Impact of land use on water quality and aquatic ecosystem health of stream networks in the upper uMngeni catchment feeding Midmar Dam, KwaZulu-Natal, South Africa

Ross van Deventer

206513292

Submitted in fulfilment of the academic requirements of

Masters of Science Degree in Environmental Science

School of Agricultural, Earth and Environmental Sciences

University of KwaZulu-Natal

Pietermaritzburg

October 2012

FRONTISPIECE

"In an age when man has forgotten his origins and is blind even to his most essential needs for survival, water along with other resources has become the victim of his indifference" (Carson, 1962: 39).

DECLARATION

This document was submitted in fulfilment of a Masters of Science degree. The thesis represents the original work of the author and any literature used is properly acknowledged both in text and in the reference chapter.

____

Ross van Deventer

____

Trevor Hill

____

Craig Morris

ABSTRACT

Freshwater in adequate supply and quality is vital to life on Earth; however, land-based activities such as development, agriculture, mining and industry, and their associated contaminants, pose a major threat to the quality of freshwater water resources and health of aquatic ecosystems. The upper uMngeni catchment draining into Midmar Dam is a strategically significant water resource, supplying clean drinking water to the eThekwini, uMgungundlovu and Msunduzi municipalities. The quality of this resource is under threat from current land-based activities such as Mpophomeni settlement and agriculture and emerging threats in the form of the Khayalisha social housing project. Monitoring sites were established in varying land use types in three sub-catchments of the upper uMngeni, to assess water quality and ecosystem health impacts of current land uses on Midmar Dam. A suite of physical, chemical and biological water parameters were sampled in conjunction with SASS5 bio-monitoring to assess the associated impacts. Water quality and ecological condition were highest in forested land use and upstream of Mpophomeni where natural land cover and sparse settlement occurred. Marked declines in water quality and ecological condition were observed at areas under commercial agriculture, indicated predominantly by rises in nutrient concentrations and declines in the SASS5 indices. The most notable declines in water quality and ecological condition were observed at sites downstream of Mpophomeni settlement as a result of severe sewage contamination, indicated by high *E. coli* counts. Nutrient concentrations downstream of Mpophomeni settlement ranged from mesotrophic to hypertrophic, with nitrogen to phosphorus ratios indicative of nitrogen limitation. Ecological condition remained in the 'seriously/critically modified' category over the study period. Nutrient loads produced by Mpophomeni are the highest of all the land uses, followed by that of commercial agriculture; both should be viewed as a concern, more so when viewed in terms of their compound effect on Midmar Dam water quality. Current water quality draining the commissioned Khayalisha social housing development area is good and although not natural, is of no contamination concern to Midmar Dam. Results indicate that with current land use activities, urban development and agriculture pose a potential threat to the quality of Midmar Dam resource and that further development in the form of the Khayalisha social housing project may replicate impacts already prevailing in Mpophomeni, whereby a principle water resource may be threatened by eutrophication.

Keywords: Khayalisha social housing project, land use, Mpophomeni settlement, nutrient loading, SASS5, water quality

ACKNOWLEDGEMENTS

Thanks are owed to the following people for their time, support and knowledge; their help has proved instrumental at every stage of this research.

Trevor Hill for his guidance and supervision at every stage of the research; without his continued support and direction it would not have been possible.

Craig Morris for his guidance and advice in the thesis, most notably with regard to the statistical analysis component

Mark Graham and GroundTruth for advice and direction and the use of equipment during field work

Umgeni Water for undertaking the laboratory analysis of the water samples; without their assistance it would not have been possible

Steve Terry from Umgeni Water for his on-going advice, assistance and support

Michelle Warburton for providing simulated stream flow data for the rivers under research, the data formed an important component of the research

Staff and colleagues at UKZN for advice and assistance in all facets of the research

Colin Holmes for his dedication and assistance in the field-work component of the research

To family, friends and loved ones; without their support, love, caring and understanding during the research period it would not have been possible

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION

1.1. Introduction

"Water is critical for sustainable development, including environmental integrity and the eradication of poverty and hunger, and is indispensable for human health and well-being" (United Nations, 2003).

Freshwater is vital to all life on earth, be it aquatic or terrestrial (Department of Environmental affairs and Tourism [DEAT], 2006); however water resources and the ecosystems they support are severely threatened and poorly understood (Dudgeon, *et al.,* 2006). Good quality water in adequate supply is central not only to survival on earth but to the functioning of economies and communities (United Nations [UN]-Water, 2011a). Humans have drastically polluted, degraded and altered the natural state of freshwater systems with social, economic and environmental consequences (Dudgeon *et al.,* 2006). Less than one percent of freshwater resources are available for use by humans, yet globally the rate of water usage has increased at twice the rate of population growth placing pressure on valuable and finite resources (UN-Water, 2011b). The United Nations (2011b) have highlighted that by 2025, 1 800 million people will be faced with water scarcity and a staggering two-thirds of the world's population could potentially be under water stressed conditions. Water scarcity occurs when the total amount withdrawn is so great that supplies for human and ecosystems requirements can no longer be met; furthermore scarcity increases as resource quality declines (United Nations Environmental Programme [UNEP], 2011). Access to safe freshwater is regarded as a universal and fundamental human right and the sustainable utilization and management thereof is of global importance (Intergovernmental Panel on Climate Change [IPCC], 2007).

The small percentage of freshwater that is available for human use is declining in quality as a result of human settlements, and industrial and agricultural activities (UN-Water, 2011a). Worldwide, two million tons of human waste is disposed of into water courses every day and in developing countries seventy percent of untreated industrial waste enters freshwater systems (UN-Water, 2011b). Anthropogenic impacts not only affect the quality and quantity of water available for human use, but disrupt the structure of the aquatic ecosystem affecting the ability of organisms to survive while compromising the integrity of the system (Amisah and Coux, 2000). According to the Millennium Ecosystem Assessment, biodiversity in freshwater environments are degraded more than that of any other (UN-Water, 2011a). The pressure of securing quality freshwater resources into the future for purposes of human consumption and aquatic biodiversity conservation is ever increasing (UN-Water, 2011a; Dudgeon *et al.,* 2006; Allan, 2004). Water quality challenges therefore deserve as much priority as issues of quantity and present management challenges of global attention (UN-Water, 2011a).

Freshwater ecosystems provide important resources for economic development, socio-economic well-being and ecosystem functioning, however South Africa's freshwater systems are in poor health with eighty-two percent of main river ecosystems declared as threatened (DEAT, 2009). The state of freshwater resources in South Africa is predominantly as a result of flow modification, alien invasive species and pollution from a multitude of human activities. In addition, land transformation and poor land management surrounding waterways contribute to the decline in system quality (DEAT, 2009). The Department of Environmental Affairs and Tourism (2006) states that water will increasingly become the limiting resource in South Africa, and supply will become a major restriction to the future socio-economic development of the country, in terms of both the amount of water available and the quality of what is available. It is projected that by 2025 South Africa will experience water deficits whereby demand exceeds available supply (DEAT, 2009). Access to potable water and water based sanitation in South Africa is plagued by social, socio-political and economic inequalities, making the balance between managing this scarce resource and rectifying historical social disparities, a complex and dynamic task (Swatuk, 2002).

South Africa is classified as a 'water stressed' country bordering on 'water scarce' (DEAT, 2009), whereby uneven rainfall distribution and external pressures on water resources result in management becoming an increasing priority; while the needs for socio-economic development and sound environmental management need to be balanced simultaneously (DEAT, 2006). To achieve this, it is a priority to understand the impacts development and other land use practices have on water quality and aquatic ecosystem health, and to collect baseline data to inform management initiatives. In the face of on-going pressures to freshwater systems, predominantly through anthropogenic forces, water quality and river health monitoring is of increasing relevance (Malherbe *et al.,* 2010). Furthermore, the lack of baseline data in South Africa on freshwater threats, quality and constraints, further limits management and conservation efforts (Collares-Pereira, 2004). Thorough monitoring of freshwater resources is therefore of increasing management importance to ensure sustainable utilisation and mitigation against emerging threats.

The uMngeni catchment in Kwazulu-Natal is representative of the impacts facing freshwater resources in South Africa, with current and future land use applications threatening the quality and quantity of available resources. The upper uMngeni dominated by Midmar Dam is a key resource unit of the uMngeni, for supplying safe, clean drinking water to the eThekwini, uMgungundlovu and Msunduzi municipalities, with current demand being 268 million litres per day (Ramnath, 2010). Increases in future demand will only place greater pressure on an already pressured water resource. With threats from land use change and urbanisation emerging in this catchment, management can not only focus on future demands with regards to quantity required for domestic consumption, but needs to emphasise the quality of the upper uMngeni resource, due to its immediate influence on Midmar Dam and the cumulative downstream impacts on the lower uMngeni system. Presently, urbanisation poses a potential threat to the quality of the Midmar Dam water resource, predominantly through high density low cost housing. Mpophomeni settlement is one such high density development where a combination of elements ranging from inadequate sewage infrastructure to the lack of solid waste management contributes to negative impacts on water quality of surrounding stream networks and subsequently Midmar Dam. The commissioned Khayalisha social housing project in the same catchment could represent a threat of a similar nature and magnitude already posed by Mpophomeni and could compound water quality threats already present in the catchment.

The research that follows carried out water quality and aquatic ecosystem health monitoring at selected sites to assess the impact of Mpophomeni settlement and other land use practices on water quality entering Midmar Dam, while illustrating the danger of developing high density urban areas in close proximity to water resources in light of the Khayalisha social housing project.

1.2. Aim and objectives

1.2.1. Aim

To undertake water quality assessment and SASS5 bio-monitoring to investigate the impact of Mpophomeni settlement and other land uses on water quality of stream networks draining into Midmar Dam

1.2.2. Objectives

1. Establish sites isolating areas of pollution concern.
2. Assess the impact of Mpophomeni settlement and other land uses on water quality and ecological integrity of the Mthinzima and Gqishi sub-catchments draining into Midmar Dam.
3. Assess the status of water quality entering Midmar Dam from the Khayalisha sub-catchment.
4. Measure, predict and compare nutrient loads entering Midmar Dam from the Mthinzima, Gqishi and Khayalisha sub-catchments.
5. Evaluate the sampling and analysis techniques used.

1.3. Conclusion

Freshwater resources and the ecosystems they support are increasingly pressurised, predominantly by human activity and the need for stringent, integrated management of freshwater resources has reached global significance. South Africa is a 'water stressed' country in which freshwater is becoming a limiting resource, with regards to quantity and resource quality. The uMngeni catchment is of vital importance in terms of KwaZulu-Natal freshwater supply and requires management and conservation from source to mouth. The upper uMngeni is under threat from human related land-based activities such as urban development and agriculture; such impacts must be assessed to understand the affects they have on the water quality of Midmar Dam.

1.4. Thesis structure

The thesis follows a logical progression whereby literature relevant to the topic is critically reviewed and, where appropriate, documented in the thesis. The thesis presents methods applied, whereby the study area and sites are described. Thereafter, the methods of data collection, manipulation and analysis are presented and justified, followed by the presentation of the results and prevailing trends. The results are discussed in the context of the study area and the literature reviewed, followed by the implications of the findings. The conclusion addresses the aim and objectives of the thesis, discussing their achievement, concluding with the implications of the findings, in terms of water quality and ecosystem integrity in the upper uMngeni catchment and the broader scale implications of water resources in South Africa.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The chapter reviews freshwater resources in South Africa with regards to requirement, future demand and supply dynamics, followed by the legal framework that acts to protect freshwater resources, its users and the ecosystems they support. Physical, chemical and biological parameters determining water quality are outlined, followed by the use of biological indicators in water quality and river health assessment. An overview of threats to freshwater resources and the ecosystems they support conclude the chapter.

2.2. Freshwater resources in South Africa

Freshwater is the most essential natural resource to all life on earth (Strydom and King, 2009). South Africa is defined as a water 'stressed country', bordering on 'water scarce' according to the United Nations definitions of the terms (DEAT, 2006). South Africa receives approximately 450 mm of rain per annum however; rainfall distribution within the country is uneven with the eastern and southern regions of the country receiving larger quantities than that of the northern and western regions (DEAT, 2006). The country consists of 19 water management areas and due to the uneven distribution of water resources, a considerable amount of water is transferred between these water management areas to meet freshwater demands (DEAT, 2006). Water transfers involve the movement of freshwater from catchments with good water supply to those with supply deficits (Strydom and King, 2009). The majority of South Africa's water demands are supplied by surface water bodies which include approximately 320 major dams (DEAT, 2006).

2.2.1. Water requirements

Estimated water requirements (DEAT, 2006) suggest that agricultural irrigation accounts for the highest percentage of the total water requirements, followed by urban requirements, rural, mining and bulk industry, power generation and afforestation in descending order (Table 2.1).

Table 2.1: Water requirements (2000) in South Africa

	Irrigation	Urban	Rural	Mining & bulk industry	Power generation	Afforest -ation	Total local require-ments
Total for South Africa(million m^3/annum)	7920	2897	574	755	297	428	12871
% of total	62	23	4	6	2	3	100

(Adapted from DEAT 2006)

Of the 19 water management areas, over half ran at a deficit for the year 2000 with regard to local requirements versus reliable local yield, further illustrating the uneven distribution of water and the inherent risks of generalising with regards to South Africa's water supply. Furthermore, these surpluses and deficits across water management areas do not necessarily balance each other, resulting in dynamic management issues presented to water management agencies (DEAT, 2006).

2.2.2. Future demand

Future water demand is dependent on a number of variables including climate, national economy and population growth, to name a few. Future prediction on potable water requirements are difficult, yet it is certain that with current projections of economic and population growth, water stresses will only increase, presenting further management issues (DEAT, 2006). Water supply and demand imbalances are projected to increase with the resultant inability of supply yields to meet socio-economic development needs and living standard improvements (Strydom and King, 2009). Inter-catchment transfers form a vital component of meeting water demands in a country with imbalanced water distribution, with more than 50 per cent of all water management areas relying on transfers to augment each other's demand and to avoid supply deficits (DEAT, 2006). Future predictions for the year 2025 at 1.5% GDP growth per annum show water deficits of 234 million cubic meters per annum (m^3/annum), while predictions at 4% GDP growth per year show deficits of 2044 million m^3/annum (DEAT, 2006).

2.2.3. Water quality in South Africa

Water related issues in South Africa are not confined to problems of scarcity or issues related to demand and supply. Water pollution poses a major threat to freshwater quality (DEAT, 2009). In South Africa, the primary sources of surface water pollution are domestic and commercial sewage, industrial effluent, acid mine drainage, agricultural run-off containing fertilisers and pesticides and solid waste (DEAT, 2009; DEAT, 1999; Kidd, 2008). Eutrophication of rivers and dams is a major threat through anthropogenic nutrient loading (DEAT, 2009; 1999). Furthermore, a large portion of sewage originating from urban areas is improperly treated prior to discharge, resulting in poor water quality in many densely populated areas (Oberholster and Ashton, 2008).

2.3 Legislative framework in South Africa

South African law covers a number of elements pertaining to the protection of freshwater resources and the aquatic environment and those making use of them. The legislation protects the resources themselves and the users thereof.

2.3.1 The Constitution

The Constitution of the Republic of South Africa (Act. No. 108 of 1996) is the supreme law and cannot be superseded by any other. Among other things the Constitution states that everyone has the right to:

- an environment that is not harmful to their health or well-being; and
- to have the environment protected, for the benefit of present and future generations.

The Constitution places responsibility on local authorities to provide citizens with

- Refuse removal, refuse dumps and solid waste disposal;
- Water and sanitation services;
- Domestic waste-water and sewage disposal; and
- Socio-economic development.

2.3.2 The National Environmental Management Act (NEMA)

The National Environmental Management Act (NEMA) (Act No. 107 of 1998) (Republic of South Africa [RSA] 1998a) provides legislation that ensures everyone has the right to an environment that is not harmful to his or her health and well-being; while protecting, promoting and fulfilling social, economic and environmental rights of everyone and meeting the needs of the previously disadvantaged. The legislation acknowledges that sustainable development must integrate social, economic and environmental factors and that everyone has the right to an environment that is protected for the benefit of present and future generations. The legislation prevents pollution and ecological degradation, promotes conservation, and secures ecologically sustainable development and use of natural resources, while promoting justifiable economic and social development.

2.3.2.1. The National Environmental Management: Waste Act

The National Environmental Management: Waste Act (Act No. 59 of 2008)(RSA, 1998b) provides legislation regulating waste management to protect health and the environment by providing measures to prevent pollution and ecological degradation and secure ecologically sustainable development through norms and standards, licensing and control, regulating waste management activities, while providing remediation of contaminated land. The objectives of the Act are:

a) To protect health, well-being and the environment by providing reasonable measures for

- minimising the consumption of natural resources;
- avoiding and minimising the generation of waste;
- reducing, re-using, recycling and recovering waste;
- treating and safely disposing of waste as a last resort;
- preventing pollution and ecological degradation
- securing ecologically sustainable development while promoting justifiable economic and social development;
- promoting and ensuring the effective delivery of waste services;
- remediating land where contamination presents, or may present, a significant risk of harm to health or the environment; and
- achieving integrated waste management reporting and planning.

b) To ensure that people are aware of the impact of waste on their health, well-being and the environment

c) To secure an environment that is not harmful to health and well-being.

.

2.3.4 The Water Services Act and the Municipal Structures Act

In terms of Section 11 of the Water Services Act (Act No. 108 of 1997) (RSA, 1997), and Sections 84 and 85 of the Municipal Structures Act (Act No. 117 of 1998) (RSA, 1998b), local authorities have a responsibility to provide water supply and sanitation services.

2.3.5 The National Water Act (NWA)

The National Water Act (NWA) (Act No. 36 of 1998) (RSA, 1998c) provides legislation that ensures that both the nation and the nation's water resources are protected, so that they can be used, developed, conserved, managed and controlled in a manner that accounts for the following factors:

- meeting the basic human needs of present and future generations;
- promoting equitable access to water;
- redressing the results of past racial and gender discrimination;
- promoting the efficient, sustainable and beneficial use of water in the public interest;
- facilitating social and economic development;
- providing for growing demand for water use;
- protecting aquatic and associated ecosystems and their biological diversity;
- reducing and preventing pollution and degradation of water resources;
- meeting international obligations;
- promoting dam safety; and
- managing floods and droughts

Water-related legislation in South Africa has the over-arching aim of sustainable use and management of water resources to ensure that sufficient amounts of these scarce resources are available in good quality, to meet the needs of people and the environment into the future (Kidd, 2008).

2.4. Water quality

The term 'water quality' is used to describe the microbiological, physical and chemical properties of water that determine its fitness for a specific use, determined by substances which are either dissolved or suspended in the water (DWAF, 2001). Water of an acceptable quality is essential to the health and survival of all life forms. To understand the effects external pressures have on water resources it is important to understand what constitutes water quality (Strydom and King, 2009). The National Water Act (Act No. 36 of 1998) (RSA, 1998c) defines water quality as:

a) The quantity, pattern, timing, water level and assurance of instream flow;

b) The water quality, including the physical, chemical and biological characteristics of the water;

c) The character and condition of the instream and riparian habitat; and

d) The characteristics, condition and distribution of the aquatic biota.

2.4.1. Physical water quality determinants

Physical water quality properties include determinants such as turbidity, temperature, electrical conductivity, pH, dissolved oxygen and colour, taste and odour (Department of Water Affairs and Forestry [DWAF], 2001).

2.4.1.1. Dissolved oxygen

Oxygen enters the aquatic environment from the atmosphere or as a bi-product of photosynthesis from aquatic plants and phytoplankton and is relatively soluble in water. Saturation solubility is however non-linearly variable with temperature, salinity, atmospheric pressure and other site specific chemical and physical parameters (DWAF, 1996a). Aerobic aquatic organisms depend on the maintenance of sufficient levels of dissolved oxygen (DO) for respiratory requirements (DWAF, 1996a). DO concentrations are a balance between oxygen produced through *in situ* photosynthesis and atmospheric supply, against the amounts used in the aquatic environment by aerobic organisms (Kalff, 2002). "Dissolved oxygen is critical for the survival of aquatic organisms and low DO is known to be a modifying factor of toxicant impacts" (Landman and van den Heuvel, 2003: 4337). DO measurements are represented as milligrams per litre (mg/ℓ) or as percentage of saturation. Concentrations of less than 100% point towards depletion whereas excess or supersaturation of oxygen may indicate eutrophication of a water column (DWAF, 1996a). Systems unaffected by pollution usually display DO concentrations close to saturation; however concentrations will fluctuate on a daily basis according to photosynthetic and respiratory cycles of aquatic biota. DO levels decline in the evenings and reach a minimum at dawn then rise to a maximum by mid-day, whilst seasonal fluctuations may be influenced by temperature and biological productivity (DWAF, 1996a). Decreases in DO will result from re-suspension of anoxic sediments, release of anoxic bottom water from deep water bodies, and the presence of oxidisable organic matter from either natural or unnatural sources (DWAF, 1996a). The ability for organic wastes to deplete DO is measured as biochemical oxygen demand (BOD) and chemical oxygen demand (COD) with COD being frequently used to measure effluent as an indicator of the amount of oxygen required by organisms to degrade organic matter (DWAF, 1996a; Kalff, 2002).

"The amount of suspended material in the water affects the saturation concentration of dissolved oxygen, either chemically, through the oxygen-scavenging attributes of the suspended particles, or physically through reduction of the volume of water available for solution" (DWAF, 1996a: 53). In instances where suspended solids contain a high organic concentration, the subsequent on-site decomposition will deplete DO levels, which may result in concentrations below that suitable to aquatic life during low flow conditions (Bilotta and Brazier, 2008). High water temperatures, along with low DO concentrations, will multiply stress on aquatic organisms. When DO is low the toxicity of substances such as zinc, lead, copper, cyanide, sulphide and ammonia in the water column will increase, resulting in a compound stress response from aquatic biota. DO concentrations will increase through natural atmospheric diffusion and through turbulence in the water column. The impact of DO depletions is dependent on the frequency and duration of the depletion which will, in turn, determine behavioural and physiological stress responses of aquatic organisms (DWAF, 1996a). The sensitivity of organisms such as fish and invertebrates are dependent on the species specific tolerances to fluctuation in DO, and the life and behavioural stages of the organism's development. For instance, juveniles of many aquatic species are vulnerable to depletion in DO concentrations through physiological strain and the subsequent vulnerability to predation and disease due to weakened physiology (DWAF, 1996a). Conversely super-saturated waters can cause gas bubble disease in fish species (Lampert and Sommer, 1997). Super-saturated conditions also hinder green algae species from photosynthesising thus allowing more tolerant species such as blue-green algae to colonise, becoming a nuisance in water bodies (Kalff, 2002).

Minimal allowable values and target water quality ranges (TWQR) are set out by DWAF (1996a) as a guideline for aquatic organism's exposure to DO depletions. Minimal allowable values create boundaries within which the protection of aquatic organisms can be ensured (Table 2.2).

Table 2.2: Target water quality range for dissolved oxygen

TWQR and criteria	Concentration	Condition	Application
Target water quality range	80% - 100% of saturation	06h00 sample or lowest instantaneous concentration recorded in a 24 hour period	Will protect all life stages of most southern African aquatic biota endemic to, or adapted to, aerobic warm water habitats. Always applicable to aquatic ecosystems of high conservation value.
Minimum allowable values	>60% (sub lethal) >40% (lethal)	7-day mean minimum (see data interpretation) 1-day minimum (see data interpretation)	The 7-day mean minimum and the 1-day minimum should apply together. Violation of these minimum values is likely to cause acute toxic effects on aquatic biota.

(DWAF, 1996a)

2.4.1.2. Water temperature

Temperature plays a crucial role in water bodies with regards to chemical reactions and the metabolic rates of organisms (Lushchak, 2011) and is therefore a controlling factor of aquatic species distribution (DWAF, 1996a). "Natural variations in water temperature occur in response to seasonal and diel cycles and organisms use these changes as cues for activities such as migration, emergence and spawning" (DWAF, 1996a : 103). Unnatural perturbations in water temperature can impact severely on aquatic organisms and indeed entire communities. Inland water temperatures in South Africa generally range from 5-30 degrees Celsius and are dependent on a number of variables, including hydrological factors, climate factors and the structural characteristic of the river and catchment. Human induced temperature changes can be brought about by discharge of heated irrigation water, industrial effluent and heated power station effluent, channel and riparian modification, inter-basin transfer and discharges from impoundments (DWAF, 1996a).

Rises in temperature bring about a reduction in dissolved oxygen solubility, decreasing its availability to aquatic organisms. Elevated water temperatures bring about increases in the metabolic rates of organisms thus increasing oxygen demand, ultimately leading to a decrease in supply (DWAF, 1996a). “The toxicity of most substances, and the vulnerability of organisms to these substances, are intensified as water temperature increases” (DWAF, 1996a: 104). Water temperature serves as a key driver in aquatic systems, influencing organism metabolism, growth, feeding, fecundity, emergence and overall survival (Dallas and Ketley, 2011). Aquatic organisms survive under a set of temperature tolerances, temperatures out of this range can hinder their ability to perform natural processes and can ultimately be lethal (Dallas and Ketley, 2011). Severe changes in the natural temperature can result in mass mortality of aquatic biota while less severe changes may result in a shift in community structure (DWAF, 1996a).

