		552.500
APRIL	82	331	94.900	103.350	136.500	117.000	201.500	455.000	403.000	565.500		357.500
	85	247	81.250	89.050	130.000	234.000	149.500	461.500	377.000	455.000		260.000
MAY	73	240	84.500	156.000	91.000	110.500	117.000	403.000	325.000	552.500		448.500
	77	240	96.850	105.950	104.000	110.500	136.500	422.500	260.000	572.000		422.500
JUNE	78	260	99.450	117.000	123.500	135.850	162.500	403.000	292.500	585.000		455.000
	77	299	85.150	100.750	123.500	109.200	195.000	448.500	370.500	494.000		357.500
JULY	76	286	83.200	99.450	123.500	104.000	227.500	448.500	325.000	474.500		448.500
	121	305	91.000	130.000	136.500	149.500	240.500	487.500	357.500	513.500	622.700	474.500
SEPT	130	1313	273.000	786.500	123.500	630.500	175.500	403.000	630.500	687.050	565.500	455.000
	227	812	487.500	448.500	226.200	344.500	208.000	695.500	383.500	513.500	604.500	292.500
	152	451	228.150	221.000	169.000	111.150	98.150	516.100	357.500	447.850	518.700	474.500
OCT	292	955	474.500	448.500	175.500	344.500	149.500	695.500	422.500	513.500	604.500	487.500
	344	1365	435.500	351.000	188.500	195.000	123.500	578.500	325.000	539.500	713.050	715.000
NOV	422	1040	486.850	325.000	162.500	147.875	97.500		585.000	325.000	715.000	351.000
	325	942	440.700	260.000	196.950	167.115	110.500	487.500	292.500	500.500	390.000	383.500
DEC	319	585	232.050	167.050	130.000	153.400	114.400	682.500	227.500	630.500	357.500	221.000
	124	468	142.350	148.850	110.500	139.100	103.350	490.100	114.400	469.950	159.900	127.400

Descriptive Statistics (Chloride)										
			Confid.	Confid.	Lower	Upper		Quartile		
Site	Valid N.	Std.Dev	Mean	-95.000%	+95.000%	Median	Quartile	Quartile	Range	Range
1	19	171.5316	117.2831	225.7800	124.1500	78.0000	292.5000	349.050	214.5000	112.5522
2	19	569.4342	386.8873	751.9811	344.5000	286.0000	942.5000	1124.500	656.5000	378.7402
3	19	220.7947	143.6338	297.9557	141.0500	91.0000	435.5000	406.250	344.5000	160.0901
4	19	242.6553	157.9892	327.3213	167.0500	105.9500	325.0000	697.450	219.0500	175.6614
5	19	147.4816	130.2317	164.7315	136.5000	123.5000	175.5000	135.200	52.0000	35.7893
6	19	197.8258	136.1601	259.4915	149.5000	111.1500	234.0000	526.500	122.8500	127.9412
7	19	160.9947	137.0604	184.9290	149.5000	114.4000	208.0000	143.000	93.6000	49.6578
8	18	514.1500	466.8129	561.4871	487.5000	448.5000	578.5000	292.500	130.0000	95.1905
9	19	328.6263	293.9841	363.2685	325.0000	292.5000	377.0000	308.100	84.5000	71.8740
10	18	544.7000	511.3875	578.0125	539.5000	494.0000	585.0000	267.150	91.0000	69.1153
11	10	537.2900	407.1166	667.4634	604.5000	390.0000	687.0500	555.100	297.0500	181.9699
12	19	394.3105	340.3454	448.2757	422.5000	351.0000	474.5000	438.100	123.5000	111.9645

Appendix 15: Total Hardness expressed as CaCo3 (mg/l)

Date	1	2	3	4	5	6	7	8	9	10	11	12
MARCH	7.9744	10.9648	9.968	12.9584	10.9648	13.9552	20.9328	29.904	29.904	31.8976		49.84
	8.9712	11.9616	11.9616	13.9552	10.9648	16.9456	22.9264	34.888	29.904	3.8912		54.824
APRIL	6.9776	11.9616	8.9712	9.968	9.968	11.9616	20.9328	29.904	28.9072	32.8944		39.872
	6.9776	9.968	8.9712	10.9648	8.9712	13.9552	13.9552	28.9072	24.92	28.9072		31.8976
MAY	6.9776	6.9776	6.9776	8.9712	7.9744	7.9744	8.9712	19.936	13.9552	19.936		29.904
	7.9744	8.9712	8.9712	11.9616	8.9712	12.9584	9.968	22.9264	13.9552	33.8912		30.9008
JUNE	7.9744	10.9648	9.968	11.9616	9.968	12.9584	8.9712	26.9136	29.904	30.9008		34.888
	5.9808	8.9712	8.9712	10.9648	8.9712	9.968	13.9552	28.9072	27.9104	29.904		34.888
JULY	5.9808	10.9648	6.9776	8.9712	9.968	12.9584	19.936	31.8976	29.904	28.9072		31.8976
	7.9744	11.9616	9.968	11.9616	11.9616	13.9552	22.9264	35.8848	33.8912	29.904	18.9392	34.888
SEPT	5.9808	34.888	8.9712	9.968	8.9712	5.9808	8.9712		10.9648	34.888	3.9872	13.9552
	0.9968	32.8944	1.9936	1.9936	0.9968	0.9968	0.9968	3.9872	2.9904	2.9904	13.9552	1.9936
	4.984	29.904	13.9552	8.9712	7.9744	3.9872	3.9872	19.936	3.9872	19.936	19.936	3.9872
OCT	5.9808	36.8816	1.9936	1.9936	2.9904	0.9968	0.9968	3.9872	2.9904	8.9712	3.9872	1.9936
	4.984	37.8784	11.9616	6.9776	5.9808	2.9904	2.9904	9.968	4.984	22.9264	13.9552	4.984
NOV	6.9776	32.8944	8.9712	4.984	6.9776	2.9904	3.9872	32.8944	8.9712	22.9264	19.936	3.9872
	13.9552	39.872	18.9392	7.9744	0.9968	4.984	0.9968	34.888	5.9808	12.9584	16.9456	4.984
DEC	11.9616	36.8816	16.9456	9.968	2.9904	5.9808	4.984	8.9712	11.9616	16.9456	8.9712	5.9808
	3.9872	13.9552	3.9872	4.984	3.9872	3.9872	3.9872	17.9424	3.9872	11.9616	7.9744	3.9872