2.4.1.3. Electrical Conductivity

The electrical conductivity (EC) of water is a measure of its capacity to conduct an electrical current, as a result of ions such as carbonate, bicarbonate, chloride, sulphate, nitrate, sodium, potassium, calcium and magnesium in solution (DWAF, 1996a). EC is often used as a substitute measure for Total Dissolved Solids (TDS) as the two are directly related (Chapman, 1996). EC of a water body is established by measuring the electrical conductance represented as milli-Siemens per metre (mS/m) (DWAF, 1996a) and is a useful in determining pollution zones (Chapman, 1996).

2.4.1.4. pH (acidity and alkalinity)

pH values represent the amount of hydrogen ion activity in water expressed on a log-scale of 1 - 14. The pH of pure water containing no solutes is 7 at 24 degrees Celsius, at this point the number of H+ and OH- ions are equal and the water is considered electrochemically neutral. pH values in surface waters range between 4 and 11 and South African freshwaters range between 6 and 8 (DWAF, 1996a). pH will vary diurnally and seasonally, the former caused by varying photosynthetic rates in productive systems and the latter caused by the hydrological cycle. Industrial activity generally causes acidification of rivers rather than alkalization; this is as a result of industrial effluent, mine drainage and acid rain from fossil fuel burning. Raised pH values may point towards increased levels of biological activity or productivity in eutrophic systems. In standing waters, extremely elevated rates of photosynthesis, whether natural or anthropogenically induced, can cause high pH values (DWAF, 1996a). pH determines which chemical compounds are available and their relative toxicity in the aquatic environment. Non-toxic ammonium ions (NH_4^+) are the main form in which plants take up nitrogen, however under conditions of high pH (>8) ammonium ions are converted to toxic un-ionised ammonia (NH_3) (DWAF, 1996a). Changes in background pH levels can have chronic effects on aquatic biota which survive under set pH tolerances. Long-term changes will result in a shift in community structure and ecosystem functioning. pH can vary spatially across geographic regions and longitudinal stages of a river course and at various depths (DWAF, 1996a).

2.4.1.5. Suspended solids

Suspended solids (SS) are the mass or concentration of inorganic and organic material, which is held in turbulence suspended by a water column, in the form of particulate matter (DWAF, 1996a). All water bodies carry some degree of natural suspended solids; however anthropogenic forces alter natural concentrations affecting the physical, chemical and biological properties of the water body. Physically, unnatural increases in suspended solids can result in reduced light penetration, affecting primary production, temperature changes and sedimentation of channels and reservoirs (Bilotta and Brazier, 2008). Suspended solids may interfere with feeding mechanisms of filter feeders and gill functioning of fish and feeding efficiency of visual feeders. Suspended solids alter the composition of the substrata, thus changing the structure of aquatic communities due to microhabitat preferences (DWAF, 1996a). Chemically, unnatural increases in suspended solids cause the release of contaminants such as heavy metals, pesticides and nutrients such as phosphorus. Furthermore, if suspended solids have high organic matter content, their decomposition can deplete dissolved oxygen concentrations affecting aquatic biota (Bilotta and Brazier, 2008). Suspended solids increase with rainfall run-off and re-suspension of deposited sediment, governed by the hydrology and geomorphology of a region. Natural suspended solids are comprised of soil particles from land surfaces, through natural erosive processes however, land use practices such as overgrazing, non-contour ploughing, removal of riparian vegetation and forestry increase erosion and thus suspended solids entering waterways. Other anthropogenic sources of suspended solids include sewage discharges, industrial effluents, mining discharges and aquacultural discharges (DWAF, 1996a). DWAF (1996a) has set out target environmental water quality ranges in which aquatic integrity is retained (Table 2.3).

Table 2.3: Target water quality range for suspended solids

All Aquatic Ecosystems	Target Water Quality Range
Background TSS concentrations are < 100 mg/	Any increase in TSS concentrations must be limited to < 10% of the background TSS concentrations at a specific site and time

(DWAF, 1996a)

2.4.2. Chemical water quality determinants

Chemical water quality determinants refer to the chemical compounds dissolved in water, in the form of metallic substances, inorganic non-metallic substances, aggregate organic substances and aggregate inorganic substances (DWAF, 2001).

2.4.2.1. Nitrogen

Inorganic nitrogen refers to all nitrogen compounds including NH_3, NH_4, NO_2 and NO_3 that are present in a water column (DWAF, 1996a) and which play an important role in aquatic ecosystems with regards to nutrient cycling (Kalff, 2002). Ammonia (NH_3) and ammonium (NH_4) are reduced forms of inorganic nitrogen with their relative proportions depending on the water temperature and pH. Nitrite (NO_2) is an intermediate form of nitrogen with nitrate (NO_3) being the end product of the oxidation process of organic nitrogen and ammonia. NO_3 is more stable than NO_2 due to the rapid conversion of NO_2 to NO_3 in the aquatic environment (DWAF, 1996a). Ammonia (NH_3) is a by-product formed by biological degradation of nitrogenous matter and forms an important element of the nitrogen cycle (Batley and Simpson, 2009) and can be present in an un-ionised form (NH_3) and ionised form as ammonium ion (NH_4+). Both of these forms are reduced forms of inorganic nitrogen derived from aerobic and anaerobic decomposition of organic matter (DWAF, 1996a). Ammonia toxicity is directly dependant on the concentrations of un-ionised ammonia (NH_3) as ionised ammonium ion (NH_4+) has little or no toxicity with regards to aquatic biota (Batley and Simpson, 2009). The total Kjeldahl nitrogen (TKN) is a measure of the total ammonia nitrogen plus the total organically bound nitrogen (Chapman, 1996). Ammonia is a common chemical pollutant and a nutrient contributor to eutrophication. Anthropogenic sources of ammonia include effluent containing human or animal wastes, agricultural sources, discharges from industry and atmospheric deposition originating from distillation and combustion of coal (Barimo and Walsh, 2005; DWAF, 1996a). Many commercial fertilisers contain high concentrations of soluble ammonia, If these concentrations exceed the requirement of the plants the excess will be transported by surface flows (natural or irrigation) or leached into aquatic systems (DWAF, 1996a). The toxicity of un-ionised ammonia is affected by water temperature and pH, with an increase in either causing an increase in the relative proportion of un-ionised ammonia in solution thus resulting in increased toxicity. Ammonia toxicity is influenced by dissolved oxygen, carbon dioxide and dissolved solids with toxicity increasing as dissolved oxygen decreases, due to ammonia being oxidised into nitrate in oxygenated systems, thus decreasing toxicity (DWAF, 1996a).

Effluent discharges containing human and animal excrement, agricultural fertilizers and organic industrial wastes contribute to inorganic nitrogen pollution entering aquatic systems (DWAF, 1996a). Nitrogen compounds form a crucial element of the nutrient cycle in aquatic ecosystem, making nutrients available for uptake by plants (Camargo and Alonso, 2006). Ammonification, nitrification, denitrification, and the active uptake of nitrate by organisms are all influenced by temperature, oxygen availability and pH (DWAF, 1996a). Inorganic nitrogen in unimpacted systems is generally low as available nitrogen is taken up as soon as it becomes available. As a result, nitrogen acts as a major limiting factor driving the biodiversity and functioning of an ecosystem (Vitousek *et al.,* 1997).

In South Africa, inorganic nitrogen concentrations are usually below 0.5 milligrams per litre (mg N/ℓ) in unimpacted, systems but may increase to above 5 - 10 mg N/ℓ in enriched waters (DWAF, 1996a). Inorganic nitrogen concentrations below 0.5 mg N/ℓ are considered low enough to prohibit the onset of eutrophication and the rapid growth of nuisance blue-green algae and other aquatic plants. Nitrogen transforming processes are predominantly governed by temperature, pH, oxygen availability and bacterial activity (DWAF, 1996a). In unimpacted, well-oxygenated systems (80-120% saturation) the majority (>80%) of inorganic nitrogen is present as nitrate, with ammonia concentrations typically being below 0.1 mg N/ℓ. Systems affected by effluent discharges containing high ammonia or nitrate concentrations will experience decreases in dissolved oxygen and increases in biological oxygen demand, chemical oxygen demand and pH (DWAF, 1996a). Increases in inorganic nitrogen compounds in freshwater systems can have detrimental effects on the quality of the water resource and the ecological state of the system through alteration of its trophic status (Table 2.4).

Table 2.4: Changes in aquatic systems trophic status associated with an increase in nitrogen concentrations

Average summer inorganic nitrogen concentration (mg N/ℓ)	Effect
< 0.5	Oligotrophic conditions; usually moderate levels of species diversity; usually low productivity systems with rapid nutrient cycling; no nuisance growth of aquatic plants or blue-green algae.
0.5-2.5	Mesotrophic conditions; usually high levels of species diversity; usually productive systems; nuisance growth of aquatic plants and blooms of blue-green algae; algal blooms seldom toxic.
2.5-10	Eutrophic conditions; usually low levels of species diversity; usually highly productive systems, with nuisance growth of aquatic plants and blooms of blue-green algae; algal blooms may include species which are toxic to man, livestock and wildlife.
>10	Hypertrophic conditions; usually very low levels of species diversity; usually very highly productive systems; nuisance growth of aquatic plants and blooms of blue-green algae, often including species which are toxic to man, livestock and wildlife.

(DWAF, 1996a)

2.4.2.2. Total organic carbon

Total organic carbon is a measure of the sum of all forms of organic matter in a water body and consists of dissolved and particulate material. Organic carbon arises from living material in the aquatic environment or as matter enters from the terrestrial environment, and is a constituent of organic wastes and effluents. Total organic carbon can be a useful indicator of unnatural discharges into a water body arising from industrial or sewage sources (Chapman, 1996).

2.4.2.3. Phosphorus

Orthophosphates, polyphosphates, metaphosphates, pyrophosphates and organically bound phosphates are all present in natural water bodies. Of these forms of phosphates, soluble reactive phosphorus (SRP) or orthophosphates are those available for uptake by aquatic biota. Forms of phosphorus are continually changing in a water column due to processes of decomposition and synthesis among organically bound and inorganic oxidised forms of phosphorus. Phosphorus is an essential macronutrient accumulated by many living organisms; in unimpacted systems it is readily taken-up by plant species and converted to cell structures through photosynthetic processes (DWAF, 1996a). Phosphorus is often viewed as the limiting nutrient in inland freshwaters, thus playing an influential role in eutrophication (Srivastava *et al.,* 2009). Natural sources of phosphorus in aquatic systems originate from land, through weathering processes, atmospheric deposition and decomposing organic matter (Kalff, 2002). Phosphorus concentrations in South Africa are rarely high in unimpacted systems with concentrations of between 10 and 50 micrograms per litre (*µ*g P/*ℓ*) being common, including levels as low as 1 *µ*g P/*ℓ* in pristine waters. High levels may result from point source discharges such as domestic and industrial effluents and non-point sources such as urban run-off, atmospheric precipitation and drainage from agricultural land where fertilisers are used (DWAF, 1996a). Increases in phosphorus compounds in freshwater systems have the same effect on system quality as nitrogen through a shift in trophic status (Table 2.5). The effect is however dependent on the form of phosphorus, as not all phosphorus compounds are available for immediate uptake by organisms. Inorganic phosphorus concentrations of less than 5 *µ*g P/*ℓ* are considered to be low enough to limit the nuisance growth of aquatic algae and the onset of eutrophication (DWAF, 1996a).

Table 2.5: Changes in aquatic systems trophic status associated with an increase in phosphorus concentrations

Average summer inorganic phosphorus concentration (µg P/ℓ)	Effect
< 5	Oligotrophic conditions; usually moderate levels of species diversity; usually low productivity systems with rapid nutrient cycling; no nuisance growth of aquatic plants or blue-green algae
5-25	Mesotrophic conditions; usually high levels of species diversity; usually productive systems; nuisance growth of aquatic plants and blooms of blue-green algae; algal blooms seldom toxic.
25-250	Eutrophic conditions; usually low levels of species diversity; usually highly productive systems, with nuisance growth of aquatic plants and blooms of blue-green algae; algal blooms may include species which are toxic to man, livestock and wildlife.
>250	Hypertrophic conditions; usually very low levels of species diversity; usually very highly productive systems; nuisance growth of aquatic plants and blooms of blue-green algae, often including species which are toxic to man, livestock and wildlife.

(DWAF, 1996a)

2.4.3. Microbiological water quality

"Water-related microbial diseases have been a major cause of human misery since time immemorial, and microbial water quality needs to be managed in order to safeguard people from the hazards of drinking contaminated water" (DWAF, 2003: 5).

Microbial water quality refers to the presence or absence of micro-organisms in a water column and is, for the most part, reported as the count of an indicator organism per given volume of water (DWAF, 2003). There are numerous micro-organisms that can potentially contaminate water, as a growing form (vegetative), resting form (spores of fungi and bacteria) or faecal material of human or animal origin (DWAF, 2003). Microbiological pollution can originate from point-source such as discharges of treated and untreated sewage and from non-point sources such as urban and agricultural run off (Kirschner *et al.,* 2009). Faecal matter contains especially high abundances of micro-organisms and requires safe treatment and disposal to avoid water contamination (DWAF, 2003). The use of bacterial indictors of water quality is widely recognised (Noble *et al.,* 2003), their presence and relative abundance point towards sources of contamination (DWAF, 2003). These indicator organisms may not pose a direct threat of disease however their presence may point towards the presence of more hazardous pathogens (Noble *et al.,* 2003).

2.4.3.1. *Escherichia coli (E. coli)*

"Microbiological indicators have been used for decades to monitor faecal pollution of water as well as the possible presence of other microbiological pathogens" (Omar and Barnard, 2010: 172).

Escherichia coli (E. coli) is a faecal bacterium located in the intestinal tracts of homoeothermic animals and is used as an indicator of faecal contamination in water bodies (Yost *et al.,* 2011). This bacterium can be subdivided into three categories, namely commensal, diarrheagenic, and extra-intestinal, of which some are harmless while others can cause intestinal tract disease or infections outside the intestinal tract (Carrero-colon *et al.,* 2011; Omar and Barnard, 2010). The bacterium is common in the natural environment as it forms part of a mammal's intestinal bacterial communities (Table 2.6); however they are commonly detected in systems outside of their hosts where they become indicators of faecal contamination. Since the 1980s *E. coli* has been used extensively as an indicator of faecal contamination for water treatment safety purposes (Carrero-colon *et al.,* 2011). Studies of factors affecting the survival of *E. coli* in natural waters are of interest due to the importance of these microorganisms as indicators of faecal pollution in natural waters (Wcisło and Chrost, 2000). The survival of *E. coli* outside of a host depends on numerous factors including temperature, protozoa grazing, exposure to UV radiation and nutrient availability. Under favourable temperature (15-18 degrees Celsius), nutrient and micro-floral conditions *E. coli* can survive in water from 4-12 weeks (Carrero-colon *et al.,* 2011).

Table 2.6: Concentration of *E. coli* in various hosts

Indicator bacterium	Host	Concentration (CFU/g faeces) [a]
Escherichia coli	Human	10^8
Escherichia coli	Bovine	10^5-10^8
Escherichia coli	Swine	10^7
Escherichia coli	Poultry	10^7-10^8

(Adapted from Yost *et al.,* 2011)

The survival of *E. coli,* and indeed other microorganisms outside of their indigenous habitat, depends upon their ability to tolerate an alien set of biological, physical and chemical conditions (Flint, 1987). Variables such as light, temperature, pH, and toxicity of heavy metals are believed to have a significant impact on bacterial mortality (Harwood *et al.,* 2011). Rainfall is another external variable significantly impacting on the concentrations of *E. coli* in surface waters, predominantly due to overland run-off and the subsequent transport of material containing these bacteria. *E. coli* can be harboured in large quantities in soils along river banks and beaches commonly leaching into waterways and can survive from a couple of days to five months depending on the environmental conditions and the soil type (McElhany and Pillai, 2011).

Faecal contamination of waterways can result in negative environmental impacts originating from a number of sources, namely municipal sewage, livestock, wildlife and urban run-off into surface waters (Harwood *et al.,* 2011). Water with high concentrations of *E. coli* pose public health concerns (Table 2.7) with regards to exposure to human enteric pathogens and the risk of contracting waterborne diseases originating from animals and transmittable to humans (Harwood *et al.,* 2011). Gastroenteritis is a common disease associated with a particular *E. coli* strain, the disease is accompanied by chronic vomiting, watery diarrhoea, fever and stomach cramps. The incubation period is short, lasting 8-48 hours with recovery in healthy individuals being good. Elderly, young and immuno-compromised individuals are those most at risk from gastroenteritis; whereby the disease can become life threatening in some cases (DWAF, 2003).

Table 2.7: Recommended *E. coli* counts for full human recreational contact and associated health implications

***E. coli* range (counts/100mℓ)**	**Effects**
Target Quality Range 0 - 130	A low risk of gastrointestinal illness is indicated for contact recreational water use. This is not expected to exceed a risk of typically < 8 illnesses/1 000 swimmers
130 - 200	A slight risk of gastrointestinal effects among swimmers and bathers may be expected. Negligible effects are expected if these levels occur in isolated instances only
200 - 400	Some risk of gastrointestinal effects exists if geometric mean or median *E. coli* levels are in this range, particularly if this occurs frequently. The risk is minimal if only isolated samples fall in this range. Re-sampling should be conducted if individual results > 400/100 mℓ are recorded
> 400	Risks of health effects associated with contact recreational water use increase as *E. coli* levels increase. The volume of water which needs to be ingested in order to cause ill effects decreases as the *E. coli* density increases. Gastrointestinal illness can be expected to increase

(DWAF, 1996b)

2.5. Aquatic bio-indicators

Aquatic organisms are affected by external forces imposed on the freshwater environment that alter the physical, chemical and biological processes of freshwater systems, with resultant changes in floral and faunal communities (Karr, 1991). Aquatic organisms are effective biological indicators of the quality of the system they inhabit and point towards external pressures impacting on aquatic ecosystems. Measurement of physical and chemical water quality variables alone may neglect the interactions and effects external forces have on localised aquatic biota. Bio-monitoring using aquatic biological communities can contribute to traditional physical, chemical and biological water quality measurements (Karr, 1991). Furthermore spot water quality sampling of streams and rivers will reflect conditions for the time of sampling whereas aquatic biological communities provide insight into conditions preceding sampling, illustrating ecosystem integrity not only water quality at a given point in time (Hooda *et al*., 2000). In South Africa, bio-indicators form the basis of indices such as the South African scoring system version 5 (SASS5) (Dickens and Graham, 2002), Fish Assemblage Integrity Index (FAII) (Kleynhans, 1999), the Macroinvertebrate Response Assessment Index (MIRAI) (Thirion, 2007) and the Fish Response Assessment Index (FRAI) (Kleynhans, 2007).

2.5.1. Aquatic macroinvertebrates

"Aquatic macroinvertebrates have been used to assess the biological integrity of stream ecosystems with relatively good success throughout the world, more commonly than any other biological group" (Thirion, 2007: 1).

The term 'aquatic macroinvertebrates' includes all organisms that do not have vertebra in their anatomical make-up, including arthropods, molluscs and annelids, all inhabiting aquatic environments for all or part of their life cycle (Thirion, 2007). Aquatic invertebrates play crucial roles in aquatic ecosystems including the retention, breakdown and transportation of organic material and exchange energy along trophic levels as predators and prey (Malherbe *et al.,* 2010; Thirion, 2007; Welch, 1992). Aquatic invertebrates are sensitive to physical and chemical changes in the aquatic environment and thus prove useful in inferring the quality or health of an aquatic system (Azrina *et al.,* 2006; Hooda et al, 2000). The distribution and community structure of aquatic invertebrate populations is predominantly determined the physical-chemical tolerances of various species, illustrating their applicability as biological indicators of water quality and river condition (Thirion, 2007). The advantages of using macroinvertebrates as bio-indicators include their widespread distribution, range of ecological requirements, low mobility (Malherbe *et al.,* 2010), range of life cycles, visibility to the naked eye and ease of identification (Dickens and Graham, 2002). Aquatic invertebrates include grazers, detrital feeders and predatory species all forming functional units within the aquatic ecosystem (Welch 1992).

2.5.1.1. Aquatic Invertebrate habitat

"Habitat functions as a temporally and spatially variable physical, chemical, and biological template within which aquatic invertebrates can exist" (Thirion, 2007: 2).

The aquatic habitat is a set of physical, chemical, biological and hydrological variables all interacting over space and time, structuring suitable conditions for the survival of aquatic biota. This includes physical and chemical variables, water velocity, depth and substrate, all of which form interactive roles at various stages of an invertebrates' life cycle (Thirion, 2007). The availability, quality and diversity of aquatic habitats therefore structure the aquatic biotic communities. The survival of any aquatic organism can be hindered by one or a combination of unfavourable environmental conditions that make-up its optimum habitat template (Thirion, 2007). “Suitable environmental conditions and resources (quantity, quality and timing) have to be available in order to sustain a viable long-term population” (Thirion, 2007: 2).

2.6. Threats to freshwater resources

Freshwater ecosystems and the species they support are of the most endangered in the world (Saunders *et al.,* 2002; Dudgeon *et al.,* 2006), as a result of their vulnerability to human activities and environmental change (Vorosmarty *et al.,* 2010). Human activities include overexploitation, water pollution, flow modification, destruction or degradation of natural habitats and the introduction of invasive alien species (Dudgeon *et al.,* 2006). These threats are of concern in terms of both biodiversity conservation and resource management for human consumption, with human activities and the associated impacts, predominantly responsible for the decline in quality of freshwater systems (Table 2.8).

Table 2.8: Human activities responsible for impacts on aquatic ecosystems

Human Activity	Impacts on Aquatic Ecosystem
Population and consumer growth	Increased water demand, increased water diversion, increased cultivation
Infrastructure development (e.g. dams, levees, diversions, weirs etc.)	Loss of ecosystem integrity and river connectivity, alteration of flow rates and flow quantities. Changes in water temperature, nutrient and sediment exchange.
Land conversion and poor land use (e.g. wetland drainage, deforestation)	Loss of ecosystem integrity, ecosystem function and associated good and services. Loss of habitats and associated biodiversity. Alteration in flow patterns and run-off rates.
Overharvesting and overexploitation	Depletion of natural resources and biodiversity. Ecosystem function and structure compromised.
Introduction of exotic species	Elimination of native flora and fauna. Alteration of natural production, nutrient cycling and biodiversity.
Release of chemical and biological pollutants to water, land and air	Pollution of water bodies and associates changes in chemical, physical and biological water quality. Resultant changes in freshwater ecology and ecosystem functioning.
Greenhouse gas emissions inducing climate change	Long-term changes in rainfall, evaporation, transportation, temperature.

(Adapted from Dailey (1997) in Gleick *et al.,* 2001)

Pollution of water resources is a human-induced impact and defined by the National Water Act No. 107 of 1998 (RSA, 1998c) as 'the direct or indirect alteration of the physical, chemical or biological properties of a water resource so as to make it –

a) Less fit for any beneficial purpose for which it may reasonably be expected to be used;

b) Harmful or potentially harmful -

   i) to the welfare, health or safety of human beings;

   ii) to any aquatic or non-aquatic organisms;

   iii) to the resource quality; or

   iv) to property.

Pollutants can enter the aquatic environment from point sources (discrete and defined) or non-point sources (diffuse) and stem from a number of causes, such as surface water pollution originating from agricultural, urban run-off, industries and mining (Strydom and King, 2009). Land cover and land use has a major role to play in water quality, as various activities are associated with different pollutants (Table 2.9) (Hohls *et al.,* 2002).

Table 2.9: primary pollution sources and associated causes

Pollution Source	**Pollution Cause**
Agricultural	Irrigation return flows, fertilizers, pesticides, and run-off from feed lots
Urban	Urban run-off (storm water systems, roads etc., effluent return flows (bacteriological contamination, salts and nutrients)
Industrial	Discharge of chemical substances in watercourse
Mining	Discharge of acids and salts

(Strydom and King, 2009)

The extent and severity to which point and non-point source pollutants affect the environment is dependent on the nature of the source. Some pollution sources have far reaching effects whereas others are localised (Table 2.10).

Table 2.10: Anthropogenic sources of pollution and geographic significance

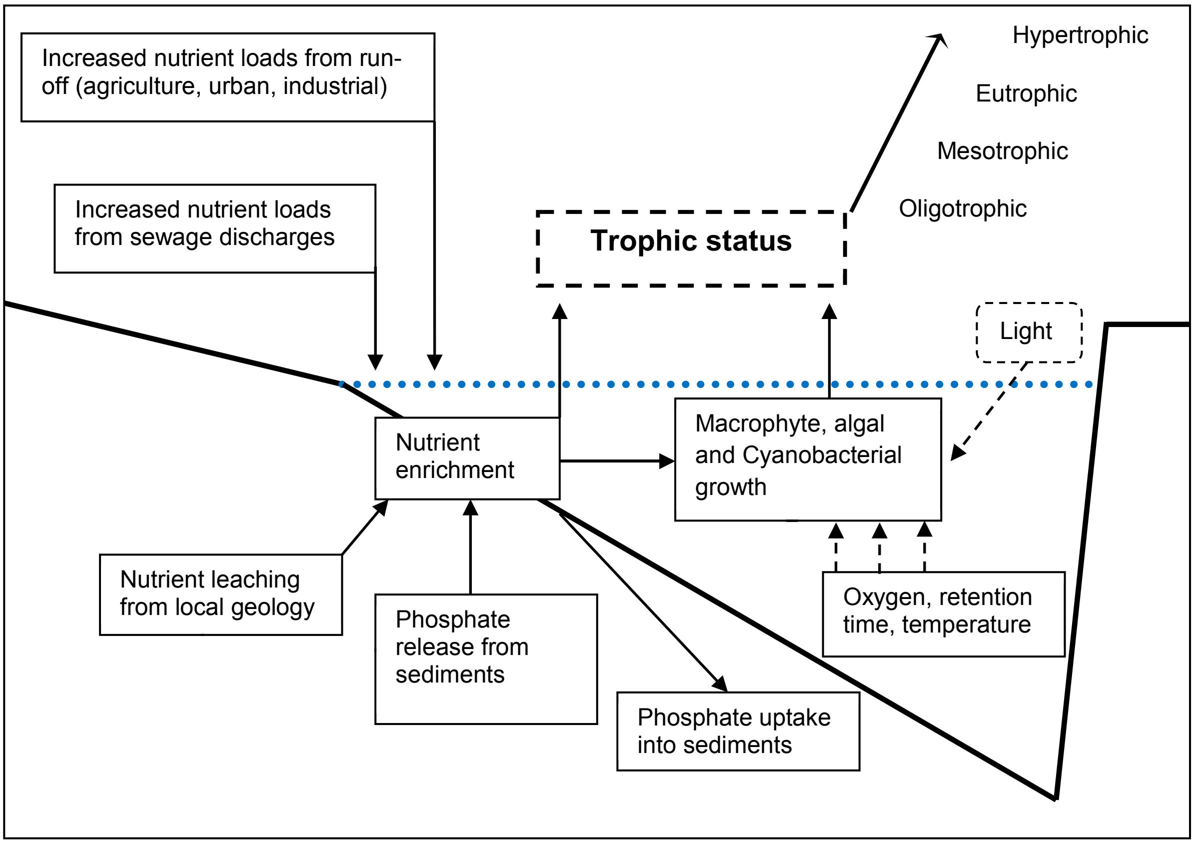
Source	Bacteria	Nutrients	Trace elements	Pesticides/ Herbicides	Industrial Organic micro-pollutants	Oils and greases
Atmosphere		x	xxxG	xxxG	xxxG	
Point sources						
Sewage	xxx	xxx	xxx	x	xxx	
Industrial effluent		x	xxxG		xxxG	xx
Diffuse sources						
Agriculture	xx	xxx	x	xxxG		
Dredging		x	xxx	xx	xxx	x
Navigation and Harbours	x	x	xx		x	xxx
Mixed sources						
Urban run-off and Waste disposal	xx	xx	xxx	xx	xx	xx
Industrial waste Disposal sites		x	xxx	x	xxx	x
X – Low local significance			XXX – High local/regional significance			
XX – Moderate local/regional significance			XXXG – Global significance			

(Chapman, 1996)

As water runs off a land surface it carries with it pollutants associated with the land use practices of the area. This flushing of residues from the land surface is a common form of non-point source pollution, enriching the nearby water systems with various contaminants. Nutrient or sediment loads can calculated using export coefficients, which are presented as the quantity of the parameter per unit area per unit time (kg/ha/annum), which is useful in land use and water quality studies (McFarland and Hauck 2001). Land use therefore has an influential role in determining the physical, chemical and biological nature of the run-off that enters a receiving water body (Tong and Chen, 2002). “Changing land use and land management practices are therefore regarded as one of the main factors in altering the hydrological system, causing changes in run-off, surface water supply yields, as well as the quality of receiving water” (Tong and Chen, 2002: 378).

2.6.1. Eutrophication

Eutrophication refers to the nutrient enrichment of a water body with plant nutrients, most notably nitrogen and phosphorus compounds (Van Ginkel, 2002). Nutrient enrichment is regarded as the most widespread water quality problems impacting freshwater and coastal ecosystems (UN-Water, 2011a). Eutrophication is a natural and gradual process through which lakes age (Van Ginkel, 2002; Oberholster and Ashton, 2008) as they move through a natural succession from one trophic status to the next (low productivity to high). Although the process is natural over a large temporal scale, human activities within catchments have drastically accelerated eutrophication by altering natural biochemical cycling of nutrients (Oberholster and Ashton, 2008). This accelerated form of eutrophication is termed cultural eutrophication and can originate from agricultural and urban run-off and municipal and industrial wastewater effluents (Van Ginkel, 2002; 2011) (Figure 2.1). In freshwater systems, phosphorus is predominantly considered the foremost limiting nutrient in terms of plant growth, although nitrogen plays an important role in terms of primary production in aquatic systems (DWAF, 1996a; Correll, 1998; Camargo and Alonso, 2006). Nutrient enriched systems are presented with an excess of usable plant nutrients which promote the growth of nuisance aquatic plants such as algae (Van Ginkel, 2002) (Figure 2.1).



(Adapted from Van Ginkel, 2011)

Figure 2.1: Process of eutrophication in aquatic systems

This high productivity is accompanied by large bacterial populations and elevated respiration rates, which increase biological oxygen demand resulting in decreased levels of dissolved oxygen (hypoxia or anoxia) (Correll, 1998). The excessive growth of algae as a result of elevated nutrient inputs may cause toxicity in aquatic environments, directly effecting aquatic biota and transferred through trophic levels to terrestrial organisms through bio-accumulation (Table 2. 11) (Camargo and Alonso, 2006). Among the various groups of toxic algae, cyanobacteria, dinoflagellates and diatoms are the most predominant. Cyanobacterial blooms are associated with ample sunlight, warm water temperatures and high nutrient concentrations (phosphate, ammonium, nitrate), conditions easily produced by human activities (Camargo and Alonso, 2006).

Table 2.11: Ecological and toxicological effects of eutrophication on aquatic ecosystems

Ecological and toxicological effects
- Reductions in water column transparency and light availability
- Increased sedimentation of organic matter
- Decreased concentrations of dissolved oxygen (hypoxic or anoxic conditions) in bottom waters and sediments
- Formation of reduced (toxic) chemical compounds in bottom waters and sediments
- Phosphorus releases from sediments that can reinforce eutrophication
- Increased biomass and productivity of phytoplankton
- Shifts in phytoplankton composition to bloom-forming species, some of which may be toxic (e.g., cyanobacteria in freshwaters and Alexandrium dinoflagellates in coastal waters)
- Increased biomass, and changes in productivity and species composition, of freshwater periphyton, being usually favoured filamentous species at the expense of other attached microalgae
- Increased biomass, and changes in productivity and species composition, of freshwater macrophytes, often with proliferation of weeds
- Increased biomass and productivity, and shifts in species composition
- Losses of species diversity in phytoplankton, periphyton, macrophyte and macroalgae communities
- Changes in biomass, productivity and species composition of benthic invertebrates and fish, often with mass mortality events in sensitive populations and reductions in the area of suitable habitat for reproduction
- Losses of species diversity in zooplankton, benthic invertebrates and fish communities
- Alterations in the food web structure of freshwater, estuarine, and coastal marine ecosystems, with ramifying effects on every trophic level

(Adapted form Camargo and Alonso, 2006)

Assessment of a system's susceptibility to eutrophication should involve an assessment of the nitrogen: phosphorus (N: P) ratios (DWAF, 1996a), as a means of understanding the limiting nutrient in a system (Van Ginkel, 2002). In unimpacted systems N : P ratios are typically greater than 25-40:1 (DWAF, 1996a), which indicates phosphorus limitation, a desirable state from a eutrophication perspective (Van Ginkel, 2002). Impacted systems experiencing unnatural nutrient inputs have N: P ratios of less than 10:1, indicating nitrogen limitation, a state less desirable from a eutrophication perspective. At such low N: P ratios nitrogen is likely to be fixed, resulting in additional nitrogen availability in the system (DWAF, 1996a). At N: P ratios of less than 10:1 cyanobacteria are able to fix atmospheric nitrogen promoting their development, posing toxic environmental impacts (Van Ginkel, 2002).

2.7. Conclusion

Freshwater is a vital and finite resource under threat from declining quality and supply deficits predominantly as a result of human related activities and population growth. South Africa is a water-stressed country in which water related services are plagued by inequality and demand for freshwater is ever increasing. South African legislation does protect water resources and the users thereof, while promoting the equal distribution of water and other basic needs. Understanding the determinants of water quality is paramount in ensuring sound freshwater monitoring and management. Water quality is a set of physical, chemical, and biological properties of a water body, which determines its fitness for a specific use. Aquatic bio-indicators can prove to be successful contributors or alternatives to conventional water quality analysis as a means of understanding external forces impacting on the aquatic environment. Threats to freshwater systems are predominantly as a result of human activity and the associated discharge of pollutants into water courses, of which eutrophication through anthropogenic nutrient loading is a major threat.

CHAPTER THREE

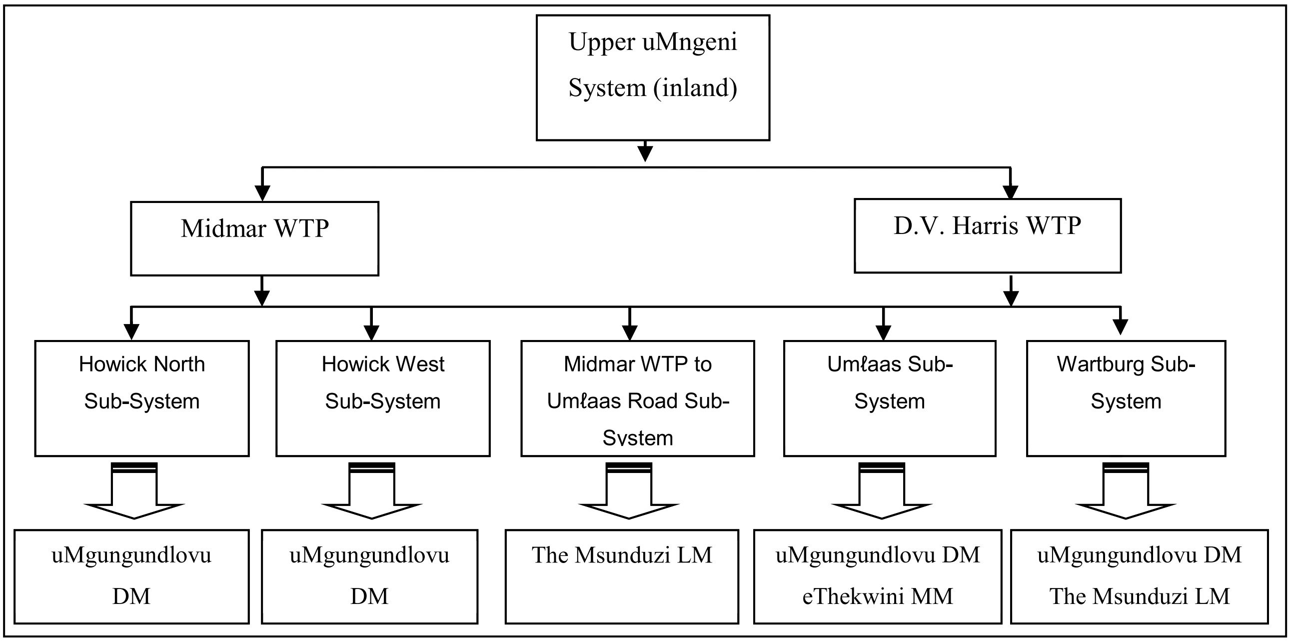
METHODS

3.1 Introduction

The chapter describes the study area and associated biophysical attributes. The specific sites selected for the study are discussed along with reasons for their selection; thereafter, data collection, analysis, and interpretation techniques are presented. Statistical techniques used are presented, with reference to their application and justification of use, followed by the methods of nitrogen to phosphorus ratio and nutrient load calculation.

3.2. Study area

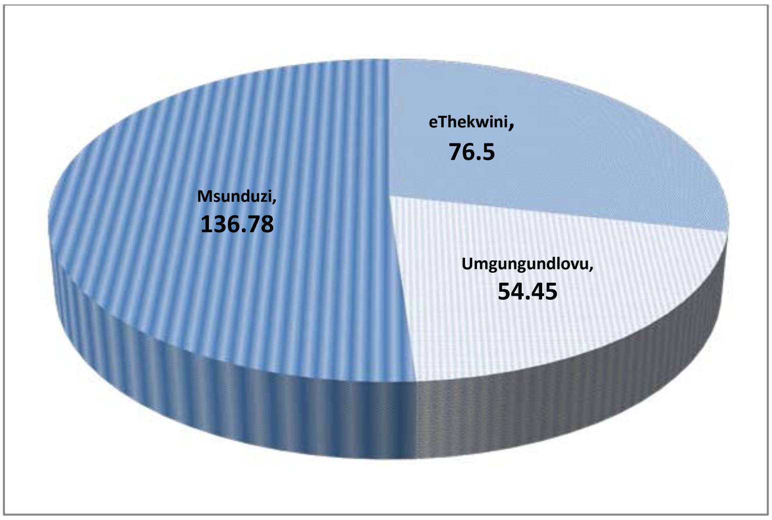
The study region lies within the upper uMngeni catchment draining into Midmar Dam in the KwaZulu-Natal province of South Africa. The Upper uMngeni System, supplies water to various regions within the uMgungundlovu, Msunduzi and eThekwini (Outer West) municipal areas (Figure 3.1) (Ramnath, 2010).



(Ramnath, 2010)

Figure 3.1: Supply reach of the upper uMngeni resource unit (WTP-Water Treatment Plant, LM-Local Municipality, DM-District Municipality)

The upper uMngeni catchment's water supply is dominated by the uMngeni River and its tributaries draining into Midmar Dam, with periodic supplementation from the Mooi-uMngeni transfer scheme (MMTS). Water is treated at two water treatment plants (WTP); Midmar WTP in Howick and DV Harris WTP in Pietermaritzburg. The design capacity of Midmar WTP is 250 megalitres per day (Mℓ/day), with a current (2010) utilisation of 173 Mℓ/day. The Pietermaritzburg WTP has a design capacity of 140 Mℓ/day, with a current utilisation of 80 Mℓ/day in the main plant and an additional 15 Mℓ/day in dissolved air flotation (Ramnath, 2010). Currently water demand from the Upper uMngeni system is approximately 268 Mℓ/day, which is distributed among three major water supply areas, namely the Msunduzi, eThekwini and uMgungundlovu municipalities (Figure 3.2).



(Ramnath, 2010)

Figure 3.2: Water demand from the upper uMngeni resource unit (Mℓ/day)

Due to increases in water demand, eThekwini municipality will require further supply from the upper uMngeni system in the form of a load-shifting operation, which should be fully commissioned by 2013. This operation will place increased pressure on the Upper uMngeni supply region, as areas of eThekwini municipality currently being served by the Lower uMngeni system will be transferred to the Upper system served under gravity from Midmar WTP. This load-shifting will save eThekwini pumping costs whilst increasing available water resources in the Lower uMngeni. This load-shift will however place greater pressure on the Upper uMngeni system and specifically Midmar Dam (Ramnath, 2010). Following the second phase of the Mooi-uMngeni transfer scheme, to be commissioned in 2013, the yield of the uMngeni system at Midmar will increase from 322.5 Mℓ/day to 476.2 Mℓ/day. This increase will not support the requirements of the load-shift to supply eThekwini's increasing demand for any significant time period (Ramnath, 2010). Currently the trophic status of Midmar Dam is mesotrophic, one trophic level above oligotrophic, the most desirable in terms of drinking water supply and one trophic level below eutrophic (Hohls *et al.,* 2002). The freshwater ecosystem health of the upper uMngeni resource unit was most recently assessed according to Table 3.1.

Table 3.1: General health of the upper uMngeni resource unit

Attribute	Description
Water quality	Generally good
Riparian habitats	Degraded by invasive trees such as wattles, gums and pines but are in good condition
Instream habitats	Good, although the large number of farm dams have modified water flow, which in turn affects downstream habitats.
Invertebrates	Close to natural. For most biota the upper reaches of the uMngeni and Lions rivers are in better condition than downstream towards Midmar Dam.
Fish	Good condition but lower down are only in fair condition due to the impact of aliens (trout, carp and bass) and invasive indigenous catfish. For most biota the upper reaches of the uMngeni and Lions Rivers are in better condition than downstream towards Midmar Dam.
Wetlands	Damage to wetlands is widespread. Many of the catchment's wetlands have been destroyed by human activities and the state of the remaining wetlands varies greatly. Some are in good condition while others are degraded and their original functions impaired

(Adapted from Water Research Commission [WRC], 2002)

The study area under research consists of three sub-catchments within the upper uMngeni catchment where mixed land uses, dominated by commercial agriculture, forestry, livestock and urban development are prevalent. The investigation focused on three river networks feeding Midmar Dam, all of the same order, altitudinal belt and ecoregion (Table 3.2).

Table 3.2: Midland Foothill streams ecoregion

Characteristic	Description
Veld Type	41% N gongoni v eld of N atal m ist-belt w ith 30% highland sourveld and Dohne sourveld
Terrain	Low mountains (41%) and undulating hills and lowlands (40%)
Geology	42% shale and siltstones with 35% dolerite & 16% sandstones
Soil	64% well-drained soils, 25% shallow soils on weathering rock
Average Altitude	1 200 m
Average air temp	15°C
Mean annual precipitation	930 mm

(WRC, 2002)

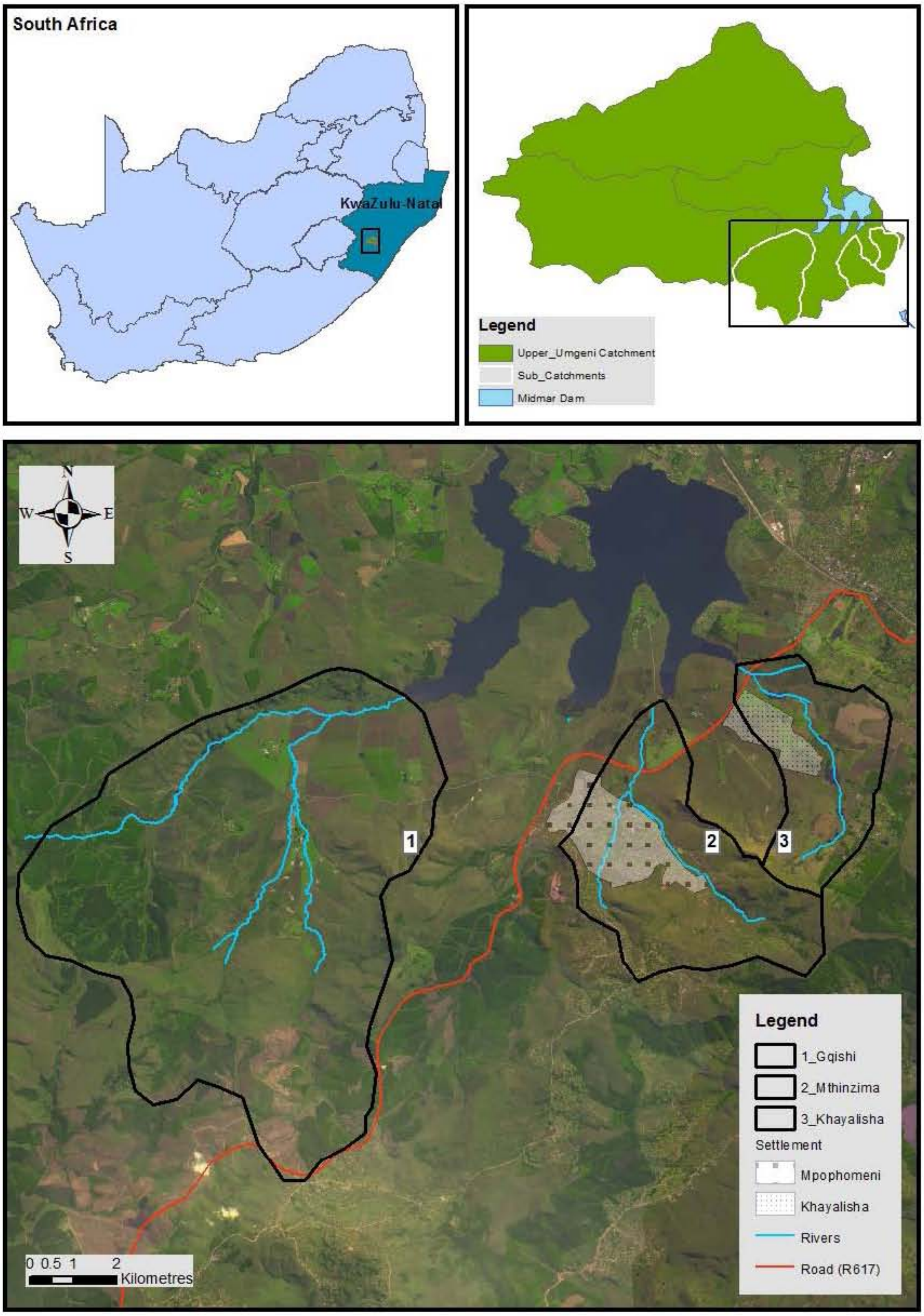


Figure 3.3: Study sub-catchments within the upper uMngeni catchment

3.2.1. Mthinzima sub-catchment

The Mthinzima system has its source in the foothills above the Mpophomeni settlement, a 6 000 unit settlement developed in the 1960s. The river flows adjacent to the settlement where it is met by a tributary that dissects Mpophomeni, after which it flows under the district road (R617), through a wetland system and into Midmar Dam (Figure 3.3). Mpophomeni has a wastewater treatment plant located adjacent to the Mthinzima River which historically treated the settlements domestic wastewater. Observed and potential water quality impacts within Mpophomeni range from solid waste in and around water courses, damaged and inadequate sewage infrastructure, surcharging sewage manholes and river bank erosion, many of which have been published in popular press (Appendix A) (Douman, 2008; Beaver, 2011; Govender, 2011; Radebe, 2012). Analysis of the National Land Cover (NLC) database (South African National Biodiversity Institute [SANBI], 2009) shows that urban development; particularly Mpophomeni settlement forms a large portion of the Mthinzima sub-catchment and indeed the largest high density urban development in the greater upper uMngeni catchment. Although the Mthinzima sub-catchment only forms 1.92% of the greater upper uMngeni catchment, the urban areas comprise 22.32% of development in the upper uMngeni catchment (SANBI, 2009) (Table 3.3).