			Confid.	Confid.	Lower	Upper	Quartile			
Site	Valid N.	Std.Dev	Mean	-95.000%	+95.000%	Median	Quartile	Quartile	Range	Range
1	19	7.03006	5.69522	8.36491	6.97760	5.98080	7.97440	12.95840	1.99360	2.76947
2	19	21.03773	14.91453	27.16092	11.96160	10.96480	34.88800	32.89440	23.92320	12.70413
3	19	9.44337	7.36535	11.52139	8.97120	6.97760	11.96160	16.94560	4.98400	4.31139
4	19	8.97120	7.31462	10.62778	9.96800	6.97760	11.96160	11.96160	4.98400	3.43699
5	19	7.39731	5.74603	9.04858	8.97120	3.98720	9.96800	10.96480	5.98080	3.42599
6	19	8.44657	5.97402	10.91911	7.97440	3.98720	12.95840	15.94880	8.97120	5.12993
7	19	10.28278	6.46249	14.10307	8.97120	3.98720	19.93600	21.92960	15.94880	7.92616
8	18	23.48018	18.17334	28.78702	27.91040	17.94240	31.89760	31.89760	13.95520	10.67155
9	19	16.84067	11.25638	22.42496	13.95520	4.98400	29.90400	30.90080	24.92000	11.58603
10	18	23.97566	19.37446	28.57687	28.90720	16.94560	31.89760	31.89760	14.95200	9.54637
11	10	12.85872	8.38094	17.33650	13.95520	7.97440	18.93920	15.94880	10.96480	6.25950
12	19	22.08699	13.52357	30.65040	29.90400	3.98720	34.88800	52.83040	30.90080	17.76699

Appendix 16: Nitrate in the upper Kat River (mg/l)

Date	1	2	3	4	5	6	7	8	9	10	11	12
MARCH	0	3	3	4	0	5	0	3	5	3		7
	0	5	3.5	5	0	6	0	3	3	4		7
APRIL	0	5	2.5	4	0	5	0	2	2	3.7		9
	0	5	2	3	0	6	0	2	7	3.9		8
MAY	0	2	1	3	0	3	0	1	6	1		7
	0	3	1.8	2	0	3.5	0	2.5	8	1.2		8
JUNE	0	2	1.5	2	0	3	0	1.5	5	2		10
	0	3	2	3	0	4	0	2	6	3		9
JULY	0	4	2	2	0	3	0	2	9	3		8
	0	4	3	4	0	5	0	3	8	3.3	25	11
SEPT	1	12	2	2	0	1	0		6	1	15	6
	3	20	12	10	0	7	0	5	7	7	20	11
	0	10	4	5	0	1	0	6	5	3	15	8
OCT	1	10	8	10	0	7	0	9	4	7	25	12
	2	16	7	8	0	5	0	7	6	7	20	13
NOV	3	20	10	13	0	6	0	8	4	5	15	7
	0	15	11	12	0	6	0	5	3	7	12	9
DEC	0	20	12	15	0	7	0	9	1	9	11	13
	1	15	2	4	0	2	0	0	2	2	3	4

Site	Valid N	Std.Dev	Mean	-95.000%	+95.000%	Median	Quartile	Quartile	Range	Range
			Confid.	Confid.	Lower	Upper		Quartile		
1	19	.55556	.03757	1.07354	0.00000	1.00000	3.00000	1.00000	1.041618	
2	19	8.83333	5.50288	12.16379	3.00000	15.00000	18.00000	12.00000	6.697234	
3	19	4.90556	2.94651	6.86461	2.00000	8.00000	11.00000	6.00000	3.939464	
4	19	5.94444	3.83138	8.05751	3.00000	10.00000	13.00000	7.00000	4.249183	
5	19	0.00000	0.00000	0.00000	0.00000	0.00000	0.000000			
6	19	4.63889	3.69764	5.58013	3.00000	6.00000	6.00000	3.00000	1.892754	
7	19	0.00000	0.00000	0.00000	0.00000	0.00000	0.000000			
8	18	4.17647	2.78629	5.56665	2.00000	6.00000	8.00000	4.00000	2.703824	
9	19	5.27778	4.20163	6.35392	4.00000	7.00000	8.00000	3.00000	2.164026	
10	18	4.11667	2.93380	5.29954	3.00000	7.00000	8.00000	4.00000	2.378643	
11	10	17.55556	13.55939	21.55173	15.00000	20.00000	14.00000	5.00000	5.198825	
12	19	9.05556	7.98393	10.12718	7.00000	11.00000	7.00000	4.00000	2.154946	

Appendix 18: Faecal coliforms (organisms/100ml) in the upper Kat River catchment

Date	1	2	3	4	5	6	7	8	9	10	11	12
MARCH												
APRIL												
MAY												
JUNE												
JULY												
SEPT	1000	1300	1100	1150	200	800	150		250	400	1300	1250
	650	1100	900	950	200	700	100	800	400	250	1250	1100
	300	1350	650	700	150	350	150	650	400	500	600	450
OCT	350	1150	450	450	100	250	100	400	350	350	550	350
	400	950	350	400	100	200	100	700	450	300	700	450
NOV	900	1350	1050	1150	100	750	150	750	350	500	1250	700
	750	1150	900	1000	150	600	100	650	300	550	1300	750
DEC	850	1200	950	1100	100	700	100	700	300	650	1000	700
	350	950	450	500	100	450	100	400	500	350	600	600

Descriptive Statistics (Faecal coliforms)										
			Confid.	Confid.	Lower	Upper		Quartile		
Site	Valid N.	Std.Dev	Mean	-95.000%	+95.000%	Median	Quartile	Quartile	Range	Range
1	9	616.667	407.920	825.413	650.000	350.000	850.000	700.0000	500.0000	271.5695
2	9	1166.667	1049.776	1283.557	1150.000	1100.000	1300.000	400.0000	200.0000	152.0691
3	9	755.556	536.920	974.191	900.000	450.000	950.000	750.0000	500.0000	284.4341
4	9	822.222	582.890	1061.554	950.000	500.000	1100.000	750.0000	600.0000	311.3590
5	9	133.333	100.049	166.618	100.000	100.000	150.000	100.0000	50.0000	43.3013
6	9	533.333	359.319	707.348	600.000	350.000	700.000	600.0000	350.0000	226.3846
7	9	116.667	97.450	135.883	100.000	100.000	150.000	50.0000	50.0000	25.0000
8	9	631.250	504.979	757.521	675.000	525.000	725.000	400.0000	200.0000	151.0381
9	9	366.667	305.898	427.435	350.000	300.000	400.000	250.0000	100.0000	79.0569
10	9	427.778	327.720	527.836	400.000	350.000	500.000	400.0000	150.0000	130.1708
11	9	950.000	692.898	1207.102	1000.000	600.000	1250.000	750.0000	650.0000	334.4772
12	9	705.556	474.600	936.512	700.000	450.000	750.000	900.0000	300.0000	300.4626