Table 3.3: Land use in the Mthinzima sub-catchment

Land Cover	Area (ha)	% of Total
Natural	1021	57.4
Cultivated	159	8.9
Degraded	16	0.9
Urban	577	32.4
Water bodies	3	0.2
Plantations	3	0.2
Total	**1776**	
% of total upper uMngeni catchment	1.92	

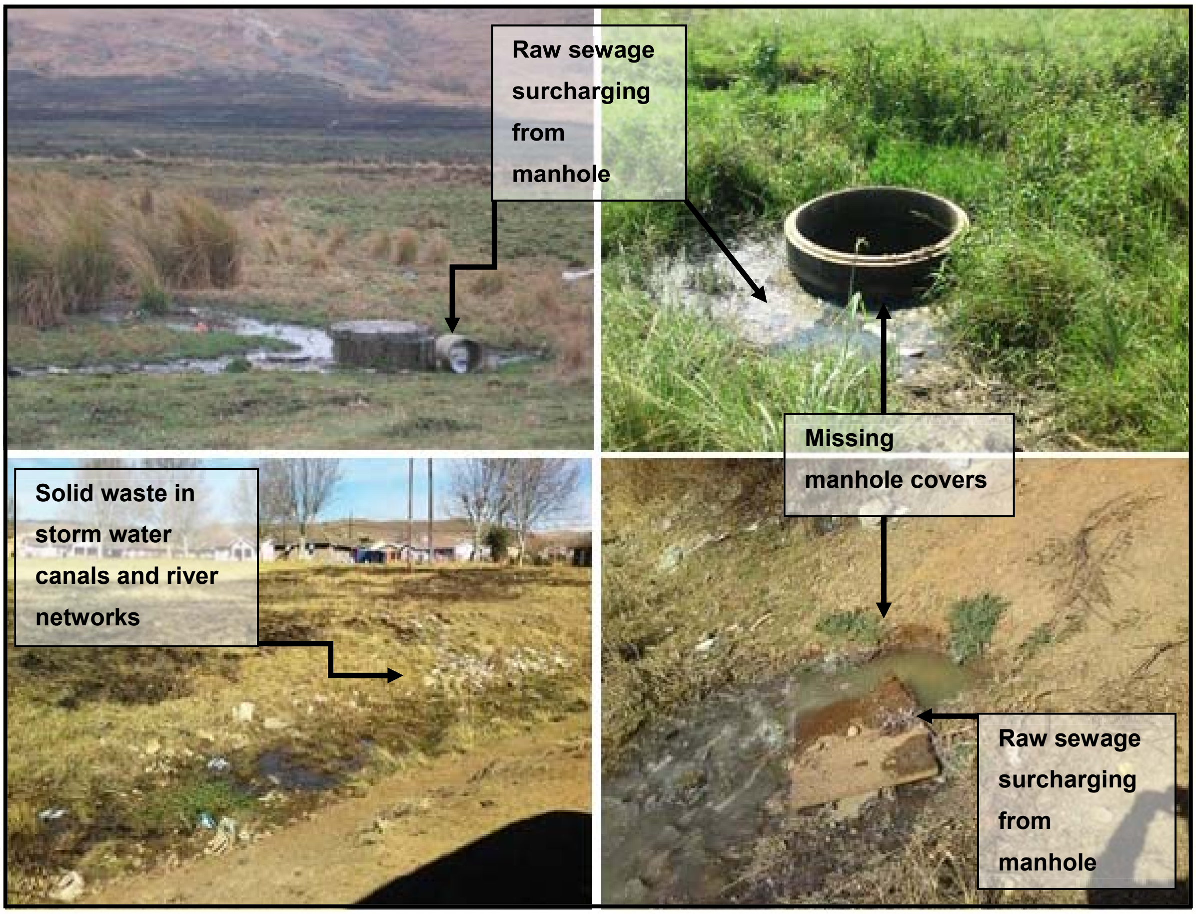


Figure 3.4: Observed potential water quality impacts in Mpophomeni settlement

3.2.2. Khayalisha sub-catchment

The second system is located to the east of the Mthinzima system and is impounded by small dams from source to inflow into Midmar Dam. This system is located adjacent to the commissioned Khayalisha social housing project, a proposed 1 500 unit development (Figure 3.3). The National Land Cover (NLC) database (SANBI, 2009), shows that this sub-catchment is dominated by natural land cover (51%) and cultivation (23%). If the development is fully implemented, urban areas in this sub-catchment will increase from 1.6% to 18.4% and Khayalisha will be the second largest high density urban development in the greater upper uMngeni catchment after Mpophomeni (Table 3.4).

Table 3.4: Land use in the Khayalisha sub-catchment

Land Cover	Area (ha)	% of Total
Natural	543	51.2
Cultivated	317	29.9
Degraded	66	6.2
Urban	17	1.6
Water bodies	43	4.1
Plantations	74	7
Total	**1060**	
% of total upper uMngeni catchment	1.15	

The Khayalisha social housing project was commissioned with the intention to relocate informal settlers from areas in Howick. EIA-5349 of the Khayalisha social housing project stipulated (ROD 10. 10) that the Mpophomeni wastewater treatment plant was to be upgraded. The plant was decommissioned in 1999 and raw sewage generated by the settlement was pumped to Howick wastewater treatment plant for treatment (Terry, 2011, pers. comm). The R30 million upgrade was to be launched by the end of 2008 to solve sewage issues at Mpophomeni and relieve pressures imposed by new housing developments such as Khayalisha (Appendix A) (Naidoo, 2008). Mpophomeni would then treat its own sewage instead of piping it to Howick and the sewage generated by the new Khayalisha development would be piped to Howick for treatment. The Howick plant is due for upgrade due to underperformance and has run between 18% and 63% compliant between 2003 and 2007 (Umgeni Water, 2010). The development of Khayalisha has begun without the commencement of either the Mpophomeni or Howick wastewater treatment plant upgrades.

3.2.3. Gqishi sub-catchment

The Gqishi River system is located to the west of the Mthinzima system. The upper catchment is dominated by forestry, thereafter proceeding through areas of mixed agriculture and livestock production where it is met by a tributary that dissects areas of agriculture before entering Midmar Dam. The system is impounded by three small dams in its upper, middle and lower reaches on its path to Midmar Dam (Figure 3.3). According to the National Land Cover (NLC) database (SANBI, 2009) the sub-catchment is dominated by natural land cover (64%), plantations (21%), and cultivation (15%) (Table 3.5).

Table 3.5: Land use in the Gqishi sub-catchment

Land cover	Area (ha)	% of Total
Natural	3863	63.9
Cultivated	884	14.6
Degraded	2	0.03
Urban	42	0.7
Water bodies	18	0.3
Plantations	1239	20.5
Total	**6048.00**	
% of total upper uMngeni catchment	6.54	

3.3. Study sites

Nine sites were selected for physical, chemical and biological water quality monitoring, of which six were SASS5 bio-monitoring sites (Figure 3.5). Sites were located in the upper, middle and lower reaches of the respective systems, based on accessibility and ability of the site to isolate areas of potential pollution contamination associated with changes in land use. It was also ensured that SASS5 sites had comparable bio-tope availability, quality and diversity, thus ensuring a similar habitat template at each site.

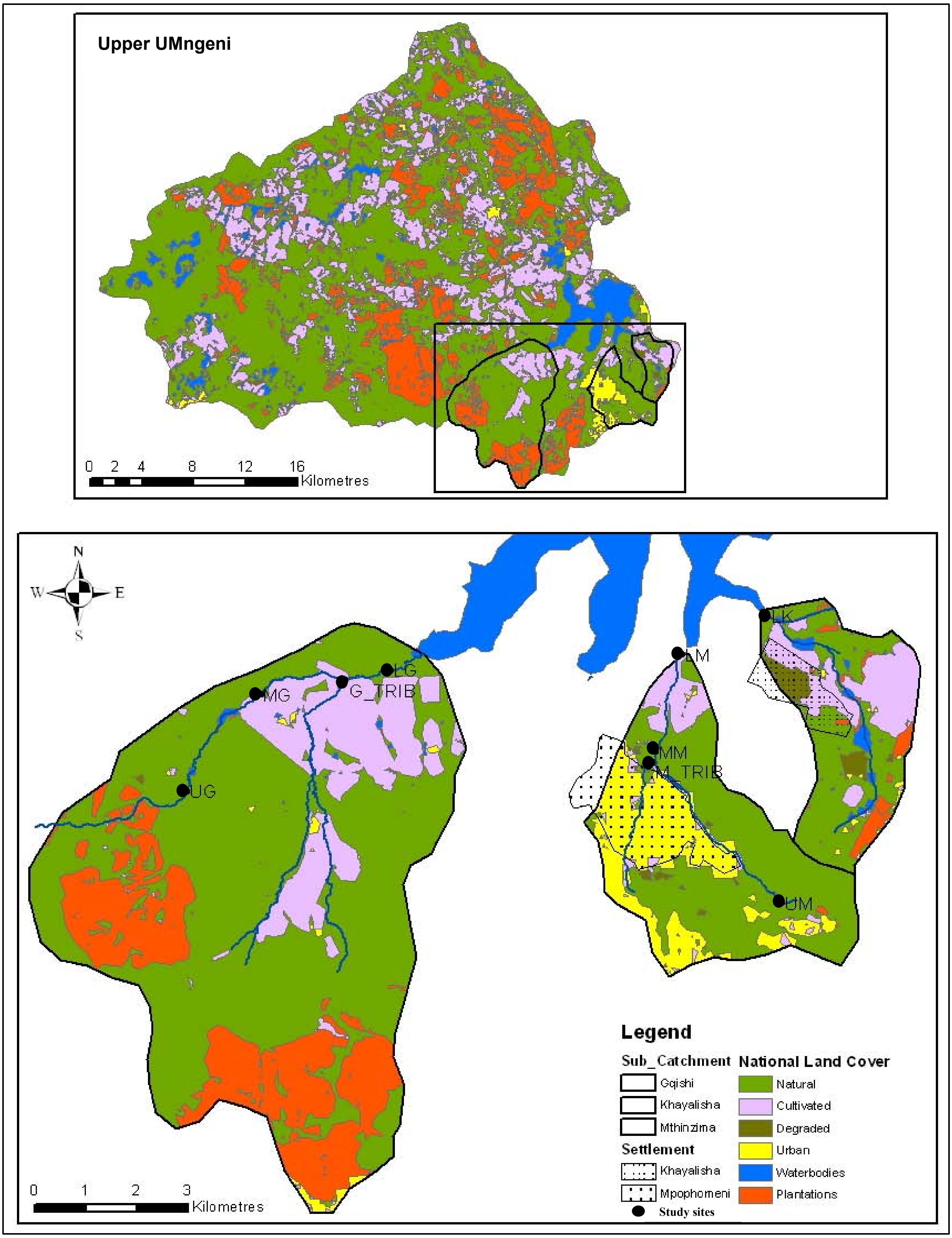


Figure 3.5: Land cover and study sites in the three sub-catchments

3.3.1. Upper Mthinzima (UM)

Located in the upper reaches of the Mthinzima River prior to it flowing adjacent to Mpophomeni settlement. This site is in a relatively undisturbed area surrounded by low density peri-urban/rural settlement (SANBI, 2009) (Figure 3.5). The site was selected to understand the status of the system with regards to water quality and ecological health before encountering any impacts associated with the settlement downstream. The site therefore acts as a reference point against which sites downstream can be compared. The site is not intended to represent local unimpacted reference conditions but to represent conditions prevailing in the Mthinzima system without the impacts associated with Mpophomeni settlement.

3.3.2. Mthinzima tributary (M-trib)

Located on a tributary of the Mthinzima River that dissects Mpophomeni settlement before entering the main Mthinzima channel (Figure 3.5). The site was established to assess its contribution to water quality of the Mthinzima system and SASS5 was not carried out at this site (Table 3.6).

3.3.3. Middle Mthinzima (MM)

Located in the middle reaches of the Mthinzima River below the Mpophomeni settlement, in areas of natural land cover (SANBI, 2009) (Figure 3.5). This site was selected to assess the impact of the settlement on water quality and ecological health by accounting for pollutant inputs between upper Mthinzima and this point. The site is located downstream of Mthinzima tributary thus accounting for the cumulative impacts of Mpophomeni settlement including the main channel and tributary.

3.3.4. Lower Mthinzima (LM)

Located in the lower reaches of the Mthinzima River prior to it entering Midmar Dam (Figure 3.5). This site was selected to assess water quality and nutrient loads entering the Midmar Dam considering upstream impacts associated with the settlement.

3.3.5. Lower Khayalisha (LK)

Located in the lower reaches of the river system draining the Khayalisha development area (Figure 3.5), this is the only site sampled in this system, and serves as a water quality monitoring site and not a SASS5 site (Table 3.6), with the intention of assessing the current status of water quality and nutrient loads entering Midmar Dam from this sub-catchment. The site was selected to compare current conditions at this site to that of lower Mthinzima and highlight the consequences associated with developing high density settlements adjacent to water courses.

3.3.6. Upper Gqishi (UG)

Located in the upper reaches of the Gqishi River in a forested land use (Figure 3.5), this site allows for a comparison with upper Mthinzima and between downstream sites in the Gqishi, located in commercial agriculture. Although the land cover is categorised as natural (Figure 3.5) forestry does extend around the site.

3.3.7. Middle Gqishi (MG)

Located in the middle reaches of the Gqishi River where the land cover is in transition to commercial cultivation (Figure 3.5). This site was selected to compare with upper Gqishi to illustrate changes in water quality as land use changes along the river gradient.

3.3.8. Gqishi tributary (G-trib)

Located on a tributary of the Gqishi River, prior to it entering the Gqishi main channel (Figure 3.5), this site was selected to assess the water quality inputs from this region of the Gqishi sub-catchment, where commercial agriculture is prevalent, and SASS5 was not carried out (Table 3.6).

3.3.9. Lower Gqishi (LG)

Located in the lower reaches of the Gqishi River before entering Midmar Dam (Figure 3.5), this site was selected to assess water quality and nutrient loads entering Midmar Dam considering upstream land use. The site also chosen for comparison with lower Khayalisha and lower Mthinzima to highlight differences in water quality and nutrient loads associated with land use practices.

3.4. Data collection

Sampling was conducted at bi-monthly intervals starting in October of 2010 and concluding in July of 2011 (i.e. five sample periods) to account for seasonal variability. Chemical, physical and biological parameters were sampled at the same sites at the same sampling frequency to ensure consistency over the sampling period.

3.4.1. Water quality

Water quality data falls within three categories, namely chemical, physical and microbiological (Table 3.6); Data within these categories required different collection and processing techniques.

3.4.1.1. Physical and chemical samples

Water samples for chemical analysis were collected in 2ℓ plastic bottles in accordance with the Umgeni Water sampling protocol (Terry, 2011, pers. comm) (Table 3.6). Samples were placed in a cooler on ice prior to delivery to Umgeni Water for laboratory analysis. *In situ* physical water parameters were measured and recorded using a Ysi handheld water meter (Table 3. 6). The probe was placed under the water and allowed to stabilise before recordings were taken.

3.4.1.2. Microbiological samples

Microbiological water samples were collected to measure *E. coli* concentrations (Table 3.6). Water samples for microbiological analysis were collected in 500mℓ sealed/sterilised plastic bottles in accordance with the Umgeni Water sampling protocol (Terry, 2011, pers. comm). Sample bottles were placed in a cooler on ice prior to delivery to Umgeni Water for laboratory analysis.

Table 3.6: Physical, chemical and biological variables sampled

	Site	UM	MM	M-trib	LM	LK	UG	MG	G-trib	LG
Chemical	NH_3 (mg N/ℓ)	✓	✓	✓	✓	✓	✓	✓	✓	✓
	NO_2 (mg N/ℓ)	✓	✓	✓	✓	✓	✓	✓	✓	✓
	NO_3 (mg N/ℓ)	✓	✓	✓	✓	✓	✓	✓	✓	✓
	TKN (mg N/ℓ)	✓	✓	✓	✓	✓	✓	✓	✓	✓
	TP (*µ*g P/ℓ)	✓	✓	✓	✓	✓	✓	✓	✓	✓
	SRP (*µ*g P/ℓ)	✓	✓	✓	✓	✓	✓	✓	✓	✓
	TOC (mg C/ℓ)	✓	✓	✓	✓	✓	✓	✓	✓	✓
Bio	*E. coli* (count/100mℓ)	✓	✓	✓	✓	✓	✓	✓	✓	✓
	SASS5	✓	✓	×	✓	×	✓	✓	×	✓
Physical	pH	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Temperature (°C)	✓	✓	✓	✓	✓	✓	✓	✓	✓
	SS (mg /ℓ)	✓	✓	✓	✓	✓	✓	✓	✓	✓
	DO (% saturation)	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Conductivity(mS/m)	✓	✓	✓	✓	✓	✓	✓	✓	✓

NH_3 - Ammonia
NO_2 - Nitrite
NO_3 - Nitrate
TP - Total Phosphorus
SRP – Soluble Reactive Phosphorus
TKN - Total Kjeldahl Nitrogen
TOC – Total Organic Carbon
E. coli - Escherichia coli
SASS5 – South African Scoring System (version 5)
SS – Suspended Solids
DO – Dissolved Oxygen

3.5. SASS5: The South African Scoring System Version 5

The South African Scoring System is a biotic index originally developed by Chutter (1994; 1998) and refined by Dickens and Graham (2002) to produce its current version SASS5. The system is a rapid bio-assessment method for determining the health or condition of rivers based on aquatic macroinvertebrate communities. It can be applied to river health and water quality monitoring (Dickens and Graham, 2002), and to gauge the ecological state of aquatic ecosystems (Thirion, 2007). The system makes use of sensitivity scores assigned to macroinvertebrates at family level. The scores range on a scale from 1 to 15, with 1 assigned to tolerant taxa with low sensitivity to changes in water quality and 15 being taxa that are intolerant to poor water quality and highly sensitivity to fluctuations thereof. The SASS5 methodology has undergone field testing and is used extensively in South Africa (Dallas, 1997; Vos *et al.,* 2002).

Site selection is important when using SASS5 as results are positively influenced when a diversity of aquatic habitats are sampled, although habitat poor rivers produce valuable results. Data cannot be interpreted independently but must be viewed in light of habitat availability, quality and diversity, and overall ecoregion and season (Dickens and Graham, 2002). Biotopes fall into three broad categories, namely vegetation, stones and GSM (gravel, sand and mud) which are further subdivided (Table 3.7).

Table 3.7: SASS5 biotope groups

SASS Biotopes	Abbr.	Description
Stones in current	SIC	Stones in flowing water, may include bedrock
Stones out of current	SOOC	Stones out of any perceptible current (with visible silt seen accumulating on stone surfaces), may include bedrock
Marginal vegetation in current	MV-IC	Emerged and submerged vegetation in fast current, at the river's edge or on the edge of the in-channel islands
Marginal vegetation out of current	MV-OC	Emerged and submerged vegetation out of any perceptible current, at the river's edge or on the edge of the in-channel islands
Aquatic vegetation	AQV	Submerged or partially submerged vegetation within the channel, normally in flowing water
Gravel	G	Stones <2cm in diameter
Sand	S	Sand grains >2mm in diameter
Silt/Mud/Clay	M	Particles <0.06mm in diameter

(Dallas, 2005)

The operator scores the taxa identified under each biotope group by ticking its presence on the score sheet under the appropriate biotope. Abundances of identified taxa are noted using a 1 for one specimen present, an 'A' for 2-10, a 'B' for 10-100, a 'C' for 100-1 000 and finally a 'D' for >1 000 specimens. SASS5 scores can be produced on-site or preserved for laboratory analysis (Dickens and Graham, 2002). The system makes use of three indices namely the SASS5 score, number of taxa (No. Taxa) and average score per taxa (ASPT). The SASS5 score is calculated by totalling the individual scores assigned to the respective invertebrate families, without duplication if the family occurs at two or more biotopes. The number of taxa is the total number of different families collected which is used to calculate the ASPT by dividing the SASS5 score by the number of taxa. For taxa that require the number of species to be recorded (Baetidae and Hydropsychidae), the total column must only show the total number of species per site, e.g. a single species A may be present in the Veg biotope and single species B may be present SIC and the SOC biotope, the total column must reflect two species without duplication if the species was present in more than one biotope (Appendix B) (Dickens and Graham, 2002).

Invertebrates were collected in accordance with the SASS5 protocol (Dickens and Graham, 2002) at available biotopes, for each site. A standard SASS5 net of 30 x 30 cm with a 1 000 *µ*m mesh was used along with waders and a stopwatch. At polluted sites where faecal contamination was prevalent, face masks, gloves, goggles and ear plugs were used to avoid contact with water. Stones in current (SIC) were sampled for two to five minutes and stones out of current (SOOC) and bedrock were sampled for one minute. The 'kick method' was used to undertake this sampling, whereby the net is placed downstream of the field technician's feet and the substrata disturbed dislodging invertebrates and allowing them to flow into the net. Two metres of marginal vegetation in and out of current was swept and 1m^2 of gravel sand and mud was swept and stirred. SASS5 samples were taken in close proximity to water quality samples to ensure accurate representation of the water quality conditions under which invertebrates occurred. Samples from the three biotope groups (stones, vegetation and GSM) were analysed and scored on the SASS score sheet (Appendix B).

3.6. IHAS: Invertebrate Habitat Assessment System

A habitat assessment evaluates a set of variables which collectively make-up conditions in which invertebrates can exist. Invertebrates have evolved to survive in a particular suite of conditions making it essential to assess the quality, diversity and availability of aquatic habitats when making deductions regarding aquatic invertebrate communities (Kleynhans *et al.,* 2005). IHAS is a habitat assessment technique developed by McMillan (1998) used to collect habitat information when sampling aquatic invertebrates. IHAS assesses the SASS5 biotopes sampled and the details thereof and is represented as a score or percentage (Dallas, 2005). It has been recognised that IHAS (McMillan, 1998) does require refinement; however as an interim measure it has been modified for continued use (Kleynhans *et al.,* 2005; Dallas, 2005). Data gathered regarding invertebrate communities (i.e. SASS5 scores) were interpreted in conjunction with IHAS results to account for changes or differences brought about by changes in the aquatic habitat (Thirion, 2007). IHAS score sheets were filled out on-site following the collection of the SASS5 samples. IHAS scores the availability, diversity and quality of the SASS5 site sampled based on the biotopes sampled. It was however ensured that during the site selection, sites represented all three biotope groups (stones, veg, GSM), at each site and every sample period to ensure consistency and comparability across sites.

3.7. Statistical analysis

Multivariate techniques were chosen to analyze the data due to the size of the dataset and the interrelatedness of the variables. "The multivariate treatment of data is widely used to characterise and evaluate surface and freshwater quality and it is useful for evidencing temporal and spatial variations caused by natural and anthropogenic factors linked to seasonality" (Singh *et al.,* 2004: 3981).

3.7.1. Principle component analysis

Principal component analysis (PCA) is a multivariate analysis technique applied to large data sets with numerous interrelated variables with the goal of extracting key information from the data set, while creating new orthogonal values known as principle components (Abdi and Williams, 2010). Thus, the dimensionality of the data set is reduced while retaining a maximum amount of variability within the data set (Singh *et al.,* 2004). These are then displayed as a pattern of similarity in the variables as points on a graph (Abdi and Williams, 2010).

Physical and chemical data sets were $\log_{10}$ transformed to reduce skewness as not all variables represented normal distributions. pH, dissolved oxygen and temperature were not log transformed as these variables displayed a normal distribution. A standardised PCA was performed on all physical and chemical water quality variables. Invertebrate data including SASS5 score, number of taxa and ASPT and *E. coli* data were represented along the PC1 axis indicating biological changes along PC1.

3.7.2. Non-metric multidimensional scaling

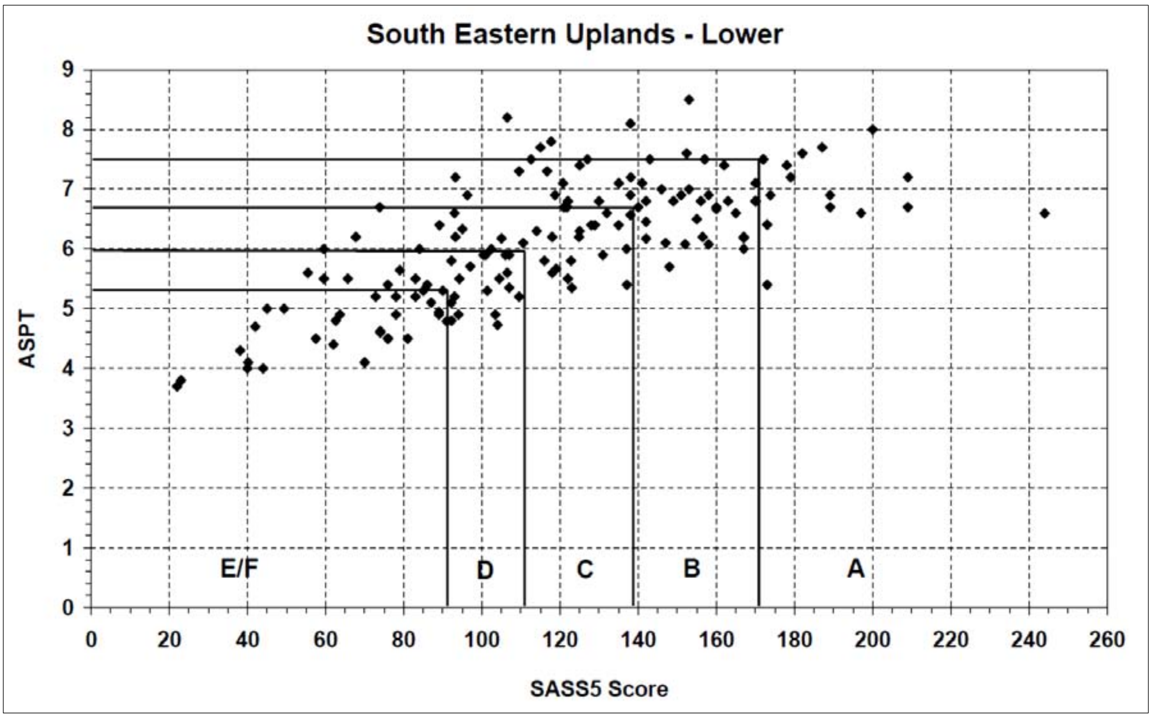
Non-metric multidimensional scaling (NMS) is a method of data analysis that constructs a spatial representation of a set of elements on the basis of a table of 'proximities' that define the relations between the elements (Young *et al.,* 1995). NMS was conducted on invertebrate presence/absence data based on Sørensen's distance metric to generate dissimilarities between sites. Sites representing close spatial proximity are regarded as similar in taxa composition (Laurance *et al*., 2002). NMS was executed using Canoco 4.5 and Canocodraw 4.1 software (ter Braak and Šmilauer, 1997).

3.7.3. Cluster analysis

Cluster analysis is a broad term collectively given to a number of techniques used to create classification within a dataset by empirically forming groups (clusters) of similar entities (Aldendefer and Blashfield, 1984). The dataset is summarised into a set of groups while retaining important patters in similarity and dissimilarity (Everitt *et al.,* 2011). Hierarchical algorithmic clustering produces a graphical output known as a dendrogram illustrating the underlying grouping of patterns, while illustrating the similarity levels at which groupings differ (Abonyi and Feil, 2007). Agglomerative cluster dendrogram (using average linking algorithm) based on Sørensen's distance for presence of families was undertaken on invertebrate data based on their presence at each site. The Agglomerative cluster dendrogram was produced using PRIMER 6 (PRIMER, 2009).

3.8. Water quality and SASS5 interpretation guidelines

Water quality variables were analysed in terms of 'Target water quality ranges' set out by the Department of Water Affairs and Forestry (DWAF, 1996a). SASS5 data were compared to reference conditions in the relevant ecoregion as set out by Dallas (2007) in South African scoring system (SASS) data interpretation guidelines. The study area fell within the South Eastern Uplands-Lower ecoregion, which was used for interpretation (Figure 3.6). Interpretation makes use of a SASS5 score and the ASPT, whereby if either of the metrics falls within the band value, the site will be in that biological band (Figure 3.6; Table 3.8) (Dallas, 2007).



(Dallas, 2007)

Figure 3.6: Reference conditions for South East Uplands - Lower

Table 3.8: Ecological categories for interpreting SASS5 data

Ecological Category	Ecological Category Name	Description
A	Natural	Unmodified natural
B	Good	Largely natural with few modifications
C	Fair	Moderately modified
D	Poor	Largely modified
E/F	Seriously Modified/ Critically Modified	Seriously modified/Critically modified

(Dallas, 2007)

3.9. Nutrients

Nutrient data refers to nitrogen and phosphorus compounds measured and used to calculate nitrogen to phosphorus ratios and nutrient loads entering Midmar Dam.

3.9.1. Nitrogen to phosphorus ratios

By calculating the nitrogen: phosphorus (N: P) ratios, it could be established which of the nutrient compounds were the limiting nutrients in the respective systems and this could provide insight into the potential concern of eutrophication. From a eutrophication perspective, phosphorus limitation (N: P of 25-40: 1) is desirable whereas nitrogen limitation (N: P of > 10:1) is of increasing eutrophication concern (DWAF, 1996a; Van Ginkel, 2002). Mean total nitrogen and mean total phosphorus concentrations over the five sample periods were used for calculating the overall N: P ratios for the three systems for the study period.

3.9.2. Nutrient loading

Nutrient loads at Midmar inflow sites were calculated using simulated stream flow data generated by Warburton *et al.,* (2010). Simulated flow data did not cover the sample period (2010 - 2011) therefore simulated mean daily flow (M^3/day) from 1990 - 1999 was calculated and converted to litres per day. Mean nutrient concentrations for ammonia (NH_3), nitrate (NO_3), total phosphorus (TP) and soluble reactive phosphorus (SRP) were standardised to milligrams per litre (mg/ℓ) and multiplied by mean daily flow (ℓ/day) to generate daily nutrient loading. Daily loads were multiplied by 365 and converted to kilograms (kg's) to generate nutrient loads (kg/annum). Loads were analysed per catchment and assessed based on land use and load per hectare (ha).

Simulated flow data for the Khayalisha sub-catchment was unavailable and flow was generated based on the simulated flow of the Mthinzima and Gqishi sub-catchments, by means of calculating a factor using catchment size and simulated flow, which could be applied to the Khayalisha sub-catchment. The factor calculated for catchment size and simulated flow for the Mthinzima and Gqishi were comparable and thus a mean between the two was calculated and applied to the Khayalisha sub-catchment.

3.10. Conclusion

The upper uMngeni catchment drains into Midmar Dam, a principle water resource supplying water to the uMgungundlovu, Msunduzi and eThekwini municipal areas. The resource is under pressure from domestic demand which is projected to increase. The three researched sub-catchments all drain into Midmar Dam and are characterised by land uses, ranging from natural to urban, forestry and agriculture. Study sites were strategically located in the respective sub-catchments to isolate pollution zones and suggest sources of inputs from land-based activities. Physical, chemical and biological water quality parameters were assessed alongside the use of SASS5 to understand the drivers of water quality in the respective systems. Nitrogen to phosphorus ratios and nutrient loads were calculated to assess the eutrophication vulnerability of Midmar Dam. The multi-metric approach to analysis and interpretation included various methods of displaying and presenting data, to generate a broad understanding of the water quality and related ecosystem effects of land-based activities in the upper uMngeni.

CHAPTER FOUR

RESULTS

4.1. Introduction

The chapter presents graphical summaries of the physical and chemical water quality variables and an overview of trends (section 4.2) using mean values over the five sampling periods to illustrate trends between sites (Appendix C). Data for lower Khayalisha (LK) on May 2011 are not available due to logistical reasons and means were calculated excluding this data. Seasonal biological water quality (*E. coli*) (section 4.3), macroinvertebrate data and the SASS5 related indices (SASS5 score, number of taxa and ASPT) are presented (section 4.4). Following the descriptive section, multivariate results are presented in both graphical and tabular form, including physical-chemical principle component analysis (PCA) and sites seasonal trajectories along the PCA (section 4.4.1). SASS5 score, number of taxa, ASPT and *E. coli* are displayed along the PC1 axis to assess their relationships (section 4.5.2 and 4.5.3). Seasonal trajectories from the non-metric multidimensional scaling (NMS) for macroinvertebrate families are presented along with the prevalence of families across the NMS plot as are SASS5 scores, number of taxa, ASPT, *E. coli* and PC1 and PC2 (section 4.5.3). Agglomerative cluster dendrogram results are displayed illustrating similarity and dissimilarity in macroinvertebrate family composition across all sites (section 4.5.3). Nutrient results are presented illustrating nitrogen to phosphorus ratios (section 4.6.1) followed by nutrient load results produced by each sub-catchment (section 4.6.2).

4.2. Physical and chemical water quality

Summary graphs are presented below (Figure 4.2; 4.3) for all sites (Figure 4.1) with associated data in Appendix C. Trends in similarity and dissimilarity across all sites are presented using mean concentrations over the five sample periods.

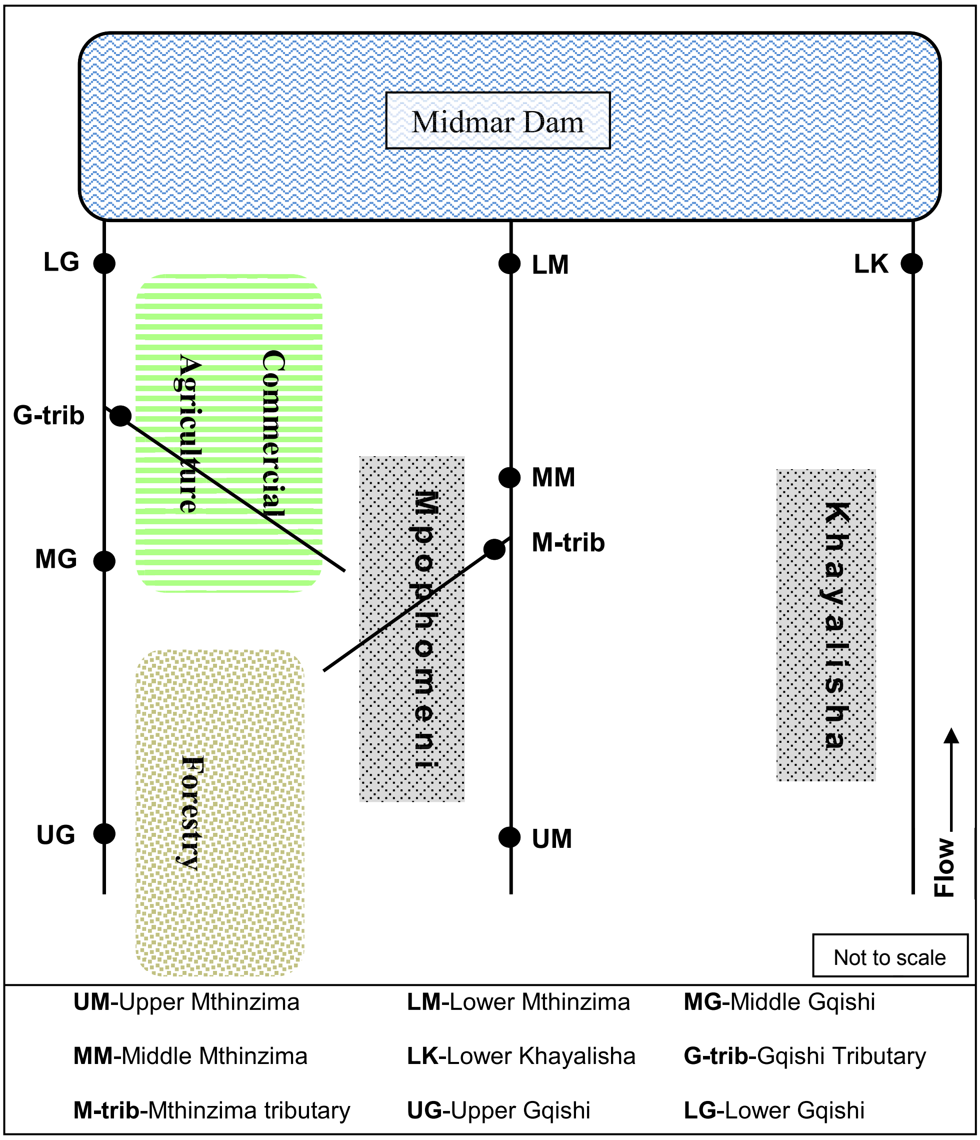


Figure 4.1: Site orientation in the Gqishi, Mthinzima and Khayalisha sub-catchments

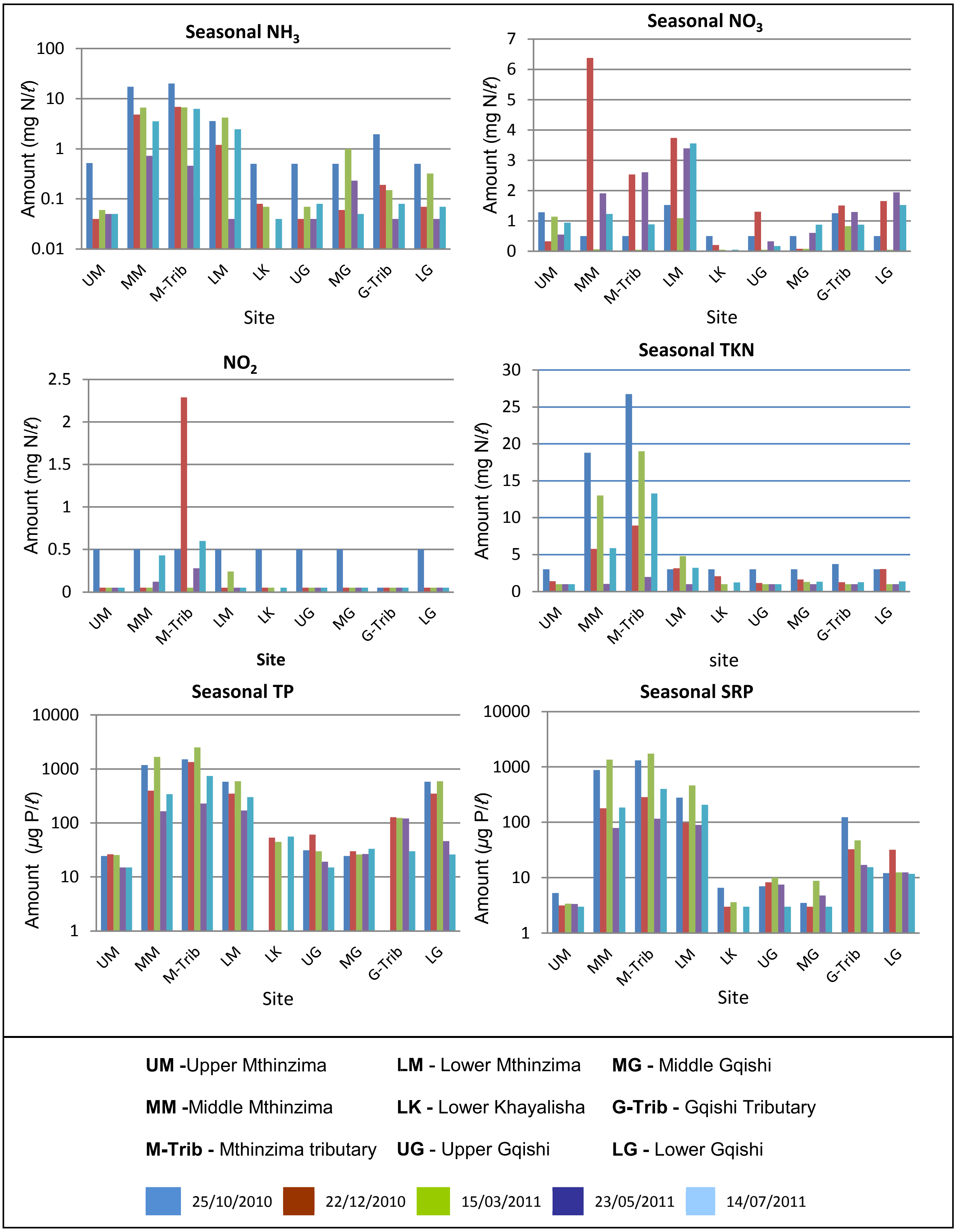


Figure 4.2: Seasonal physical and chemical variables, NH_3, TP and SRP in log-scale due to large variance in data ranges (Table 3.7 for full parameter names)

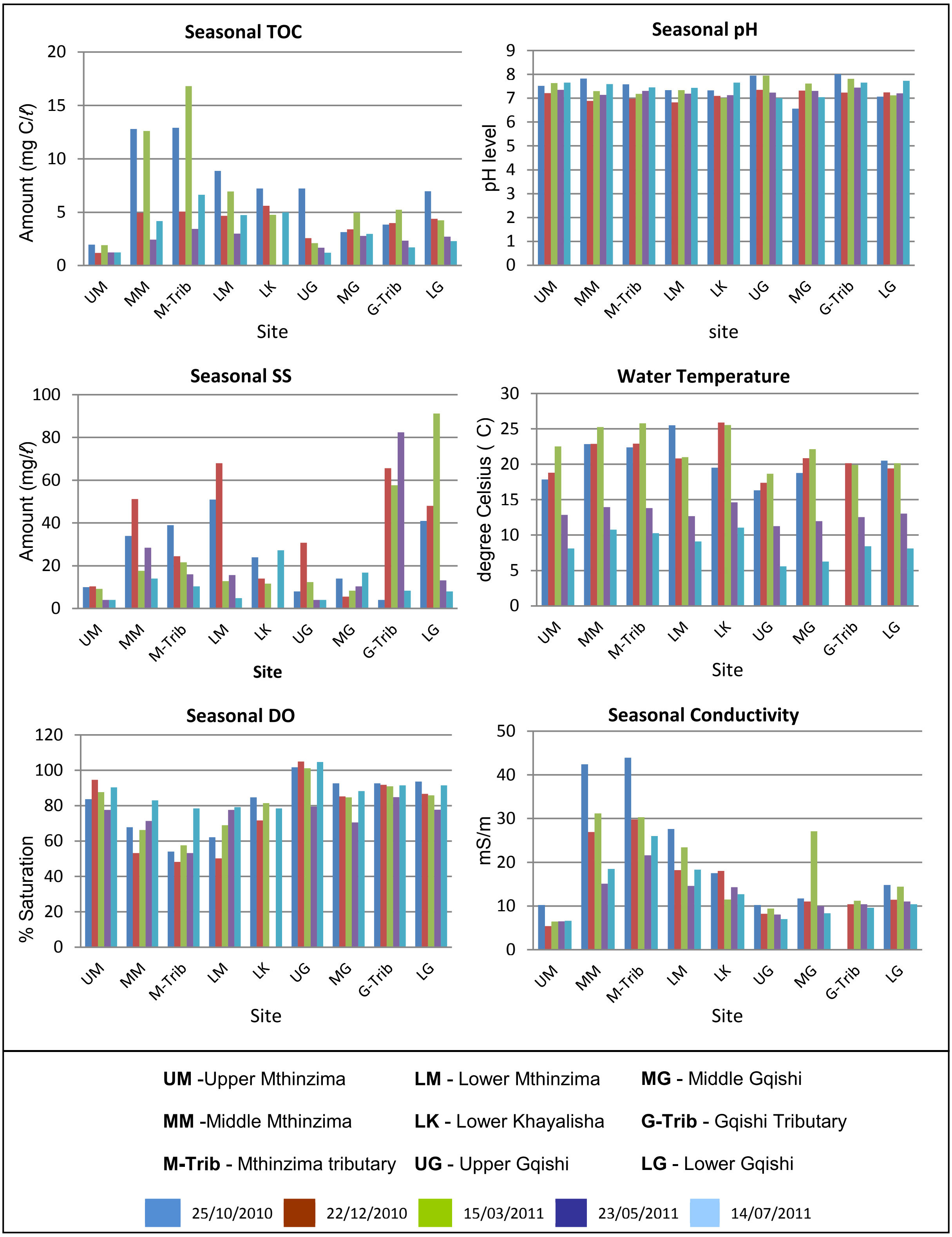


Figure 4.3: Seasonal physical and chemical variables (Table 3.7 for full parameter names)

4.2.1. Ammonia (NH_3)

NH_3 concentrations in the Mthinzima were lowest upstream of Mpophomeni at UM (mean 0.14 mg N/ℓ) with elevated concentrations downstream at MM and M-trib (mean 6.60 and 8.06 mg N/ℓ respectively), with similar NH_3 trends across all seasons. NH_3 concentrations at LM (Midmar inflow) were lower than those at MM and M-trib yet still substantially elevated (mean 2.30 mg N/ℓ). NH_3 concentrations at LK were relatively low (mean 0.17 mg N/ℓ) with concentrations marginally higher than UM and UG (mean 0.14 and 0.15 mg N/ℓ respectively). UG, located in forestry, had low concentrations with higher concentrations present at MG (mean 0.37 mg N/ℓ) where agriculture begins. The highest concentrations in the Gqishi system were present at G-trib and LG (mean 0.48 and 0.20 mg N/ℓ respectively) which drain dense commercial agriculture (Figure 4.2; Appendix C). NH_3 should typically be > 0.1 mg N/ℓ (DWAF, 1996a) making UM, UG, LK marginally above this level. MG, G-trib and LG were in excess of 0.1 mg N/ℓ however not as severe as the excess at MM, M-trib and LM.

4.2.2. Nitrite (NO_2)

Nitrite trends were relatively homogenous across all sites and seasons with UM, LM, LK, UG, MG, G-trib, LG representing mean concentrations ranging between 0.05 – 0.18 mg N/ℓ, with sites below Mpophomeni (MM and M-trib) having the highest mean concentrations of 0.23 and 0.74mg N/ℓ respectively (Figure 4.2; Appendix C).

4.2.3. Nitrate (NO_3)

Nitrate concentrations in the Mthinzima were lowest upstream of Mpophomeni at UM (mean 0.85 mg N/ℓ) with elevated concentrations downstream of Mpophomeni at MM, M-trib and LM (mean 2.02, 1.32 and 2.66 mg N/ℓ respectively). UM demonstrated little seasonal variation in NO_3 concentrations whereas MM and M-trib show large seasonal fluctuations. Concentrations at LK were the lowest across all sites with a mean of 0.20mg N/ℓ. In the Gqishi catchment, similar concentrations exist at UG and MG (mean 0.47 and 0.43mg N/ℓ respectively) and the same similarity exists between G-trib and LG (mean 1.16 and 1.14mg N/ℓ respectively) (Figure 4.2; Appendix C).

LK, UG and MG had mean concentrations representative of oligotrophic concentrations (< 0.5 mg N/ℓ), UM, MM, M-trib, G-trib and LG had mean concentrations representative of mesotrophic concentrations (0.5 – 2.5 mg N/ℓ), although UM falls on the lower end of these ranges. LM (Midmar inflow) is representative of eutrophic concentrations (>2.5 mg N/ℓ) (DWAF, 1996a).

4.2.4. Total Kjeldahl Nitrogen (TKN)

Total Kjeldahl nitrogen concentrations at UM, LK, UG, MG, G-trib and LG were relatively uniform with seasonal means, ranging from 1.44 to 1.88 mg N/ℓ. The highest concentrations were present at MM and M-trib (mean 8.90 and 13.98mg N/ℓ respectively) followed by LM (mean 3.03mg N/ℓ). MM and M-trib boast large seasonal fluctuations in comparison to the remainder of the sites (Figure 4.2; Appendix C).

4.2.5. Total Phosphorus (TP)

TP concentrations in the Mthinzima were lowest upstream of Mpophomeni at UM (mean 21 µg P/ℓ) with elevated concentrations downstream of the settlement at MM, M-trib and LM (mean 751, 1264 and 399 µg P/ℓ respectively). LK, UG and MG all represent concentrations within a similar range with means of 42, 31 and 28 µg P/ℓ respectively. G-trib and LG, located in high density agricultural areas were substantially higher (mean 181 and 68 µg P/ℓ respectively), with the highest concentrations in the Gqishi system (Figure 4.2; Appendix C).

4.2.6. Soluble Reactive Phosphorus (SRP)

SRP trends were similar to those of TP as SRP forms a portion of TP. Concentrations in the Mthinzima were lowest at UM (mean 3.6 µg P/ℓ) with elevated concentrations downstream of Mpophomeni at MM, M-trib and LM (mean 536, 772 and 228 µg P/ℓ respectively). LK, UG and MG represent concentrations within a similar range with seasonal means of 4.05, 7.14 and 4.61 µg P/ℓ respectively. G-trib and LG, draining the highest density cultivated areas were substantially higher (mean 47.06 and 16.13 µg P/ℓ respectively), boasting the highest concentration in the Gqishi system (Figure 4.2; Appendix C). Mean concentrations at UM, LK and MG are considered oligotrophic (< 5 µg P/ℓ), UG and LG had mean concentrations representative of mesotrophic concentrations (5 – 25 µg P/ℓ) although UG marginally falls within this category (DWAF, 1996a). LM (Mthinzima Midmar inflow) and G-trib (commercial agriculture) were representative of eutrophic concentrations (25 – 250 μg P/ℓ) whereas sites downstream of Mpophomeni (MM and M-trib) were representative of hypertrophic concentrations (> 250 μg P/ℓ) (DWAF, 1996a).

4.2.7. Total Organic Carbon (TOC)

Total organic carbon concentrations were lowest upstream of Mpophomeni (UM) and in areas under forestry (UG) (mean 1.50 and 2.95 mg C/ℓ respectively), with the highest concentrations downstream of Mpophomeni at MM and M-trib (mean 7.38 and 8.97 mg C/ℓ respectively). LM and LK had similar concentrations (mean 5.64 and 5.64 mg C/ℓ respectively), with MG, G-trib and LG (mean 3.45, 3.41 and 4.12 mg C/ℓ respectively) falling within the middle range. In general, sites in the Mthinzima, downstream of Mpophomeni, showed larger seasonal fluctuations than the remainder of the sites (Figure 4.3; Appendix C).

4.2.8. PH

The range of pH values for all sites and seasons are 6.56 – 8.01; however these values do not represent the general trends of pH values with means per site ranging from 7.23 – 7.63 (Figure 4.3; Appendix C).

4.2.9. Suspended Solids (SS)

Suspended solids concentrations were seasonally variable across all sites; however most variability exists at G-trib and LG, where the highest mean SS concentrations occurred (mean 43.60 and 40.28 mg/ℓ respectively). This was followed by LK, M-trib, MM and LM (mean 19.20, 22.28, 29.04 and 30.44 mg/ℓ respectively), with UM, UG and MG measuring the lowest seasonal averages (mean 7.52, 11.84 and 11.04 mg/ℓ respectively) (Figure 4.3; Appendix C). Although large variation occurs between sites and seasons, all sites fell within the target water quality range of < 100 mg/ℓ (DWAF, 1996a).

4.2.10. Water Temperature

The most prominent trend is the temperature changes in conjunction with seasonal change. For the most part, the seasonal trends were homogeneous with a few exceptions, whereby the time of sampling and the prevailing weather conditions was the cause. Mean water temperatures across all sites reached their highest in December 2010 and March 2011 (mean 20.5 and 21°C respectively) with lowest temperatures being experienced in July 2011 (mean 8.6 °C) (Figure 4.3; Appendix C).

4.2.11. Dissolved Oxygen (DO)

Dissolved oxygen concentrations were high with mean saturation levels at UM, LK, UG, MG, G-trib and LG of 87%, 79%, 98%, 84%, 90% and 87% respectively. The lowest saturation levels were present downstream of Mpophomeni at MM, M-trib and LM (mean 68, 58 and 68 % respectively) (Figure 4.3; Appendix C). The Gqishi system is well-oxygenated in comparison to the Mthinzima, with the exception of UM. UM, LK, UG, MG, G-trib and LG had mean DO saturations of 80% and above, all within target water quality ranges, whereas MM, M-trib and LM are all below target water quality ranges and long term exposure can prove harmful to aquatic biota (DWAF, 1996a).