Appendix 19: Potassium (mg/l) in the upper Kat River catchment

	Site											
Date	1	2	3	4	5	6	7	8	9	10	11	12
MARCH												
APRIL												
MAY												
JUNE												
JULY												
SEPT	2.700	0.000	3.000	3.500	0.000	3.100	0.000		0.000	0.000	2.000	0.000
	1.000	10.000	4.000	3.000	0.000	3.000	0.000	10.000	5.000	0.000	2.000	5.000
	0.000	8.000	0.000	2.000	0.000	0.000	0.000	8.000	4.000	6.000	5.000	0.000
OCT	1.000	14.000	4.000	6.000	0.000	3.000	0.000	20.000	15.000	5.000	0.000	7.000
	1.000	12.000	3.000	4.000	0.000	3.000	0.000	14.000	9.000	7.000	0.000	6.000
NOV	0.000	10.000	1.000	7.000	0.000	2.300	0.000	15.000	11.000	9.000	4.000	7.000
	4.000	12.000	4.000	5.000	0.000	2.000	0.000	10.000	7.000	7.000	2.000	5.000
DEC	3.000	14.000	5.000	3.000	0.000	1.700	0.000	10.000	5.000	8.000	3.000	7.000
	0.000	11.000	0.000	3.000	0.000	1.800	0.000	0.000	0.000	0.000	5.000	0.000

Descriptive Statistics (potassium)										
			Confid.	Confid.	Lower	Upper		Quartile		
Site	Valid N	Std.Dev.	Mean	-95.000%	+95.000%	Median	Quartile	QuartileRange		Range
1	9	1.41111	.278503	2.54372	1.00000	0.00000	2.70000	4.00000	2.700000	1.473469
2	9	10.11111	6.839879	13.38234	11.00000	10.00000	12.00000	14.00000	2.000000	4.255715
3	9	2.66667	1.228620	4.10471	3.00000	1.00000	4.00000	5.00000	3.000000	1.870829
4	9	4.05556	2.803599	5.30751	3.50000	3.00000	5.00000	5.00000	2.000000	1.628735
5	9	0.00000		0.00000	0.00000	0.00000	0.00000	0.000000	0.000000	
6	9	2.21111	1.441056	2.98117	2.30000	1.80000	3.00000	3.10000	1.200000	1.001804
7	9	0.00000		0.00000	0.00000	0.00000	0.00000	0.000000	0.000000	
8	8	10.87500	5.991249	15.75875	10.00000	9.00000	14.50000	20.00000	5.500000	5.841661
9	9	6.22222	2.441309	10.00313	5.00000	4.00000	9.00000	15.00000	5.000000	4.918785
10	9	4.66667	1.842400	7.49093	6.00000	0.00000	7.00000	9.00000	7.000000	3.674235
11	9	2.55556	1.111814	3.99930	2.00000	2.00000	4.00000	5.00000	2.000000	1.878238
12	9	4.11111	1.666903	6.55532	5.00000	0.00000	7.00000	7.00000	7.000000	3.179797

Appendix 17: Ammonium (mg/l) in the upper Kat River catchment

Date	1	2	3	4	5	6	7	8	9	10	11	12
MARCH	0	0	0	0	0	0	0	0	0	0		0
	0	0	0	0	0	0	0	0	0	0		0
APRIL	0	0	0	0	0	0	0	0	0	0		0
	0	0	0	0	0	0	0	0	0	0		0
MAY	0	0	0	0	0	0	0	0	0	0		0
	0	0	0	0	0	0	0	0	0	0		0
JUNE	0	0	0	0	0	0	0	0	0	0		0
	0	0	0	0	0	0	0	0	0	0		0
JULY	0	0	0	0	0	0	0	0	0	0		0
	0	0	0	0	0	0	0	0	0	0	1	0
SEPT	0.5	0.5	0.5	0.5	0	0	0		0	0	0.5	0
	1	5	3	2	0	1	0	0	0	0	2	0
	0	6	0.5	0.5	0	0.5	0	0	0	0	0.5	0
OCT	2	4	3	2	0	1	0	0	0	0	0	0
	1	8	2	2	0	0.5	0	0	0	0	1.5	0
NOV	2	7	3	3	0	1.4	0	0	0	0	1.5	0
	0	9	2	3	0	1	0	0	0	0	1.2	0
DEC	0	7	4	5	0	2.5	0	0	0	0	0.1	0
	0	0	0	0	0	0	0	0	0	0	0	0

Descriptive Statistics (Ammonium)										
			Confid.	Confid.	Lower	Upper	Quartile			
Site	Valid N .	Std.Dev	Mean	-95.000%	+95.000%	Median	Quartile	Quartile	Range	Range
1	19	.342105	.02025	.66396	0.000000	0.000000	.500000	2.0000	.500000	.66776
2	19	2.447368	.81506	4.07967	0.000000	0.000000	6.000000	9.0000	6.000000	3.38664
3	19	.947368	.28060	1.61414	0.000000	0.000000	2.000000	4.0000	2.000000	1.38338
4	19	.947368	.24295	1.65179	0.000000	0.000000	2.000000	5.0000	2.000000	1.46149
5	19	0.000000	0.000000	0.000000	0.000000	0.0000 0.000000	0.00000			
6	19	.415789	.08604	.74554	0.000000	0.000000	1.000000	2.5000	1.000000	.68416
7	19	0.000000		0.000000	0.000000	0.000000	0.0000 0.000000	0.00000		
8	18	5.263158	-5.79433	16.32064	0.000000	0.000000	0.000000	100.0000	0.000000	22.94157
9	19	0.000000		0.000000	0.000000	0.000000	0.0000 0.000000	0.00000		
10	18	0.000000		0.000000	0.000000	0.000000	0.0000 0.000000	0.00000		
11	10	.830000	.32075	1.33925	.750000	.100000	1.500000	2.0000	1.400000	.71188
12	19	0.000000		0.000000	0.000000	0.000000	0.0000 0.000000	0.00000		

Appendix 20: Water Quality Workshop Report

The upper Kat River water quality discussion: issues discussed at a workshop held at Fairbairn on Monday the 4th of December 2000

M.K. Soviti

Catchment Research Group

Department of Geography

Summary

A study whose aim was to assess the impact of rural land use and related activities was carried out in the upper Kat River Valley from March to December 2000 by Soviti Malixole, a Masters student under the Catchment Research Group, Geography Department, Rhodes University. The findings of the study were reported to the concerned communities in a workshop that was held at Fairbairn on the 4th of December 2000. Following is a summary of the workshop proceedings.