4.2.12. Conductivity

The lowest conductivity readings were recorded at UM and UG (mean 7.02 and 8.56 mS/m respectively), followed by G-trib, LG, MG and LK (mean 10.40, 12.40, 13.62 and 14.8 mS/m respectively). The highest readings and seasonal variability were present downstream of Mpophomeni at MM, M-trib and LM (mean 26.82, 30.32, 20.42 mS/m respectively) (Figure 4.3; Appendix C).

4.3. Biological water quality

4.3.1. *Escherichia coli*

E. coli counts were highly variable across seasons. UM, UG and LK had the lowest *E. coli* counts (mean 319, 246 and 236 counts/100mℓ respectively), followed by that of MG, LG and G-trib (mean 500, 543 and 663 counts/100mℓ respectively). Concentrations downstream of

Mpophomeni at MM, M-trib and LM were the highest with means of 318 606, 294 259 and 26 269 counts/100mℓ respectively. MM and M-trib both reached maximums of 816 000 counts/100mℓ with LM reaching a maximum of 126 000 counts/100mℓ, although LM's maximum was somewhat of an outlier as the next highest *E. coli* count recorded at LM was 1 960 counts/100mℓ. In comparison to the high maximums recorded at MM, M-trib and LM, collectively, the remainder of the sites *E. coli* counts did not exceed 1 380 counts/100mℓ over all seasons. Majority (67%) of sites reached maximum *E. coli* counts in October (LK, G-trib and LG) and December (MM, M-trib and LM), with the remaining sites reaching maximums in March (UM and UG) and May (MG) (Figure 4.4; Appendix C).

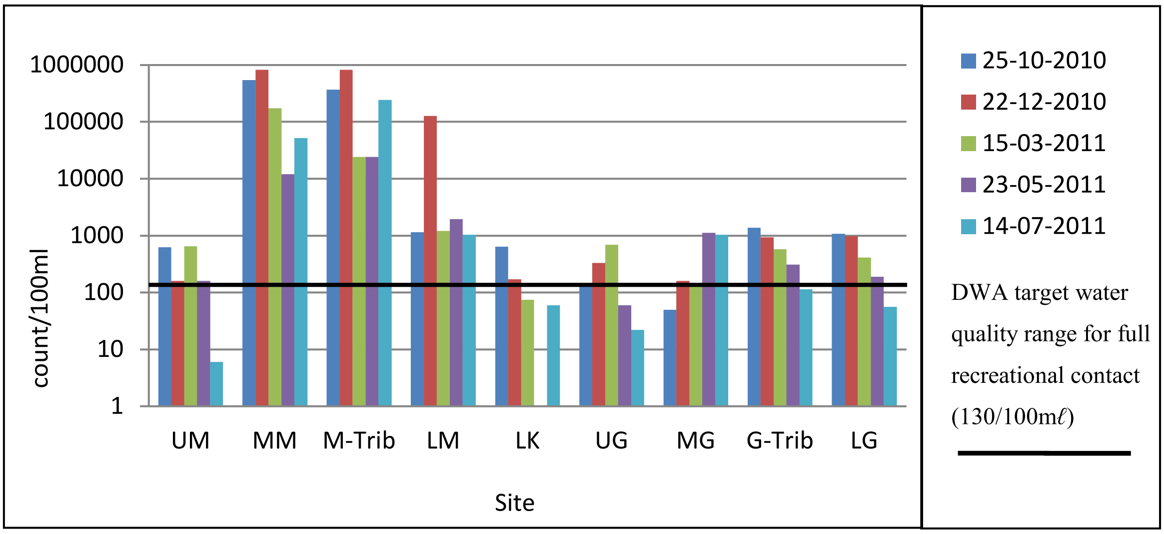


Figure 4.4: Seasonal *E. coli* counts, DWA target water quality range indicated (graph in log scale due to data range)

MM, M-trib and LM were consistently in excess of target water quality ranges and although the remaining sites did exceed target water quality ranges in some instances, the risks are less severe (DWAF, 1996b) (Figure 4.4; Table 2.7). The target water quality range is for that of full recreational contact as environmental water quality target ranges are not available (DWAF, 1996a).

4.4. Aquatic macroinvertebrates

During the sample period a total of 56 different taxa were collected from all sites over all seasons (Table 4.1; Appendix D). UM, UG, MG and LG had the highest total number of taxa over all seasons with 38, 39, 38 and 35 taxa respectively. MM and LM have substantially lower total number of taxa over all seasons (17 each).

Table 4.1: Macroinvertebrate families and associated SASS5 sensitivity scores for all sites and seasons (figures refer to frequency of occurrence of families out of a total of five sampling periods)

Group/Order	Family	SASS5 sensitivity	UM	MM	LM	UG	MG	LG
Turbellaria		3	0	2	2	3	2	4
Annelida	*Oligochaeta*	1	2	3	5	4	1	4
	Hirudinea	3	0	2	5	2	0	4
Crustacea	*Potamonautidae*	3	5	0	5	4	4	3
	Atyidae	8	5	1	5	5	5	5
Hydracarina		8	0	0	1	0	0	0
Plecoptera	*Perilidae*	12	4	0	0	5	0	1
Ephemeroptera	*Baetidae*	4	5	2	3	5	5	5
	Caenidae	6	5	0	0	4	4	5
	Leptophlebiidae	9	3	0	0	4	5	3
	Polymitarcyidae	10	0	0	0	0	0	1
	Tricorythidae	9	5	0	0	4	3	3
Odonata	*Chlorolestidae*	8	0	0	0	0	2	0
	Coenagrionidae	4	5	1	1	4	4	3
	Protoneuridia	8	0	0	0	1	0	0
	Aeshnidae	8	5	1	1	4	4	5
	Corduliidae	8	0	0	0	0	1	0
	Gomiphidae	6	1	1	0	4	1	1
Lepidoptera	*Pyralidae*	12	2	0	1	5	1	1
Hemiptera	*Corixidae*	3	1	0	1	0	0	1
	Gerridae	3	3	0	0	3	2	2
	Naucoridae	7	5	0	0	5	3	5
	Nepidae	3	0	1	0	0	0	0
	Notonectidae	3	4	0	0	0	0	0
	Pleidae	4	1	0	0	0	0	0
	Veliidae	5	1	0	0	2	3	2
Trichoptera	*Ecnomidae*	8	1	0	0	0	1	0
	Hydropsychidae	4	5	0	0	5	5	5
	Philopotamidae	10	1	0	0	0	1	0
	Psychomyiidae	8	1	0	0	0	0	0

	Hydroptilidae	6	1	0	0	1	0	0
	Leptoceridae	6	0	0	0	2	2	3
	Sericostomatidae	13	0	0	0	0	0	1
Coleoptera	*Dytiscidae*	5	0	0	2	0	1	3
	Elmidae/Dryopidae	8	3	0	0	5	4	5
	Gyrinidae	5	5	1	0	5	5	5
	Helodidae	12	0	0	0	2	1	0
	Hydraenidae	8	0	0	0	1	1	1
	Hydrophilidae	5	1	2	0	2	4	3
	Psephenidae	10	5	0	0	5	1	0
Diptera	*Athericidae*	10	2	0	0	4	0	1
	Chironomidae	2	3	5	5	4	3	2
	Culicidae	1	2	3	1	0	2	0
	Dixidae	10	1	0	0	1	0	0
	Muscidae	1	1	1	2	1	1	2
	Psychodidae	1	0	0	0	0	1	0
	Simulidae	5	3	3	3	1	3	3
	Tabanidae	5	2	0	0	5	4	0
	Tipulidae	5	4	0	0	4	5	1
Gastropoda	*Ancylidae*	6	3	2	0	4	2	3
	Lymnaeidae	3	0	0	0	1	0	0
	Physidae	3	0	5	3	1	3	2
Plectropoda	*Corbiculidae*	5	2	0	0	1	2	5
	Sphaeriidae	3	1	0	0	2	0	0
	Unionidae	6	0	0	0	0	0	1
Total number of Taxa	***56***		**38**	**17**	**17**	**39**	**38**	**35**

4.4.1. SASS5

UM, ups tream o f M popphomeni, and U G, located i n forestry, recorded the highest m ean SASS5 scores for all seasons (mean 139.8 and 165 respectively), followed by MG and LG (116 and 119.6 respectively), with the lowest scores present at M M and LM (25 and 34 respectively). N umber of taxa c ollected at U M, U G, M G and LG for all s easons r ange between 18 – 29, w ith a substantially l ower range recorded at M M an d LM (3 and 13). Average score pe r t axa (ASPT) is a function of the SASS5 s core a nd the num ber of t axa (SASS5 ÷ number of taxa). The highest mean ASPT were present at UM and UG (6.48 and 6.41 respectively) f ollowed by MG and LG (5.72 and 5. 60 respectively), w ith t he l owest present at MM and M-trib (3.07 and 3.57 respectively) (Figure 4.5; Table 4.2).

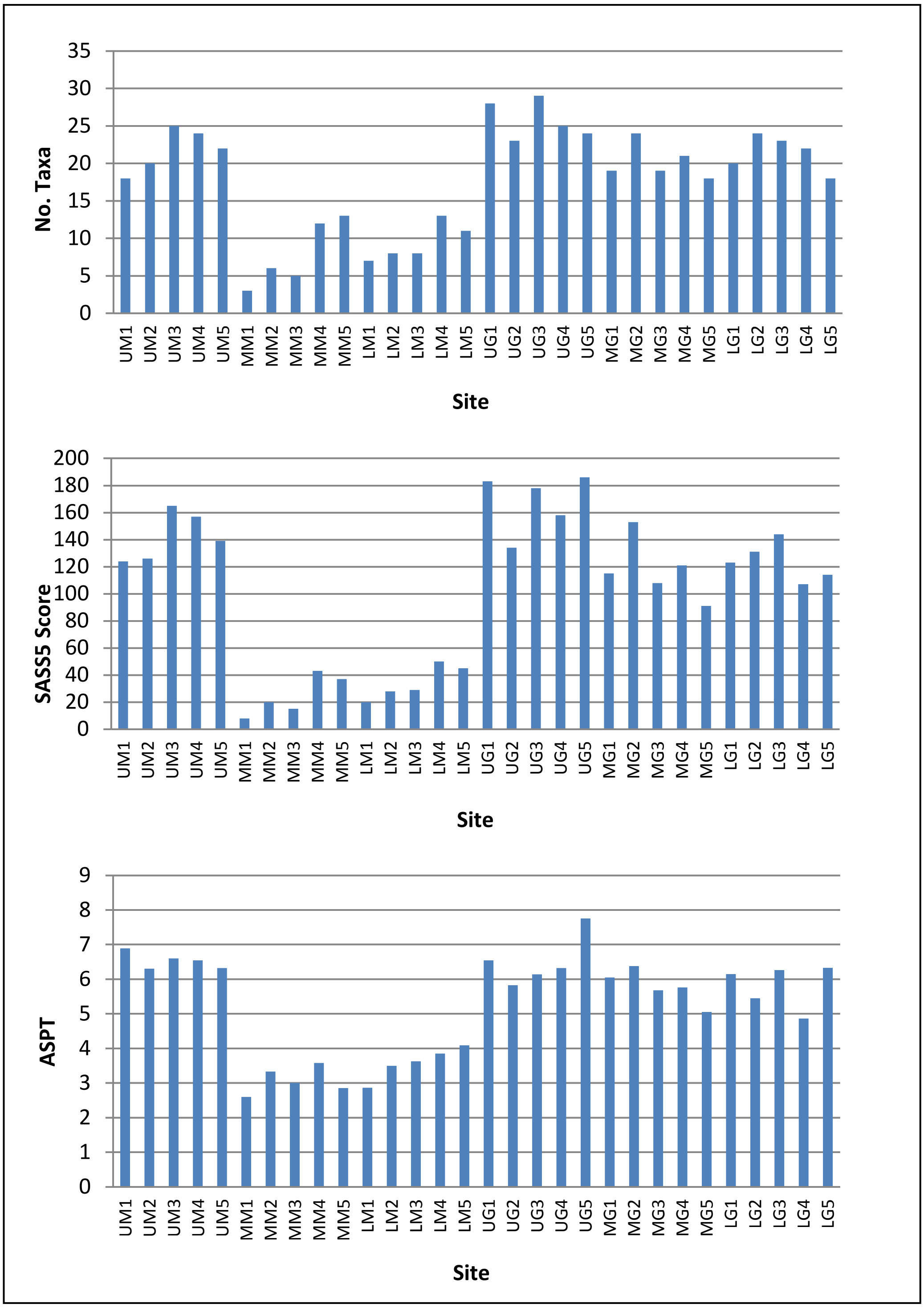


Figure 4.5: SASS5, No. Taxa and ASPT for all sites and seasons (1-25/10/2010, 2-22/12/2010, 3-15/03/2011, 4-23/05/2011, 5-14/07/2011)

4.4.2. SASS data interpretation guidelines

According to the South African Scoring System data interpretation guidelines (Dallas, 2007), UM (upstream of Mpophomeni) and UG (forestry) were in the best ecological condition, followed by MG and LG and finally MM and LM. On average, UM and UG fell under ecological category B, classified as 'largely natural with few modifications'. UG tends towards the upper extent of the category and 60% of the sample periods fell under ecological category A, classified by 'unmodified natural' conditions. On average MG and LG fell under ecological category C, classified by 'moderately modified' conditions. Sites downstream of Mpophomeni (MM and LM) fell under ecological category E/F classified by 'seriously/critically modified' conditions. UM was consistent, falling under category B 60% of the sample periods, whereas the remaining sites were more variable. SASS5 indices did increase downstream of Mpophomeni in May and July, however remained in the 'seriously/critically modified' category for all sample periods. Sites located in agriculture (MG and LG) were represented by the greatest seasonal variation in ecological condition based on the SASS5 indices, evident by the range of ecological categories from 'good' to 'poor' during the five sample periods at both MG and LG (Table 4.2).

4.4.3. IHAS: Invertebrate Habitat Assessment System

IHAS results do not yield significant differences in habitat scores across sites, as sites were selected and sampled based on their similarity and comparability to other sites. As a result habitat scores based on the IHAS were similar (65 - 75%) and could not form the basis for explaining differences in invertebrate family composition or SASS5 related indices. This is not necessarily due to inefficiencies in the system itself but rather to specific site selection, whereby sites were representative of similar biotope availability, diversity and quality. Differences in invertebrate family composition and SASS5 related scores could therefore be attributed to other variables sampled (physical, chemical and biological water quality).

Table 4.2: Ecological condition (Dallas, 2007) of all sites and seasons based on SASS5 score and ASPT

Site	Date	No.Taxa	SASS score	ASPT	Ecological category	Condition
	25/10/2010	18	124	6.89	B	Good
	20/12/2010	20	126	6.3	C	Fair
UM	15/03/2011	25	165	6.6	B	Good
	23/05/2011	24	157	6.54	B	Good
	14/07/2011	21	127	6.05	C	Fair
	25/10/2010	3	8	2.6	E/F	Seriously/critically modified
	20/12/2010	6	20	3.33	E/F	Seriously/critically modified
MM	15/03/2011	5	15	3	E/F	Seriously/critically modified
	23/05/2011	12	43	3.58	E/F	Seriously/critically modified
	14/07/2011	13	37	2.85	E/F	Seriously/critically modified
	25/10/2010	7	20	2.86	E/F	Seriously/critically modified
	20/12/2010	8	28	3.5	E/F	Seriously/critically modified
LM	15/03/2011	8	29	3.63	E/F	Seriously/critically modified
	23/05/2011	13	50	3.85	E/F	Seriously/critically modified
	14/07/2011	11	45	4.09	E/F	Seriously/critically modified
	25/10/2010	28	176	6.29	A	Natural
	20/12/2010	23	134	5.83	C	Fair
UG	15/03/2011	29	178	6.14	A	Natural
	23/05/2011	25	158	6.32	B	Good
	14/07/2011	24	179	7.46	A	Natural
	25/10/2010	19	115	6.05	C	Fair
	20/12/2010	24	146	6.08	B	Good
MG	15/03/2011	19	108	5.68	D	Poor
	23/05/2011	21	121	5.76	C	Fair
	14/07/2011	18	91	5.05	D	Poor
	25/10/2010	20	116	5.8	C	Fair
	20/12/2010	24	131	5.45	C	Fair
LG	15/03/2011	23	137	5.96	C	Fair
	23/05/2011	22	107	4.86	D	Poor
	14/07/2011	18	107	5.94	D	Poor

4.5. Multivariate analysis

Multivariate anal ysis extracts key i nformation and r epresents maximum v ariability in t he dataset while allowing spatial and temporal trends to be highlighted.

4.5.1. Physical and chemical variables

The principle component analysis (PCA) of all physical and chemical variables revealed that 52.2% of all variability across all sites occurred along the first axis (PC1) with 11.9%, 10.3% and 8. 8% occurring on P C2, P C3 and P C4 respectively. P C1 and P C2 account f or the majority (64.1%) of the variation in the dataset and will be the basis for analysis (Figure 4.6).

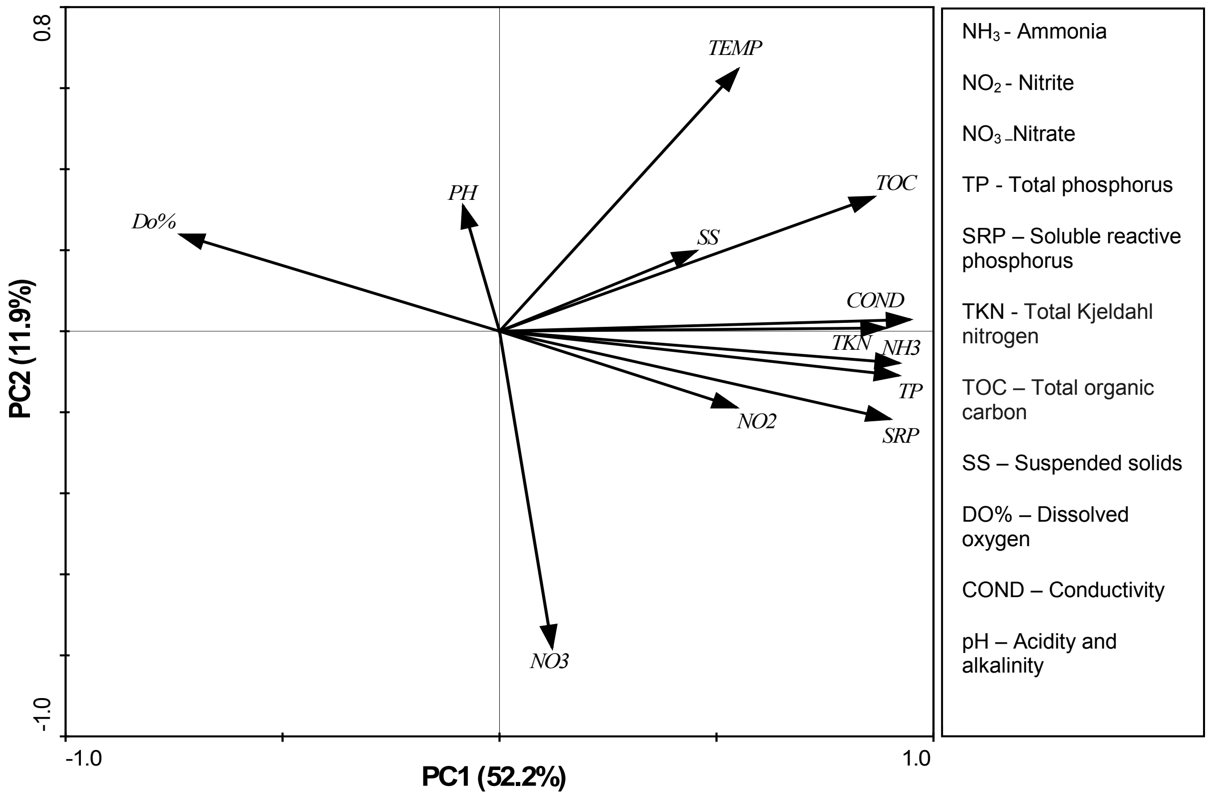


Figure 4.6: Plot of all physical and chemical parameters along the first two axes of a standardised Principal Component Analysis (PCA)

NH_3, NO_2, NO_3, TKN, SRP, TP, TOC, COND, SS and TEMP all made positive contributions towards P C1, w ith onl y pH and D O hav ing ne gative c ontributions. TOC, C OND, S S, p H, TEMP and DO made positive contributions to PC2, whereas NH_3, NO_2, NO_3, TKN, SRP and TP contribute negatively to PC2. PC1 can be v iewed as a pol lution gradient whereby water quality det eriorates al ong the P C1 ax is. T his was evident from the i ncreases i n nu trient compounds, and t he as sociated hi gh l evels of ot her v ariables. N H_3, T KN, SR P, T P, TOC, COND and D O account for most variability across PC1 with NO_3 and TEMP accounting for the majority of variability across PC2 (Figure 4.6).

Table 4.3: Correlation matrix of all physical and chemical variables (r values shaded significant at P=0.01 using Pearson's Product Moment Correlation)

n=44	NH_3	NO_2	NO_3	*TKN*	*SRP*	*TP*	*TOC*	*COND*	*SS*	*pH*	*TEMP*
NO_2	0.38										
NO_3	0.01	0.09									
TKN	0.94	0.34	-0.07								
SRP	0.78	0.13	-0.12	0.9							
TP	0.76	0.35	-0.01	0.87	0.95						
TOC	0.74	0.21	-0.15	0.83	0.88	0.85					
COND	0.88	0.41	0.14	0.84	0.77	0.79	0.82				
SS	0.11	0	0.23	0.06	0.04	0.08	0.19	0.18			
pH	-0.06	-0.01	0.01	-0.06	-0.21	-0.2	-0.11	-0.14	0.03		
TEMP	0.33	0.19	-0.06	0.35	0.39	0.43	0.56	0.48	0.3	0.18	
DO%	-0.53	-0.34	-0.44	-0.51	-0.52	-0.6	-0.49	-0.71	-0.2	0.31	-0.36

A number of significant (p=0.01) positive and negative correlations exist within the dataset (shaded in Table 4.3) however the strongest exist among NH_3 TKN, SRP, TP, TOC and COND (Table 4.3). DO had negative correlations with the majority of the remaining variables with the exception of pH, although the strongest negative correlations exist between DO and NH_3, NO_3, TKN, SRP, TP, TOC and COND. TEMP was positively correlated with NH_3 TKN, SRP, TP, TOC, COND and SS. NO_3 had no correlation with any variable with the exception of DO. SS and pH had no correlation with the remaining variables (Table 4.3).

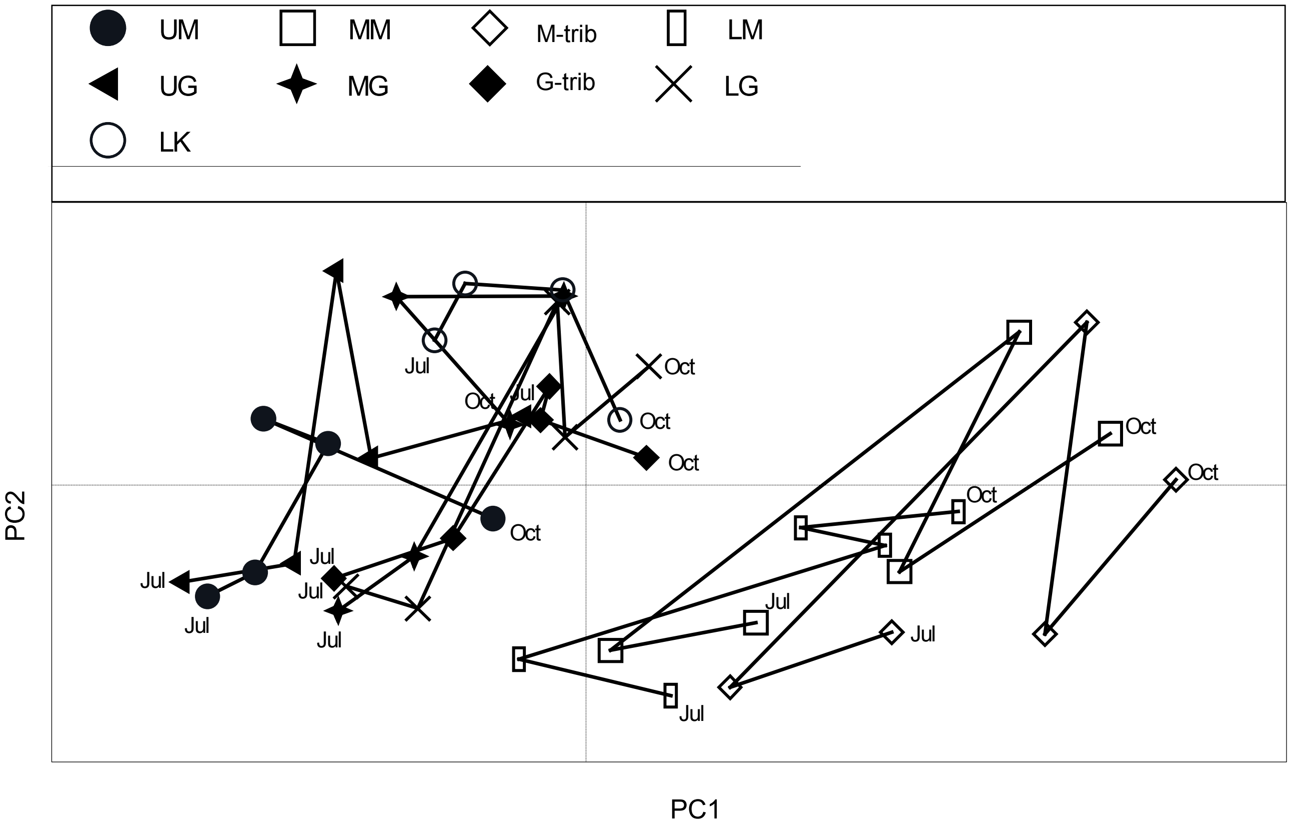


Figure 4.7: Site seasonal trajectories along first two axes of a PCA for physical and chemical parameters.