Community delegates learned that during Soviti's study, high levels of nitrate were observed in some parts of the catchment, particularly in Tamboekeisvlei and Balfour. Chloride was occasionally found at health threatening concentrations particularly at Hertzog and some parts of the catchment. Turbidity was observed to be extremely high, particularly in the Kat River. The faecal coliform count was found to be extremely high throughout the catchment.

During the workshop, it was established that most communities in the Kat River valley do not have assess to hygienically safe drinking water (including those having access to piped water). This was evidenced by the results obtained from the analysis of water samples which were brought along by the community delegates attending the workshop, collected from their respective villages' source of supply of water. For example, chloride concentration was found to be extremely high on a sample from one well in Tambokeisvlei village whilst tap water from Balfour village confirmed the high levels of nitrate found by Soviti.

The findings of Soviti and workshop water quality studies led the communities to realise that they are at risk of contracting water-borne diseases. It is that realisation that led the communities to commit themselves in action to improve the quality of their water, particularly river water. They are thus inviting the Department of Water Affairs and Forestry to join and assist them in this venture.

Following is the report of the water quality discussion workshop proceedings held at Fairbairn on Monday the 4th of December 2000. The purpose of the workshop was twofold: first was to share the water quality findings of MSc research conducted in the area by MK Soviti, a student of Rhodes University's Geography Department- Catchment Research Group, with the concerned communities, and second was to discuss and advise some means by which the affected communities can improve the quality of their water.

More than fifty community delegates attended the workshop. All neighbouring schools were invited to send at least two pupils to attend the workshop, and each concerned community was requested to send at least two delegates. The following communities were represented:

- Seymour,
- Tamboekiesvlei,
- Hertzog,
- Fairbairn,
- Stonehenge
- Balfour, and
- Paradise

Each person attending the workshop was required to bring at least one sample of water from where they are getting their water for domestic uses, irrespective of the type of water supply. An idea behind this requirement was to let communities analyse water on their own so that they see from their own results the quality of the water they are using. Water sample sources varied between piped (tap water in Balfour and the wells in Tamboekeisvlei) and non-piped (spring in Hertzog and river in all other communities) sources.

In total, 12 water samples were analysed during the day. Water samples were then labelled and the process of analysis begun. The community members were divided into groups. Each group focussed on determining a specific water quality variable in each water sample. The following water quality variables were selected for the exercise: nitrate, potassium, and chloride. The results of the analysis are summarised in Table 1 and Figure 1.

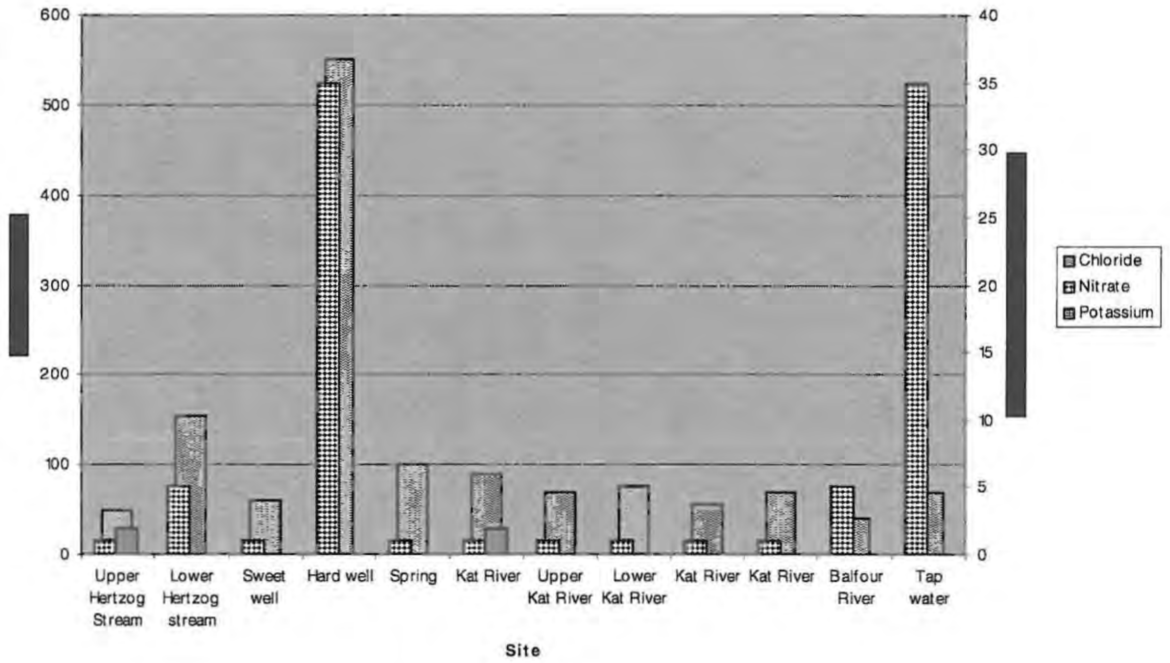

Figure 1: Results of water quality analysis during the workshop

Table 1: Results of water quality obtained during the analysis of samples in the water quality workshop

Community	Site from which water sample has been collected	Nitrate	Chloride	Potassium
Tamboekiesvlei	Upper Hertzog stream	1	50	2
	Lower Hertzog stream	5	155	
	Sweet well	1	60	
	Hard well	20 - 50	550	
Hertzog	Spring	1	100	
	Kat River	1	90	2
Fairbairn	Upper	1	70	2.5
	Lower	1	75	3.25
Stonehenge	Kat River	1	55	< 2
Paradise	Kat River	1	70	< 2
Balfour	Balfour River	5	40	
	Tap water	20 - 50	70	

The results were then explained, discussed and their implications on health and welfare of the water users were clarified. The explanation involved an attempt to simplify and translate to isiXhosa the scientific terms of the water quality field so that they could be better understood by the communities.

The water quality results of the Masters project were then shared with the communities.

The Masters work studied 11 water quality variables, (electrical conductivity, pH, turbidity, total hardness, chloride, phosphate, potassium, nitrite, nitrate, ammonium and the faecal coliforms). In the discussion the findings of the communities were compared to those of a Masters project, and were found to be corresponding well.

Results from both workshop analysis and the Masters project were put into perspective by measuring them against DWAF's water quality guidelines for domestic uses. This was done to establish whether the quality of water the people in the area are using is fit for use.

The extremely high turbidity levels in the Kat and Balfour Rivers are noticeable. Besides impacting on the aesthetic quality of water (WHO, 1984, DWAF, 1993), turbidity levels as high as those found in the upper Kat River area are often associated with serious health effects on all users. Because turbidity is often seen as indicator of microbiological water quality problem, secondary health effects may be expected where turbidity is high. An inevitable impact of suspended solids in water is the staining of clothing when water is used for laundry. (DWAF, 1999).

Elevated levels of nitrate were observed in some parts of the river and one well in Tamboekeisvlei and tap water in Balfour (Figure 1 and Table 1). Of primary concern is the impact of nitrate on the human health. In the environment, the conversion of nitrates and nitrites to one another is readily happening. When a conversion of nitrate to nitrite occurs in the gastro-intestinal tract, nitrites are then absorbed into the blood cells, and combine with the oxygen carrying red blood pigment, haemoglobin. The result of this combination is methaemoglobin. Methaemoglobin cannot transport oxygen, and the resultant condition is called methaemoglobinemia (Kruger, 1992; DWAF, 1993).

The condition could be fatal to infants under 3 months old. Serious and occasionally fatal poisonings in infants have been reported following the ingestion of well waters that contain extremely elevated concentrations of nitrate (Rao, 1998). Handa (1989) reports that approximately 2000 cases of methaemoglobinemia were diagnosed in the United States and Europe during the period 1945 and 1960 and about 7 - 8 percent of infants died. Handa (1989) also reports that, in Russia, where children were drinking water with as much as 182 mg/l of nitrate, elevated levels of methaemoglobin concentrations were found. Cuello *et al.,* (1976) and Gilli *et al.,,* (1984) linked the elevated concentrations of nitrate with an increased risk of gastric cancer. In the study by Xu *et al.,* (1992), conducted in north-eastern China, a very close association between the high levels of nitrate in drinking water supplies and neoplastic changes in the stomach was developed. Reporting from a different perspective, Lunkad (1994) revealed that the elevated concentrations of nitrate are undesirable in the fermenting and dyeing industries.

Chloride was found at undesirable concentrations in one well in Tamboekeisvlei (Figure 1 and Table

1). The results of the Masters work also indicate that, occasionally, particularly when flows are low, chloride is found at human health threatening concentrations in some parts of the upper Kat River catchment. Nausea, vomiting, and dehydration in infants are the health effects of the extremely high concentrations of chloride. The sensitive group of humans are more affected by the high chloride concentrations (DWAF, 1999).

The faecal coliform bacteria presence in water is seen as an indication that water has been faecally polluted and hence of the likely presence of the pathogens associated with faecal pollution (DWAF, 1999). The number of the faecal coliform bacteria per 100ml was found to be completely unacceptable throughout the upper Kat River catchment. In some parts of the catchment, the number of organisms per 100ml of water was as high as 1167. According to DWAF (1999), there should not be more than 10 organisms per 100ml in drinking water. When domestic water has more than 10 organisms per 100ml, clinical infections and serious health effects become common. Craun (1986) indicated that diseases like typhoid fever, hepatitis, giardisis, gastroenteritis, dysentery, amoebiasis, salmonellosis, cholera etc. are often common where water is microbiologically polluted. Communities were advised never to drink the river water without prior boiling.

After this discussion, community delegates and researchers took a transect walk down to the river. The purpose of the transect walk was to help communities establish a link between the impacted quality of water and the activities happening on land around the river. As part of this exercise, communities were given a sheet in which they were required to note down any overland activity they feel might be negatively impacting on water.

During a transect walk report-back session, community delegates noted a number of land uses and related activities which impact negatively on the quality of river water. Amongst others, they noted the use of pit latrines in the area, and their close proximity to the river location in some instances. The application of fertilisers and the pesticides during the crop farming was also noted. Also identified was the impact of cattle grazing along the riverbanks on water quality. The clearance of riverbank vegetation thereby increasing the amount of sediment into the river system, and the common practice of burning the veld and the fields after harvesting were also noted to be impacting negatively on the quality of river water.

Community delegates were then involved in a mapping exercise. During this activity, they were given the aerial photographs of their respective villages. They were then required to update the maps by marking the piece/s of land used and also indicate the type/s of land use.

The workshop was concluded by a session in which communities were to come up with resolutions on how the quality of their water is to be improved. Community delegates committed themselves to minimising the activities that impact on the river water quality. Communities indicated that fencing along the river would go a long way towards keeping domestic animals away from the river. They also requested an intervention of the Department of Water Affairs and Forestry to help them get safe drinking water in the form of treated piped water. It is also hoped that when the Kat River Water Users Association is operational, better strategies of managing the river would be in place, and that water quality may improve.

Appendix 21: In-depth literature survey on detergents

As Rosen (1978) puts it, they accrue at surfaces and interfaces, thereby lowering the surface and interfacial free energies. This property is related to the presence of both hydrophobic and hydrophilic properties in a single structure. Depending on the nature of their hydrophilic group, surfactants are classified mainly as:

- anionic - these form the largest portion of modern synthetic detergents, and differ from the rest in that in a solution, they produce colloidal ions which are electrically negative.
- cationic - these produce ions which are electrically positive in a solution.
- nonionic - these produce colloidal ions which are electrically neutral in a solution.
- amphoteric - depending on the pH of the solution, these surfactants are capable of acting either as anionic or cationic in a solution. (Gwinn *et al.*, 1986 and Matthijs *et al.*, 1995).

Surfactants are utilised in a wide variety of commercial and domestic applications. Cano and Dorn (1996) reported that hundreds of millions of kilograms of nonionic surfactants are used annually in US consumer and industrial markets. New compounds are still being developed (Versteeg *et al.*, 1996).

Surfactants have physical characteristics that promote assemblage at surfaces and interfaces, and the formation of micelles above a concentration specific for individual surfactants. , commonly known as the Critical Micelle Concentration (CMCs). After reaching the CMC, the surface tension does not change even if further surfactant is being added (Sherrard *et al.*, 1996).

Surfactants are among the most important ingredients in detergents. In the US their quantities are respectively large - around 133 000 tons for anionic and 62 000 tons for nonionic detergents (TEGEWA, 1994).

At the end of the 1950s, detergent surfactants were producing volumes of foam on river and sewage treatment plants. It is against this background that Henkel initiated a monitoring programme with a view to systematically determine the surfactant load of the Rhine River since 1955 (Schroder, 1995). The results were continually reported. At the beginning of the monitoring programme, anionic surfactants were assessed only as methylene-blue-active substance (MBAS). In the 1960s MBAS load at a certain point was averaging at 1200 grams per second. In a thirty year period following that, MBAS load has fallen by more than 90%. In 1993, the annual average was only 73g/s. Lately, the low MBAS values are no longer a reflection of the actual pollution by anionic surfactants (Schroder, 1995).