Most notable from the sites' seasonal trajectories was the distinctness of sites downstream of Mpophomeni (MM, M-trib and LM) from the remainder of the sites. MM, M-trib and LM were distributed on the positive end of PC1 where pollution concentrations were highest. Furthermore, MM and M-trib show consistency across seasons, following similar seasonal trajectories. On the opposite of the pollution gradient, UM and UG were distributed where pollution concentrations were at their lowest relative proportions. LK, MG, G-trib and LG occur in the mid-ranges with G-trib and LG tending more towards the higher end of the pollution gradient. Temperature and NO_3 were responsible for the majority of the seasonal variability in the dataset, illustrated by the shift along the PC2 axis (Figure 4.7).

4.5.2. *Escherichia coli (E. coli)*

E. coli had a positive linear relationship with PC1, illustrating the effect of faecal contamination (indicated by *E. coli* counts) on water quality and the contribution of *E. coli* to PC1 (Figure 4.8).

4.5.3. Macro-invertebrate data

Number of taxa, SASS5 scores and ASPT displayed a negative linear relationship with PC1, indicative of a decline in all three indices along PC1 (pollution gradient) (Figure 4.8). Number of taxa, SASS5 score and ASPT had a strong negative correlation with PC1 and *E. coli* (Table 4.4) and are strongly correlated with each other; however this is not significant due to the interdependence of the indices.

Table 4.4: Correlations between PC1 and PC2 and biological data (r values shaded significant at P=0.01)

n=30	*PC1*	*PC2*	*SASS5*	*No.Taxa*	*ASPT*
PC2	0.075				
SASS5	-0.844	0.324			
No.Taxa	-0.852	0.279	0.971		
ASPT	-0.848	0.268	0.952	0.882	
log*E. coli*	0.806	-0.039	-0.773	-0.759	-0.808

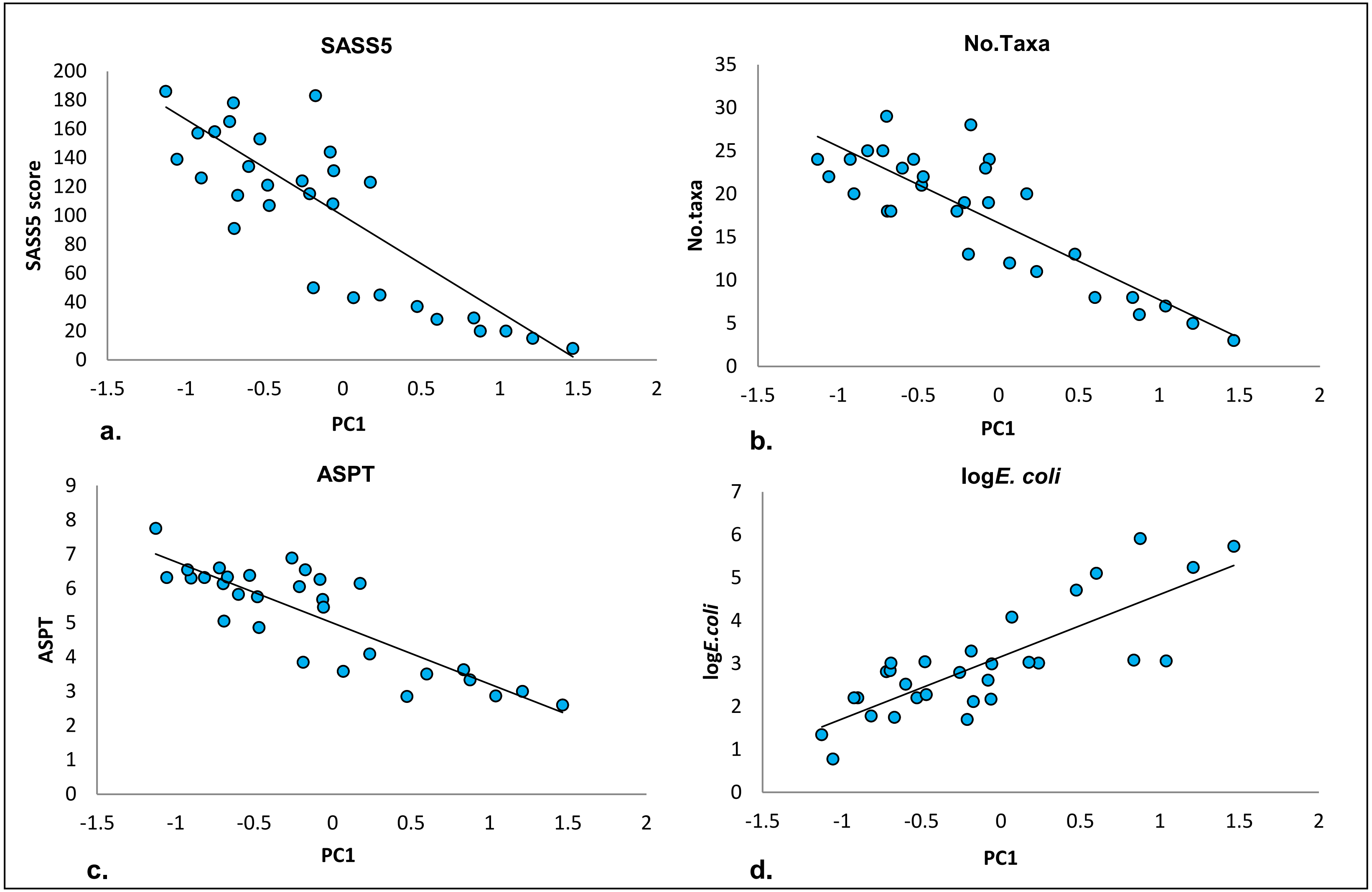


Figure 4.8: (a) SASS5 score, (b) Number of Taxa (No. Taxa), (c) Average Score Per Taxa (ASPT) and (d) log*E. coli* across PC1

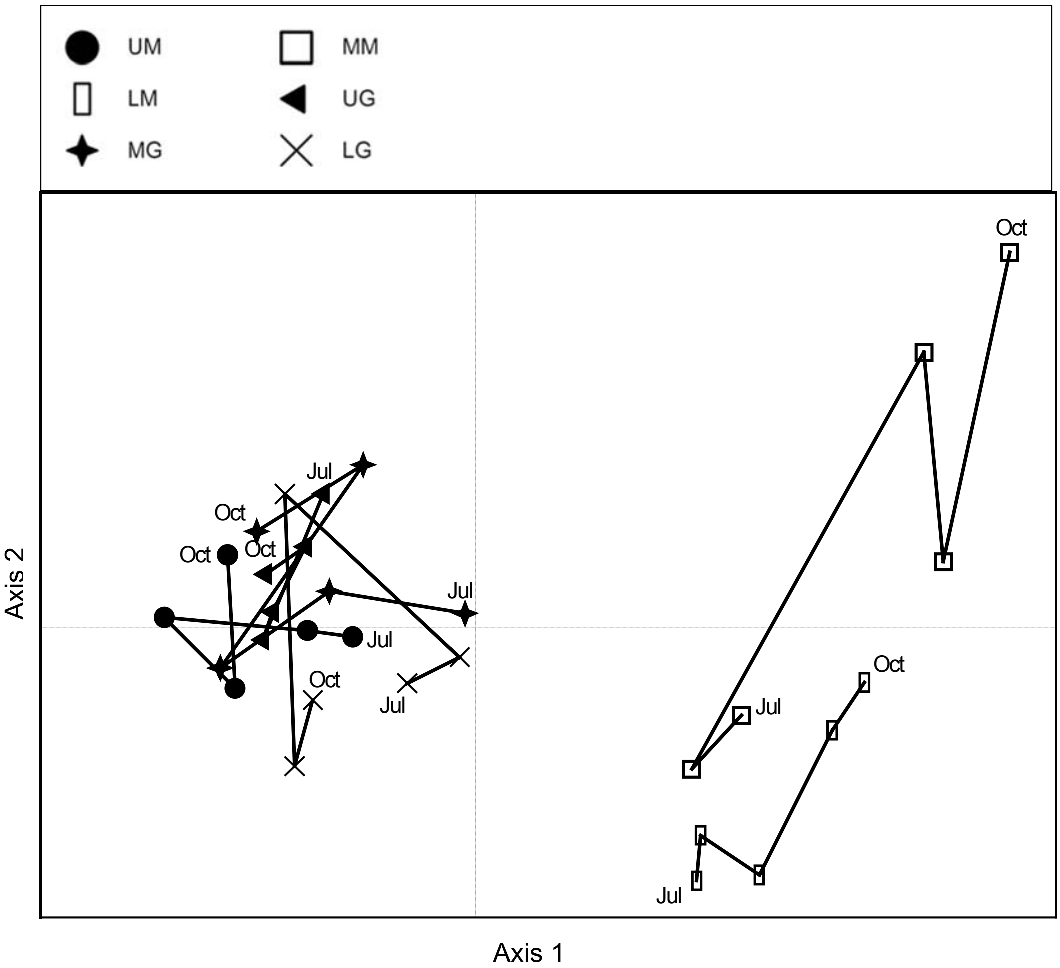


Figure 4.9: Site seasonal trajectories for all sites in a non-metric multidimensional scaling (NMS) ordination (rotated to maximum variance along horizontal axis by PCA) based on Sørensen's distance for the presence and absence of families.

Most notable from the seasonal trajectories of presence of different taxa, was the distinctness and seasonal variability in presence of invertebrate families at MM and LM in comparison to the remainder of the sites (Figure 4.9; 4.10). MM and LM's seasonal variability was accounted for by declines on both axes from October 2010 to July 2011. The remainder of the sites were clustered with UM and UG demonstrating homogeneity and less seasonal variability than MG and LG. Upstream of Mpophomeni (UM) and areas under forestry (UG) were represented by little variation in family composition whereas MG and LG, situated in areas of agriculture, were more variable (Figure 4.9).

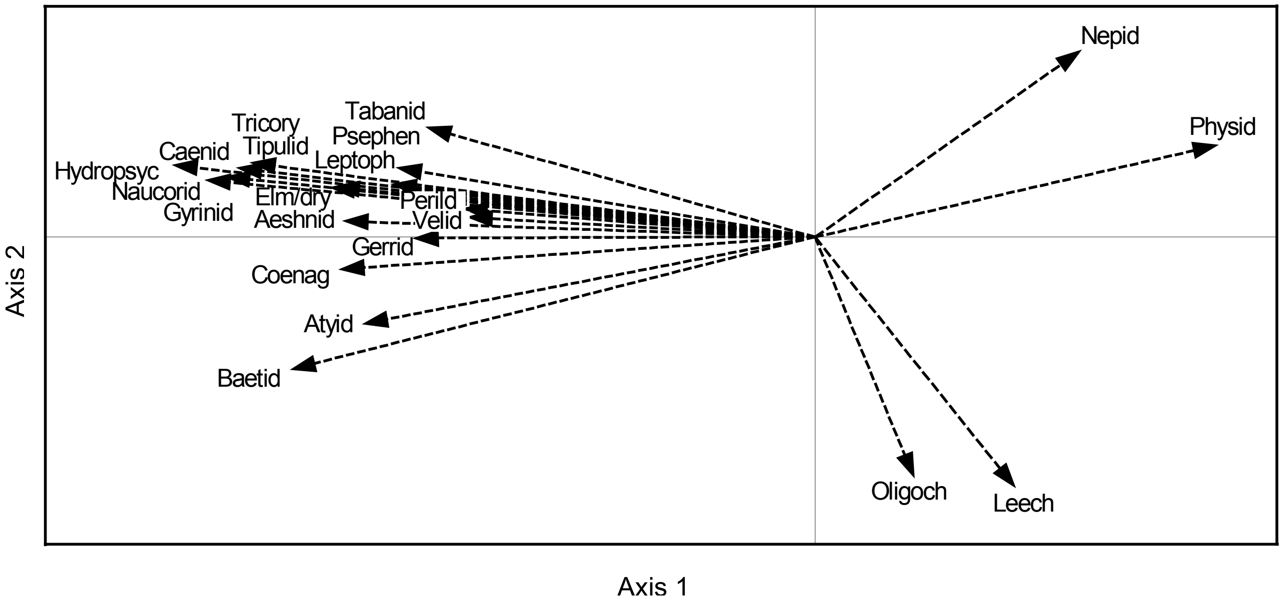


Figure 4.10: Trend in the prevalence of taxa (families) across the NMS ordination, taxa with correlation 0.5<r>-0.5 are not displayed (Table 4.1 for full family names)

MM and LM were distributed on the positive end of the NMS plot where the most prevalent taxa (*Nepidae, Physidae, Hirudinea and Oligochaeta*) (Figure 4.9; 4.10), are those tolerant of a wide range of water quality conditions, determined by their relative sensitivity scores (Dickens and Graham, 2002) (Table 4.1). On the opposite end of the trajectory, UM, UG, MG, and LG (though still variable to some degree) were distributed where taxa are more sensitive to poor water quality conditions (Figure 4.10), illustrated by their sensitivity scores (Dickens and Graham, 2002). Taxa most prevalent on the positive end of Axis 1 where MM and LM were distributed have sensitivity scores ranging from 1 - 3, whereas taxa most prevalent on the negative end of Axis 1, where UM, UG, MG and LG were distributed, have sensitivity scores ranging from 5-12.

Table 4.5: Correlations in biological data and water quality variables (PC1 and PC2) variables with the NMS plot (r values shaded significant at P=0.01)

	NMS Axis 1	NMS Axis 2
PC1	0.8301	0.0996
PC2	-0.3218	0.4903
Log *E. coli*	0.7998	0.1588
SASS5	-0.9268	0.1444
No. Taxa	-0.9245	0.0221
ASPT	-0.9336	0.1290

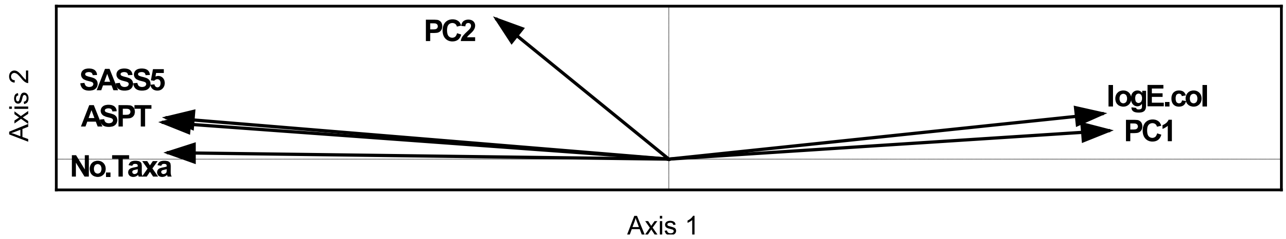


Figure 4.11: SASS5, No. Taxa, ASPT, *E. coli* and water quality variables (PC1 and PC2) projected across the NMS plot

UM, UG, MG and LG were distributed towards the negative side of Axis 1 of the NMS and have the highest SASS5 scores (determined by taxa sensitivity scores), number of taxa and ASPT, with UM and UG distributed the furthest along the negative side (Figure 4.11). On this side of the NMS plot, PC1 and *E. coli* were least prevalent illustrating better quality water and the link between water quality and the SASS5 indices. MM and LM occurred on the positive side of Axis 1 of the NMS and were represented by the highest counts of *E. coli* and the highest pollution concentrations, illustrated by the prevalence of PC1 on this side of the plot (Figure 4.11). SASS5, number of taxa and ASPT had strong negative correlations with Axis 1 of the NMS, whereas PC1 and *E. coli* had a strong positive correlation with Axis 1 (Table 4.5).

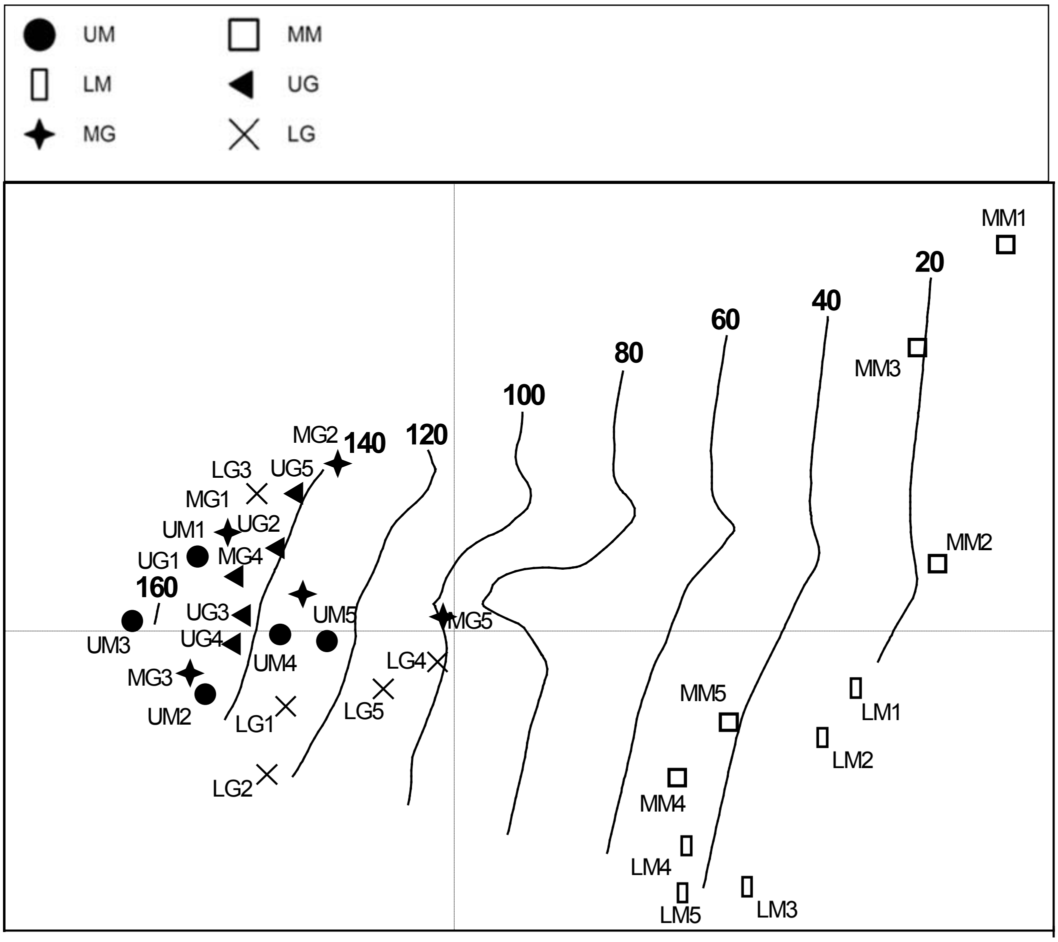


Figure 4.12: Trends in taxa (fitted by locally weighted least-squares regression smoother) in SASS5 score across the NMS (1-25/10/2010, 2-22/12/2010, 3-15/03/2011, 4-23/05/2011, 5-14/07/2011)

SASS5 scores shifted along the NMS plot in conjunction with prevailing pollution conditions. A clear gradient emerged whereby MM and LM (downstream of Mpophomeni) occurred on the positive side of NMS, where PC1 scores and *E. coli* counts were highest and SASS5 scores were lowest. In the mid-ranges of the SASS5 scores LG was most prevalent with the highest scores present at UM and UG. The SASS5 results reinforce those of the physical and chemical PCA results, whereby a similar pattern emerges, whereby sites below Mpophomeni were those most affected by poor water quality conditions and therefore the lowest SASS5 scores, number of taxa and ASPT (Figure 4.12). The homogeneity between the PCA results and the NMS results illustrates the coincidence between SASS5 data and physical and chemical water quality data.

The cluster dendrogram (Figure 4.13) further illustrates the distinctness in macroinvertebrate family composition between sites. The first major grouping distinguishes sites downstream of Mpophomeni (MM and LM) as statistically distinct from all remaining sites. Homogeneity in invertebrate family composition exists downstream of Mpophomeni, although MM1 and MM3 were statistically distinct from the remaining MM and LM samples. Further grouping exists between MM4, LM4, MM5, LM3 and LM5 and between MM2, LM1 and LM2 (Figure 4.13).

Remaining sites (UM, UG, MG and LG), were clustered by a second major grouping and deemed statistically indistinguishable in terms of invertebrate family composition. However, within this grouping similarity did exist between the upstream sites (UM and UG) and the agricultural sites (MG and LG). All UM and UG (except UG5) samples are grouped with another grouping among UG5, MG2, LG1, LG4, and LG5. Further groupings between LG2, MG3 and LG3; and MG4 and MG5 also prevailed.

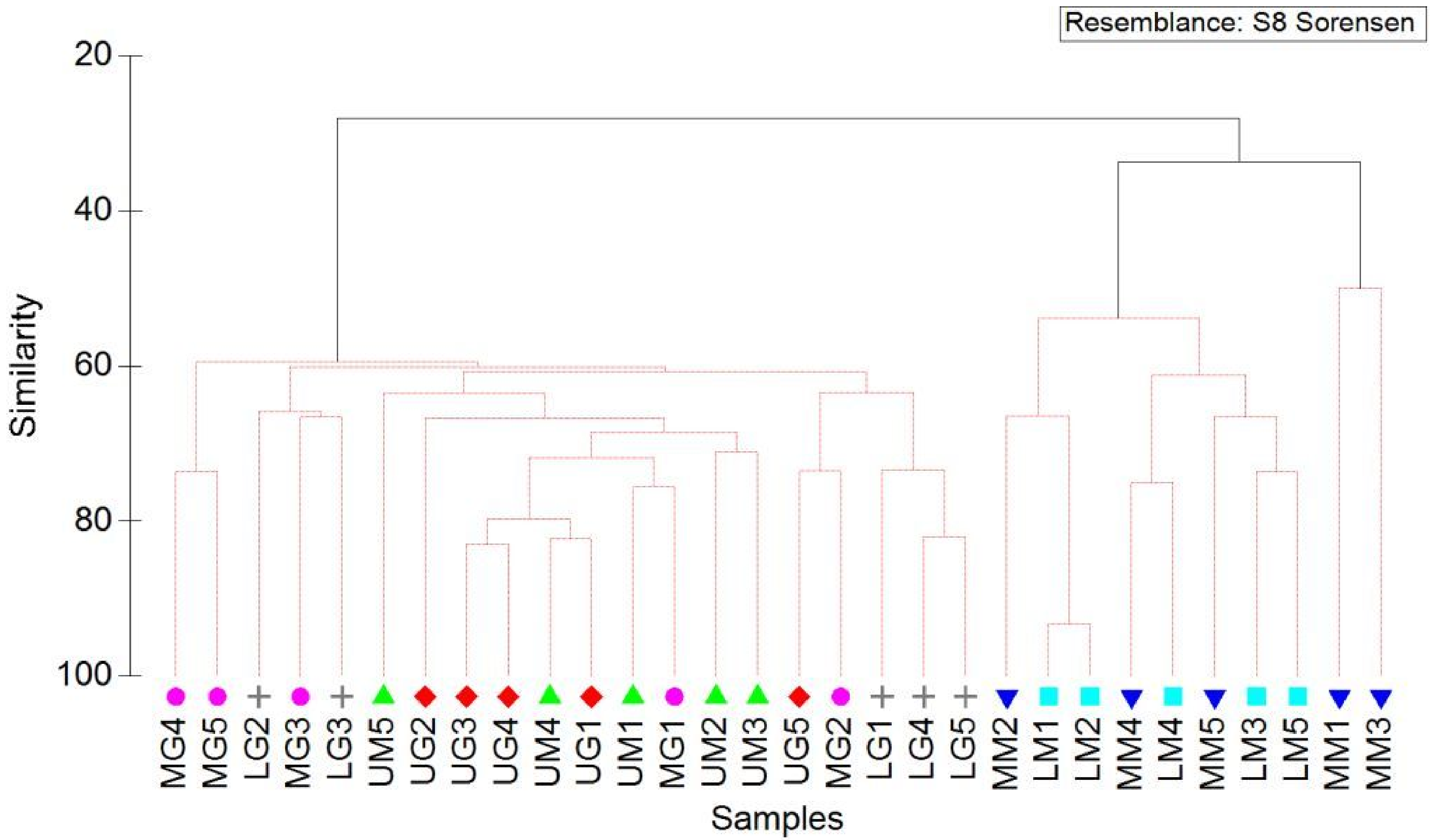


Figure 4.13: Agglomerative cluster dendrogram based on Sørensen's distance for presence of families, branches with dotted lines are not statistically distinguishable (p=0.05) (1-25/10/2010, 2-22/12/2010, 3-15/03/2011, 4-23/05/2011, 5-14/07/2011)

4.6. Nutrients

4.6.1. Nitrogen: phosphorus ratios

Nitrogen: phosphorus (N: P) ratios in the Mthinzima were highest upstream of Mpophomeni (UM), suggesting phosphorus limitation in these reaches of the stream, a state desirable in terms of eutrophication (DWAF, 1996a). The lowest N: P ratios in the Mthinzima were all sites below Mpophomeni which suggests a system in which nitrogen was increasingly the limiting nutrient, an undesirable state in terms of eutrophication (DWAF, 1996a; Van Ginkel, 2002) (Table 4.6).