Among the anionic surfactants, linear alkylbenzene sulfonate (LAS) is quantitatively the most important compound. It is estimated that on average, LAS forms 34 percent of all detergent surfactants. The LAS concentration in the Rhine River Basin fell from 23 to 5 micrograms per litre between 1988 and 1993. Over the same period, the loads decreased by 79 percent from 40 to 8.5g/s. While the LAS share was only 12 percent in 1993, the contribution of natural, non anthropogenic substances to the MBAS load in the Rhine would now appear to be clearly predominant at around 70% (Schroder, 1995).

The load of bismuth-active substance (BiAS), which represented the nonionic surfactants, fell by about 70 percent from 74 to 23g/s between 1974 and 1993. is impressive. The reduction in the surfactant loads by 90 percent and 70 percent in the Rhine Basin is probably attributable to the increasing use of nonionic surfactants at the expense of anionic surfactants (Schroder, 1995). Developments in wastewater treatment and the sustained improvements on the quality of detergents thereby making them less toxic to the ecological balance had a commendable effect on the reduction.

Surfactants have a distinctive lethal effect on aquatic organisms, which is largely attributable to their surface activity (Sherrard *et al.,* 1996). Several studies have been conducted on the impact of several surfactants on aquatic ecosystems, and they include the following:

Nonionic polyethoxylate surfactants

According to Sherrard *et al.,* (1996) surfactants are often a major constituent of domestic and industrial effluent. In 1990, 840 million kilograms of nonionic surfactants were produced in the United States (Dorn *et al.,* 1993). Cabridene and Lundahl (1976) show that discharge to the environment happens mainly via treatment effluents from publicly owned treatment works (POTW), septic tanks, and industrial wastewater treatment processes.

Linear and essentially linear alcohol ethoxylates (AE), the most widely used nonionic surfactants, have been shown by many (Hughes *et al.,* 1958; Kikuchi, 1979; and Kondo, 1980) as environmentally compatible because they are speedily bio-degradable, and show low toxicity in the aquatic environment after passing through treatment plants. According to Sherrard *et al.,* (1996), the toxicity levels of the effluents and receiving water bodies are still less understood.

Some work was done previously in the field of acute surfactant toxicity using different test species. Most common of these include *Daphnia magna* (Dorn *et al.,* 1993; Kravetz *et al.,* 1984; Lewis, 1992); fathead minnows (Dorn *et al.,* 1993; Kravetz *et al.,* 1984; Lewis, 1992;

Ankley and Burkhand, 1992); manuluminiscence bacteria (Dorn *et al.*, 1993; Poremba *et al.*, 1991; Retuna *et al.*, 1989; Ribosa *et al.*, 1993).

Sherrard *et al.*, (1996) conducted a study that used the Microtox test to measure acute toxicities of nonionic surfactants using bacteria as the test organisms. In the study, the LC_{50} values [an LC_{50} value is the concentration of a material that will kill 50% of the test subjects (animals, hopefully) when administered as a single exposure. This value gives one an idea of the relative toxicity of the material] of nonionic polyethoxylate surfactants were determined using the luminescent bacteria, *Photobacterium phosphoreum* as the test species. The surfactants tested in the experiment were the polyethoxylate nonionic surfactants typically used in the wool industry which are: nonylphenol ethoxylate (NPE), primary alcohol ethoxylate, PAE and PAE and the secondary alcohol ethoxylate (SAE). The study concluded that both PAE and SAE surfactants were toxic to aquatic organisms although from the five minute LC_{50} data, it is apparent that PAE has the highest relative toxicity and SAE the lowest.

Versteeg *et al.*, (1996) conducted a study that attempted to develop structural parameters capable of predicting the chronic toxicity of a diverse group of surfactants to rotifer *Brachious calyciflorus*. Rotifera are a various widely spread phylum predominantly occupying slow moving freshwater systems (Wallace and Snell, 1991). Depending upon environmental conditions, rotifers can account for a large part of the zooplankton biomass providing an important food source of some invertebrates and fish (Rublee, 1992).

The results of the study confirmed the findings of Maki and Bishop (1979) that surfactant toxicity increases with alky chain length. Versteeg *et al.*, (1996 : 1053) noted that: *"for the amines, and cationic surfactants, increased chain length increase toxicity by factors of approximately 3.3 and 2.2 per carbon atom respectively. For anionic surfactants like alkyl sulfates and alkyl oxyethylene sulfates toxicity increased by factors of 1.9 and 2.3 per alkyl carbon"*. The study also showed that when nitrogen substitution is increased, toxicity is reduced, and that the sulphate substituted compound of the nonionic detergents were more toxic than those with a sulphonate substitution (Versteeg *et al.*, 1996).

Alcohol ethoxylate (AE) is the most important nonionic surfactant. Its production amounted to 7x 10^5 tons worldwide in 1996. AE is used both in industrial and domestic purposes. It is biodegradable, thus most of it is removed by biodegradation and sorption from the streams. AE concentration in rivers after treatment in wastewater treatment plants still ranges between 2.5 and 37 micrograms per litre (Crescenzi *et al.*, 1995 and Fendinger *et al.*, 1995).

Tolls *et al.*, (1999) conducted a study investigating the risk that surfactant alcohol ethoxylate (AE) poses to aquatic organisms. Fish were exposed to increasing concentrations of AE. During the experiment, no signs of sub-lethal effects such as abnormal swimming or breathing behaviour were observed. The study also demonstrated that AE toxicity largely depends on the length of its hydrophilic tail with bio-concentration increasing with increasing length of the hydrophobic alkyl chain and decreasing length of the hydrophilic ethoxylate chain. (Tolls *et al.*, 1999).

Dodecyl trimethyl ammonium chloride (C12-TMAC)

Work conducted by McCormick *et al.*, (1991) aimed to assess the effects of cationic surfactant dodecyl trimethyl ammonium chloride (C12-TMAC) on benthic microbial organisms. C12-TMAC is one of the cationic surfactants. C12-TMAC belongs to a class called monoalkyl ammonium compounds (MAQs) (McCormick *et al.*,1991), and is highly soluble. Their role as surfactants is to help improve removal of certain stains like oil and grease. According to Woltering and Bishop (1989), the MAQ bioconcentration factor (used to describe the accumulation of chemicals in organisms, primarily aquatic, that live in contaminated environments) is low and are generally and completely biodegraded.

Results of Woltering and Bishop (1989)'s work show MAQs to be relatively toxic to aquatic organisms, with the most sensitive species being *Daphnia magna*. MAQs were found to be two to three times less toxic in river water compared to laboratory water. McCormick *et al.*,(1991) reported that the number of protozoan species in the mature community declined with increasing C12-TMAC concentration after two days, but no effect was identified by day fourteen of the study.

Linear Alkylbenzene Sulfonate (LAS)

The use of LAS in synthetic detergents is still common. In Japan, more than 50 percent of washing agents were reported to contain LAS as the major surfactant (Japanese Ministry of International Trade and Industry, 1981). The linear alkyl benzene sulphonate (LAS), alcohol ethoxylate (AE), alcohol ethoxylated sulphates (AES), and soap envelops about 90% of the mass of surfactants on the Dutch market (Feijtel *et al.*, 1999). Large amounts are discharged into public water bodies without treatment or pass through wastewater treatment plants. In fact, according to Sudo (1982), approximately 70 percent of waste water, including LAS, is discharged directly into public water bodies.

Maki and Bishop (1979) conducted a 48 hour study with the primary purpose of examining the acute toxicity of both anionic and nonionic surfactants to *Daphnia* and blue gill fish. In this study similar response was observed on both *D.magna* and *D.pulex*, confirming the findings of Buikema *et al.,* (1976), and Canton and Adema (1978), that both species are equally sensitive to anionic and nonionic surfactants. It was observed that the LC_{50} of *Daphnia magna* gradually decreases as the alkyl carbon chain increases. In fact, according to Maki and Bishop (1979: 602-3), "*an increase in toxicity of approximately one order of magnitude is demonstrated for each additional two carbons between* C_{10} *and* C_{16}". The chemical composition of both anionic and nonionic surfactants resulted to consistent changes in biological activity of the test species, *Daphnia.*

Yamane *et al.,* (1984) studied the inhibitory effects of synthetic surfactants and soaps that are widely used in laundry detergents as raw materials on freshwater planktonic algae. Kondo (1980) had earlier identified the following as the main surfactants used in washing agents for home use in Japan: LAS, alcohol ethoxylated sulphates (AES), *a-olefinsulfonate* (AOS), alcohol ethoxylates (AE), and alkylsulphonate (AS). Although not specified in industrial statistics, Yamane *et al.,* (1984) implicated polyexythylene alkylphenyl ether (APE) and sugar ethers as toxic compounds of washing agents. The green algae *Selenastrum capricorriutum,* a blue algae *Microcytis aeruginosa,* and adiatom *Nitzschia fonticola* were used as test organisms and the study assume the retardation of specific growth rates due to exposure of the test organisms to the surfactants as the assay criterion.

Yamane *et al.,* (1984 observed that the rate of growth of algae decreased with the increase in the concentrations of surfactants, and the specific growth rate observed in the early stage of cultivation was larger than in the latter stage. Ukeles (1965) described this as the delay in inhibitory reaction of the growth rate of the test organism and attributed it to the time required by the surfactants to penetrate the cell wall and inhibit the biochemical reaction within the cell.

Detergent enzyme, Axion

Cairns *et al.,* (1971) exposed the freshwater protozoan communities to different concentrations of the detergent enzyme Axion. The purpose of the study was to determine a rough estimate of the relative toxicity of the Axion. The study demonstrated that Axion is toxic to the fresh water protozoan and that toxicity increased with the concentration of the compound in water. For example, at 100 parts per million (ppm) of Axion, the entire population of *Paramecium caudium* was killed in approximately 20 - 30 minutes compared to up to 200 minutes required to achieve the same result at a concentration of 30 ppm (Cairns *et al.,* 1971).

Important considerations when assessing the ecological threat of a substance are the fate of the substance in the environment and the eco-toxicological consequence of the substance

(Schroder, 1995). The amounts entering the environment and the degradation and removal of the substances in a variety of environmental sections, like the surface water bodies or sewage plants, are important aspects to be considered. The predicted environmental concentration (PEC) is the concentration of a substance at which no further eco-toxicological effects are expected to occur. It is often measured against the predicted no effect concentration (PNEC). Both characteristics are compared in the ecological risk assessment (Schroder, 1995).

In most first world countries, detergents enter the aquatic environment via the sewage treatment works. After use, detergents ingredients are disposed of to municipal sewerage systems and sewage treatment plants from which they are largely removed by a combination of sorption and bio-degradation (Matthijs *et al.,* 1995). The fate of the major types of detergent surfactants during sewage treatment is well documented in the scientific literature (Gilbert and Pettigrew, 1984; Brown *et al.,* 1986; Stalmans *et al.,* 1993; Giolando *et al.,* 1994).

The fate of linear alkylbenzene sulphonate (LAS) in the sewer was studied by Moreno *et al.,*(1990), who demonstrated that LAS was removed to the extent of almost 50% in a Spanish sewage treatment plants. A later study conducted by Feijtel *et al.,* (1999) predicted that the average removals for LAS, alcohol ethoxylates (AE), alcohol ethoxylated sulphates (AES) and soap from the sewage works before being disposed to the receiving water bodies is much higher (98-99%).

The study by Moreno *et al.,* (1990) also illustrated that chemical and biological processes occurring in the sewer can result in significant drop in the concentrations of surfactants entering treatment plants. Even more appreciably, such reactions could play a significant role in reducing the environmental concentrations, particularly in situations where poor or no sewage treatment exists. In their paper, both field and laboratory data presented are indicating that the sewer is more than just a transport system for the sewage, but also serves as a site for biodegradation and sorption processes to be commenced.

Ahel and Giger (1985) and Reinhard *et al.,* (1982) reported that the bio-degradation of some nonionic surfactants like APE can result to the formation of more persistent products such as alkyl phenol. Jobling and Sumper (1993) revealed that not only are these phenols persistent, but their presence in water may cause the disturbance of the endocrine systems in fish and shellfish. The work by Yamagishi *et al.,* (1998) aimed to describe the fate of the aromatic nonionic surfactants and their degradation products in the natural aquatic environment from an eco-toxicological point of view. The study observed the presence of the new persistent organic pollutants, polyglycidyl monofluorooctyl phenyl ether nonionic surfactants in river water. These were also observed in secondary waste effluent from the treatment plants. The study also showed that APE is extremely resistant to microbial oxidation in aquatic environments, persisting in activated sludge treatment plants. Brominated alkylphenol polyethoxy carboxylates were also found in treated wastewater in potentially mutagenic concentrations. (Reinhard *et al.*, 1982; Yamagishi *et al.*, 1998).

Dorn *et al.*, (1993) realised that environmental concentrations of nonionic surfactants in waste waters ranged between 0.008 and 2.7mg^{-1} and in rivers from 0.0042 to 0.8mg/l. Feijtel *et al.*, (1999) predicts that the concentrations of LAS and other surfactants are range from 0.01 to 2μg^{-1} in surface water after treatment.

In some first world countries, like Japan, and most third world countries however, detergent is disposed directly into surface water bodies without prior treatment. Yamane *et al.*, (1984) reported that large amounts of detergents in Japan are released into public water bodies without treatment or passing through wastewater treatment plants. These findings confirmed the suspicions of Sudo (1982) who estimated that about 70 percent of all dirty water in Japan is discharged directly into public water bodies. In such circumstances, aquatic organisms may be exposed to even higher concentrations of several substances contained in that water.

The above section has explored how aquatic environments are affected by detergent toxicity. In the complex environment though, the relationship between a substance and its environment is two ways, that is, whilst the environment is affected by the substance, the substance is also affected by its host environment. This is confirmed by Feijtel *et al.*, (1999), who proclaim that the fate of any chemical is controlled by two factors within the environment: the inherent physical, chemical and transformation properties of the material, and the nature of environment into which the environment is released. The section that follows explore various ways the nature of the environment affects the level of toxicity of detergent surfactants.

The interaction of surfactants with various physical and chemical environmental factors

Many researchers have examined the effects of various physical and chemical environmental factors on the toxicity of surfactants to aquatic life. For example, Hokanson and Smith (1971) observed that acute toxicity thresholds are generally observed at lower concentrations of nonionic and anionic surfactants when test temperature is increased. Herbet *et al.*, (1957) and Hokanson and Smith (1971) examined the effects of changing concentrations of dissolved oxygen on the acute toxicity of surfactants. Their findings showed that levels of effect were significantly lower at reduced oxygen concentrations. Eisler (1965) demonstrated that at high and low salinity extremes, the effect levels of acute toxicity of surfactant were significantly reduced.

Maki and Bishop (1979) studied the impact of suspended solids and hardness ions on the toxicity of a surfactant. They observed that the presence of suspensions of purified, naturally occurring kaolin clay alters the observed acute toxicity threshold and LC 50 concentration of the surfactants. They attributed the reduced toxicity of surfactants to the loss of active surfactant from the solution resulting from the absorption of surfactant by clay, and the subsequent settling of the suspension. Earlier work by Henderson *et al.,* (1959), Hokanson and Smith (1971), and Abel (1974) reported LAS to be more toxic in soft water. The work by Maki and Bishop (1979) confirmed these findings. Maki and Bishop (1979) pointed out that, in hard water, the toxicity in LAS is independent of culture conditions. In soft water, however, the toxicity of LAS is directly related to culture water hardness levels. Consequently, in soft water, LAS is notably more toxic to *Daphnia* cultured at high hardness levels. Also, the nonionic surfactant, Neodol 45-7, was reported by Maki and Bishop (1979) to be more toxic to *Daphnia* in soft than hard water.

A common characteristic of the latest generation of detergents is tendency to sorb to the bottom sediments. McCormick *et al.,* (1991) revealed that the sorption of the cationic surfactant, C12-TMAC, is high and Versteeg *et al.,* (1996), showed that the rapid sorption and degradation of surfactants noted resulted in the decrease in test concentrations during the test period by 20 - 90 percent.

Surfactant residues are often associated with bottom sediments in the receiving water bodies after discharge from treatment. Rapid equilibrium times for nonionic surfactants binding to sediments and soils observed by the study confirmed findings of earlier works on the topic by Brownawell *et al.,* (1991) and Valoras *et al.,* (1969). Cano and Dorn (1996) conducted a study aiming to investigate the sorption of an alcohol ethoxyelate surfactant to natural sediments at environmental concentrations greater than 90 percent of the equilibrium sorption was achieved within the first two to four hours of the experiment. Equilibrium sorption was established within 24 hours.

Sediments characteristics also affect sorption. This process has been studied extensively by such authors as Karickhoff (1984) and Ditoro (1985). These authors realised that the amount of sorption for many nonionic surfactants was found to correlate well with the percentage of organic carbon in sediments having ≥ 0.2 organic carbon. The study also revealed that the amount of sorption correlated with the percentage of clay in the sediment. This was in line with later observations made by Brownawell *et al.,* (1991).

Many researches, for example Ditoro, 1985; Ditoro *et al.,* 1990; Hand *et al.,* 1990; O'Connor and Connoly, 1980; and Scamehorn *et al.,* 1982, have studied the effect of particle concentration on the sorption process. They all concluded that the amount of sorption decreases with increase in particle concentration. According to Cano and Dorn (1996), this result may be due to a greater frequency of particle-particle concentrations, which may then lead to lower sorption equilibrium. An alternative explanation also provided by Cano and Dorn (1996) is that the lower sorption equilibrium "may have been caused by the presence of colloidal materials in the experiment systems".

The fate of linear alcohol ethoxylates (AEs) surfactants in the sediment environment is presented below. It was observed that the sorption of AE surfactant to natural sediments was rapid and reversible. These sorption characteristics suggest that AE surfactants are rapidly degradable. Although the biodegradation of AE is known to occur in solution, it is not known whether sorbed surfactant can biodegrade. If the sediments to which sorption has occurred are turned into a solution through dilution, a driving force would be established for the sorbed AE to desorb from the sediment which would enable the AE to biodegrade in solution (Cano and Dorn, 1996). Poly-cyclic aromatic hydrocarbons (PAHs) are hydrophobic chemicals that sorb strongly to clay minerals, soil humus, or other organic solids (Mahro and Kastner, 1993 and Hatzinger and Alexander, 1995). Park *et al.,* (1990) suggested that microbial degradation as the important process by means of which PAHs can be removed from the contaminated soils.

In a system of soil and water, most surfactants are sorbed onto the soil solids (Edwards, *et al.,* 1994; Liu *et al.,* 1992), and addition of water to soil usually results in aqueous surfactant concentrations below the CMC. Edwards *et al.,* (1994) demonstrated that the apparent solubility of pyrene in nonionic surfactant solution at the CMC may increase by a factor of about three, compared to the solubility in water. The objective of the study was to examine the degradation of freshly added PAHs and of selected PAH contaminants present in a coal-tar polluted soil.

According to Madsen and Kristensen, 1996, the addition of bacteria to the soil samples enhanced the mineralisation of phenanthrene. Relatively low amounts of sorbed residues have also been observed for pesticides and other chemicals that were rapidly eliminated from soil by degradation and abiotic loss mechanisms (McCall *et al.,* 1981; Alexander, 1995). A recent study by Harms and Zehnder (1995) warned that easily degradable PAHs may resist desorption and persist at low levels after bio-treatment of contaminated soil.