N: P ratios in the Gqishi were highest upstream in forested areas (UG) and in the transition from forestry to agriculture (MG), where phosphorus was the limiting nutrient. G-trib draining agricultural areas had the lowest N: P ratios depicting nitrogen limitation. At LG the N: P ratios were representative of phosphorus limitation (DWAF, 1996a; Van Ginkel, 2002) (Table 4.6).

Table 4.6: Nitrogen: phosphorus ratios for all sites

Site	mean total nitrogen (mg/ℓ)	mean total phosphorus (mg/ℓ)	N: P ratio
UM	1.14	0.02	1:57
MM	8.85	0.75	1:12
M-Trib	10.13	1.26	1:8
LM	5.14	0.4	1:13
LK	0.54	0.04	1:14
UG	0.76	0.03	1:25
MG	0.94	0.03	1:33
G-Trib	1.69	0.18	1:9
LG	1.48	0.07	1:21

4.6.2. Nutrient loading

Results include nutrient loads (kg/annum) and nutrient loads per hectare (kg/annum) discharged by the three systems into Midmar Dam.

4.6.2.1. Nutrient loads

Ammonia (NH_3) loads entering Midmar from the Mthinzima system were the highest among the three sub-catchments (4 602 kg/annum), followed by the Gqishi (1 406 kg/annum) and the Khayalisha system (206 kg/annum). NO_3 loads were highest in the Gqishi system (7 998 kg/annum) followed by the Mthinzima (5 331 kg/annum) and the Khayalisha systems (245 kg/annum) (Table 4.7; Figure 4.14).

Phosphorus loads entering Midmar were highest from the Mthinzima (TP – 800 and SRP – 455 kg/annum), followed by the Gqishi system (TP – 480 and SRP – 113 kg/annum), with the lowest loads emanating from the Khayalisha system (TP – 51 and SRP – 5 kg/annum). The Mthinzima sub-catchment generated the highest total nutrient loads (phosphorus and nitrogen) of the three sub-catchments, as a result of the Mpophomeni settlement and associated effluent inputs (Table 4.7; Figure 4.14).

Table 4.7: Nutrient loading from Mthinzima, Gqishi and Khayalisha sub-catchments

	LM		LG		LK	
Mean daily flow (ℓ /day)	5482391		19254005		3320588	
Catchment size (ha)	1779		6048		1060	
	kg/annum	**kg/ha/annum**	**kg/annum**	**kg/ha/annum**	**kg/annum**	**kg/ha/annum**
NH_3	4602.47	2.60	1405.54	0.23	206.04	0.19
NO_3	5330.86	3.00	7997.54	1.32	244.89	0.23
TP	800.24	0.45	480.02	0.08	51.15	0.05
SRP	455.43	0.26	113.34	0.02	4.90	0.005

.

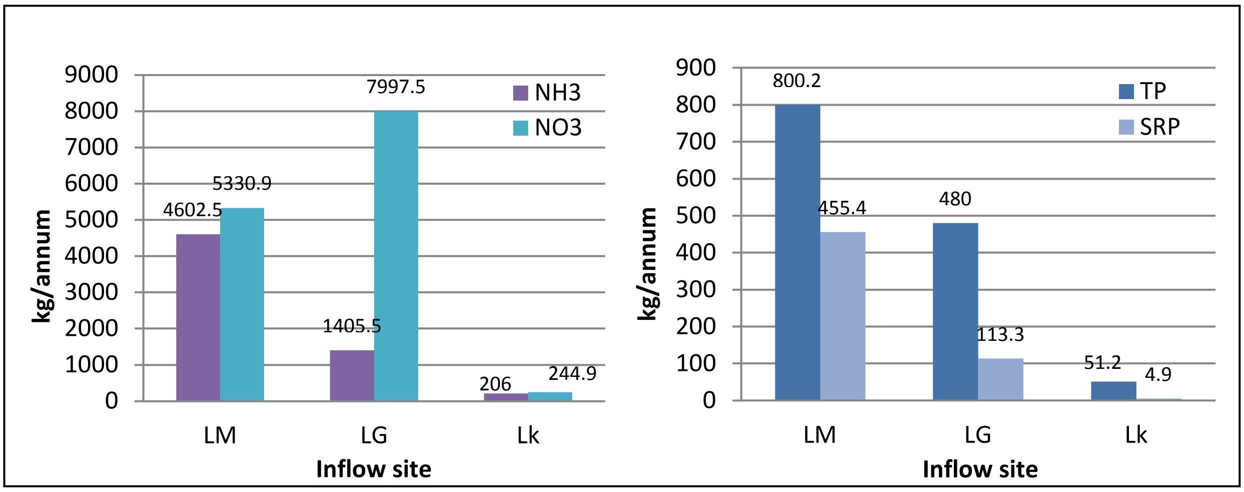


Figure 4.14: Nitrogen and Phosphorus loading at Midmar inflow sites (kg/annum) (graph scales differ)

4.6.2.2. Nutrient loads per hectare

The highest nitrogen loads per hectare emanated from the Mthinzima sub-catchment (NH_3 - 2.6 and NO_3 - 3 kg/ha/annum), where urban development is prominent, whereas the Gqishi and Khayalisha sub-catchments were similar, with the exception of NO_3 loads in the Gqishi which were higher (NO_3 – 1.32 kg/ha/annum) (Table 4.7; Figure 4.15). Phosphorus was highest in the Mthinzima (TP – 0.45 and SRP – 0.26 kg/ha/annum), while the loads per hectare emanating from the Gqishi and Khayalisha were similar, with marginally higher loads from the Gqishi sub-catchment (Table 4.7; Figure 4.15).

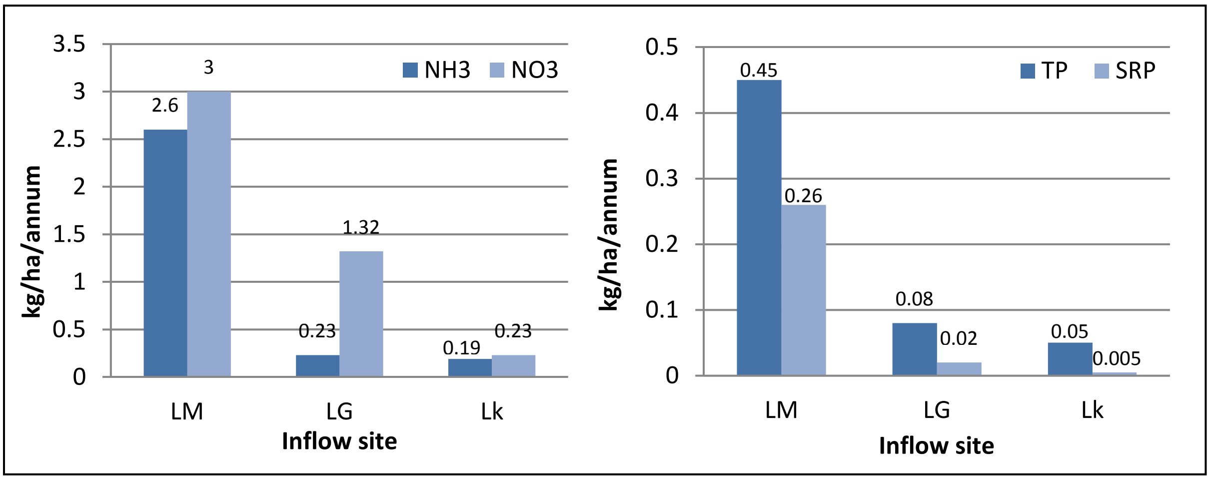


Figure 4.15: Nitrogen and phosphorus loading at Midmar inflow sites (kg/ha/annum) (graph scales differ)

4.7. Conclusion

There are distinct differences between water quality drivers in the three sub-catchments. Most notable from the suite of physical, chemical and biological parameters was the predominance of nutrient (nitrogen and phosphorus compounds) inputs into the systems from different sources. The concentrations of other parameters reinforce the presence of anthropogenic nutrient inputs, which deserve discussion in the chapter that follows. Both the Mthinzima and the Gqishi sub-catchments display a decline in water quality from upstream to downstream sites. In the Mthinzima sub-catchment the magnitude of *E. coli* counts downstream of Mpophomeni point towards substantial faecal contamination of the waterways, subsequently nutrient compounds and other water quality parameters are elevated. In the Gqishi sub-catchment the decline of water quality coincides with the prevalence of commercial agricultural, with increases in nutrient and other compounds, yet not to the same extent in the Mthinzima sub-catchment. The SASS5 indices in both sub-catchments respond according to water quality trends, with declines downstream of Mpophomeni and in areas of commercial agriculture.

The principle component analysis provides a clear pollution gradient (PC1) whereby sites downstream of Mpophomeni were distributed on the positive side of the pollution gradient, and the site upstream of Mpophomeni and the site in forestry occurred on the opposite side of the pollution gradient. Sites in commercial agriculture were distributed in the mid-ranges of the pollution gradient, although tending towards the negative side as a result of pollution inputs. All SASS5 indices were at their lowest on the positive side of the pollution gradient illustrating the link between SASS5 indices and water quality.

The non-metric multidimensional scaling (NMS) of invertebrate families illustrated the distinctness in family composition at sites downstream of Mpophomeni, comprised primarily of tolerant taxa. The remaining sites, although variable, were represented by increased family diversity and less tolerant taxa. The cluster dendrogram further illustrates the distinctness in invertebrate family composition at sites downstream of Mpophomeni. The most notable trend in the nitrogen to phosphorus ratios was the prevalence of nitrogen limitation at sites downstream of Mpophomeni, whilst the nutrient loads from the Mthinzima were the highest, followed by the Gqishi and the Khayalisha.

CHAPTER FIVE

DISCUSSION

5.1. Introduction

This chapter focuses on the water quality and SASS5 trends of the three sub-catchments and presents possible reasons for the observed and measured trends. The link between water quality and SASS5 indices are discussed, commenting on the applicability of the SASS5 methodology in depicting water quality trends. The role of land use in determining water quality is put forward and justification for differences in inter-catchment water quality and nutrient loads discussed. The implications of the findings are placed in the context of the upper uMngeni catchment, the greater uMngeni system and South African water resources.

5.2. Mthinzima sub-catchment

The recurring theme in the Mthinzima sub-catchment was the deterioration of water quality and ecological condition from sites upstream to downstream of the Mpophomeni settlement. The data clearly illustrates a system in which water quality is driven by point source sewage inputs, both within the Mthinzima main channel (MM) and the tributary that dissects Mpophomeni (M-trib). At these points, the water quality and ecological integrity was the poorest consistently over the sampled period. *Escherichia coli* (*E. coli)* counts recorded support this, with counts upstream of Mpophomeni negligible in comparison to downstream sites, isolating Mpophomeni as the source. The observation of damaged and surcharging sewer manholes discharging into the water course supports this viewpoint. *E. coli* are a bacteria abundant in the intestinal tracts of humans and other endothermic mammals (Yost *et al.,* 2011), and are released into the environment by excretion. *E. coli* counts at LM were substantially lower than those at MM and M-trib, which could be attributed to bacterial die-off, as they are not naturally occurring in aquatic systems (Flint, 1987).

The presence of faecal material in the water course downstream of Mpophomeni resulted in high concentrations of other chemical and physical water quality parameters. The most notable was the phosphorus and nitrogen compounds, conductivity, suspended solids and total organic carbon which were elevated at downstream sites (MM, M-trib and LM). Raw sewage entering an aquatic system contains high concentrations of urea, which accounts for the elevated ammonia (NH_3) concentrations at MM, M-trib and LM. Ammonia is oxidised by bacteria into nitrite (NO_2) and rapidly into the end-product of the oxidisation process, nitrate (NO_3) (DWAF, 1996a). All sites had a similar range of nitrite concentrations due to the rapid inter-conversion of nitrite to nitrate, however nitrate concentrations were high downstream of Mpophomeni, most notably at LM where the Mthinzima flows into Midmar. At this point raw sewage discharged into the water course upstream has been oxidised into nitrate, the end-product of nitrogen cycling and a nutrient readily available for uptake by lower order aquatic organisms such as macrophytes (Van Ginkel, 2002).

Sewage effluent contains high concentrations of phosphorus compounds as measured at sites downstream of Mpophomeni. The analysis of total phosphorus versus soluble reactive phosphorus, demonstrates that a large portion of all phosphorus compounds entering the Mthinzima, as a result of Mpophomeni, were in a soluble form, readily available for uptake by aquatic plants. Excess of soluble forms of phosphorus in conjunction with excess nitrogen compounds at MM, M-trib and LM pose a eutrophication threat, as phosphorus and nitrogen compounds are regarded as the limiting nutrients in aquatic systems (DWAF, 1996a). The high total organic carbon, suspended solids and conductivity at sites downstream of Mpophomeni, demonstrate the presence of sewage discharges in the water course. A water body will contain some degree of suspended solids, and organic matter (Bilotta and Brazier, 2008); however in comparison to upstream of Mpophomeni (UM), sites downstream had very high concentrations. Sewage contains high organic matter content, which was represented by the high concentrations of total organic carbon and total Kjeldahl nitrogen (TKN), which measures the ammonia nitrogen and organically bound nitrogen (Chapman, 1996). The presence of sewage in the water course explains the low dissolved oxygen concentrations at sites downstream of Mpophomeni, as bacterial organisms degrade organic matter in the process of oxidisation, thus lowering the amount of dissolved oxygen available (DWAF, 1996a).

There were improvements in water quality from the sites immediately downstream of Mpophomeni (MM and M-trib) and the Mthinzima Midmar inflow (LM). This was evident by the reduction in physical and chemical concentrations, namely conductivity, ammonia, total phosphorus, soluble reactive phosphorus and total organic carbon and the increase in dissolved oxygen. A wetland is present downstream of Mpophomeni prior to the inflow site (LM), which could explain the reduction in some of the pollutants’ concentrations, due to the purification functions of wetland systems. However, the functionality of the wetland is impeded as it is for the most part channelised, thus minimising retention times for pollutants. The improvements in water quality from sites directly downstream of Mpophomeni to the inflow into Midmar Dam cannot be entirely explained by the presence of a marginally functioning wetland. The system itself is altered and degraded to the point whereby bacterial communities dominate the aquatic environment, thus oxidising pollutants and partially treating the raw sewage (Terry, 2011, pers. comm).

The macroinvertebrate data and the associated SASS5 indices reiterated the water quality trends depicted by the physical and chemical water quality results. Upstream of Mpophomeni (UM), the number of taxa, SASS5 score and average score per taxa (ASPT) were substantially higher then sites downstream of Mpophomeni (MM and LM), illustrating a decline in the ecological integrity of the system as water quality deteriorates. This was supported by the principle component analysis (PCA) and the non-metric multidimensional scaling (NMS). Sites downstream of Mpophomeni were representative of tolerant taxa with low sensitivity scores, whereas upstream, taxa had higher sensitivity scores as illustrated by ASPT (Table 4.1; Figure 4.2; Appendix B). Taxa upstream were more sensitive to perturbations in water quality and exist within a narrower range of environmental tolerances, whereas taxa downstream of Mpophomeni were more tolerant to a wide range and poorer water quality conditions. The seasonal variation in invertebrate family composition represented in the NMS plot (Figure 4.9) was greater downstream of Mpophomeni (MM and LM), which was structured by the same seasonal variation in water quality trends as depicted in the PCA (Figure 4.7). Upstream of Mpophomeni, less seasonal variation exists in invertebrate family composition, again possibly accounted for by the low seasonal variability in water quality (Figure 4.7; Figure 4.9). Water quality improvements between MM and LM were depicted in the SASS5 indices, with improvements in the number of taxa, SASS5 score and ASPT from MM to LM (Table 4.2; Figure 4.12). This improvement coincides with the improvement in physical and chemical water quality.

Dissolved oxygen can be viewed as one of the reasons for the low SASS5 indices at sites downstream of Mpophomeni, as a result of sewage inputs. Oxidisable organic matter in the aquatic environment is degraded through bacterial action using oxygen, thus decreasing the available oxygen to other organisms. Low dissolved oxygen saturations have far reaching impacts on aquatic biota such as invertebrates, most notably those with gills. Extended periods of low dissolved oxygen levels can prove intolerable or fatal to invertebrates by restricting respiratory requirements (Landman and van den Heuvel, 2003). Furthermore, reduced dissolved oxygen increases the toxicity of ammonia which was also in high concentrations at sites downstream of Mpophomeni, causing compound stress on aquatic organisms (DWAF, 1996a).

5.3. Gqishi sub-catchment

The Gqishi system was represented by a clear decline in water quality from sites upstream at its source in forestry to downstream areas dominated by mixed agriculture. Nutrient (NH_3, NO_3, TP and SRP) concentrations were lowest in areas under plantation (UG) and where land use changes from plantation to cultivation (MG). Mean concentrations of NO_3, TP and SRP were marginally higher under plantations (UG) than at MG (transition to agriculture); however concentrations at both sites were sufficiently low not to be of serious environmental concern. The presence of a dam 500 metres upstream of MG could explain the marginally lower nutrient concentrations, as nutrients entering the impoundment are retained and taken up by aquatic organisms, thus reducing their availability downstream. Furthermore, MG was located at the transition from forestry to agriculture and the cumulative effects of this change are not yet felt, furthermore MG does not receive run-off from a sizable area of agriculture. The major distinguishing variables between UG and MG were ammonia, dissolved oxygen, total organic carbon and conductivity which were all higher at MG, with the exception of dissolved oxygen which was higher at UG. Lower dissolved oxygen at MG could be as a consequence of increased levels of ammonia and total organic carbon which point towards a rise in organic matter content, likely as a result of livestock faeces entering the water course.

The effects of intensive cultivation and livestock become increasingly evident at sites downstream. G-trib and LG illustrate the cumulative impact commercial agriculture has on nutrient pollution with substantially higher NH_3, NO_3, TP and SRP concentrations compared to the upstream reaches of the Gqishi system. Commercial agriculture is associated with high nutrient inputs due to the use of fertilisers, pesticides and run-off containing nutrient rich feeds and faecal matter (Strydom and King, 2009). Water from irrigation or rainfall runs-off the land surface, flushing residues from the surrounding agricultural practices into the aquatic environment, disrupting the nutrient balance and altering the physical and chemical properties of the water (Tong and Chen, 2002). *E. coli* counts suggested that faecal contamination was not a major contributor to nutrient concentrations, although some contribution was made, likely as a result of run-off from livestock lots. The foremost contributors to nutrient concentrations were the use of inorganic fertilizers in surrounding areas of cultivation. Fertilizers contain high levels of nitrogen, potassium and phosphorus, which are applied to cropped land as a means of increasing the productivity of soil and thus increasing yield (Shortle and Abler, 2001). Nutrient concentrations flowing into Midmar (LG) were lower than G-trib, which can be attributed to the presence of a dam 450 metres upstream of LG, retaining nutrients and allowing for their degradation and uptake by aquatic plants.

Suspended solids were a distinguishing variable between upstream sites (UG and MG) and sites downstream (G-trib and LG) where agriculture dominates, with approximately a 400% increase from upstream to downstream sites. This increase was possibly as a consequence of run-off from cultivated land containing sediment and other residues, occurring during rainfall periods, or as irrigation return flow. Natural suspended solids are comprised of soil particles produced through erosive processes; however, land use practices such as agricultural may increase suspended solids through removal of riparian vegetation, non-contour ploughing, over-grazing and increased surface flow through irrigation (DWAF, 1996a).

SASS5 results were, for the most part, representative of water quality changes in the Gqishi system, with declines in SASS5 indices from upstream in forested areas (UG) to downstream in commercial agricultural (LG). However MG was an exception, predominantly as a result of physical disturbance, through the failure of the dam wall directly upstream of MG a week prior to the March 2011 sample period. SASS5 results prior to the breakage fell into the 'Fair' (C) and 'Good' (A) categories of ecological condition (Dallas, 2007); following the breakage, the aquatic habitat had been altered and although biotopes were available for sampling, the system had been flushed and scoured and biotopes were silted. As a result, all three SASS5 indices declined, with the following sample period yielding a 'Poor' ecological condition (Dallas, 2007). Due to the rapid life cycles and unique life stages of many aquatic invertebrates, their populations recovered rapidly, which was evident in the increase in the SASS5 indices the following sample period. Although an improvement was seen, continued repairs being carried out on the dam wall meant that MG was continually affected by fine particulate matter which covered most biotopes. Although the breakage had localised effects on biota and water quality, the influential driving trends within the catchment remain; that is the decline in the systems water quality from areas of forestry to areas of high density commercial agriculture and the associated decline in ecological condition of the system, based on the SASS5 responses to water quality.

5.4. Khayalisha sub-catchment

The Khayalisha sub-catchment was sampled at the inflow into Midmar Dam as a means of understanding the current status of water quality entering the impoundment. By understanding the present water quality inputs from this system, baseline data was collected for this sub-catchment, which can be utilised into the future to understand impacts associated with the Khayalisha social housing project. Furthermore, the state of the water quality was compared to that entering Midmar Dam from the Mthinzima system, highlighting concerns associated with developing high density urban areas adjacent to waterways of strategic significance. *E. coli* counts were low suggesting the lack of faecal contamination in the system. Present land use in the Khayalisha sub-catchment is dominated by natural cover and agriculture (SANBI, 2009), similar, yet on a smaller scale, to the Gqishi sub-catchment. Conductivity at LK was consistently higher than the majority of the sites, with the exception of the sites downstream of Mpophomeni and could be explained by low flow conditions and the presence of organic matter. Total organic carbon concentrations were high and comparable with that of the Mthinzima Midmar inflow (LM); this was accompanied by low dissolved oxygen pointing towards the presence of oxidisable organic matter. Nutrient concentrations (nitrogen and phosphorus compounds) at the Khayalisha inflow were low, falling within the lower third of all sites sampled, with concentrations representative of oligotrophic conditions (DWAF, 1996a). Current water quality trends in the Khayalisha sub-catchment present no threat of pollution to Midmar Dam. The dam directly upstream of the sample point likely acts as a retainer of pollutants whereby they are taken-up by lower order aquatic organisms or absorbed into the sediment (Van Ginkel, 2011).

5.5. SASS5 applicability

SASS5 proved successful as a bio-monitoring technique to assess water quality and the ecological integrity of the aquatic environment. In both the Mthinzima and Gqishi sub-catchments, SASS5 results reflected changes in physical and chemical water quality. Both systems displayed declines in SASS5 indices associated with declines in water quality from upstream to downstream sites. In the Mthinzima system this was as a result of the settlement, whereas in the Gqishi system, the prevalence of agriculture was the cause. Further detailed analysis concurred with this observation through the emergence of a pollution gradient (PC1) in the principle component analysis (PCA) of the physical and chemical variables (Figure 4.6; Figure 4.7). The correlation between the SASS5 indices and the PCA (Table 4.4; Figure 4.8) illustrated that the SASS5 indices were an effective method of detecting changes (both declines and improvements) in water quality, evident by the linear decline in SASS5 indices along PC1. This was evident in the strong positive correlations between PC1 of the PCA and Axis 1 of the non-metric multidimensional scaling (Table 4.5; Figure 4. 11), which illustrates that PC1 (pollution gradient) was highest where all three SASS5 indices were at their lowest and macroinvertebrate families present were tolerant of poor water quality conditions (Figure 4.10). Furthermore, the SASS5 sampling methodology yielded other aquatic biota not intended to be sampled, including amphibians and fish. Most notable was the presence of indigenous fish species at upstream sites in both the Gqishi and the Mthinzima sub-catchments. In the Gqishi sub-catchment an *Amphilius natelensis (*Natal mountain catfish) was recorded and in the Mthinzima *Barbus viviparous* (bow-striped barb) were recorded on a number of occasions. The presence of these species point towards long-term ecosystem stability and quality, as fish life stages are entirely water bound. The sites at which the indigenous fish were recorded were the sites at which the SASS5 indices were highest.

5.6. Land use, water quality and nutrient loading

At a catchment scale, the three systems were distinct in their drivers of water quality. The Mthinzima sub-catchment, containing the highest density development within the greater upper uMngeni catchment, is a system driven by point source effluent discharges from broken and dysfunctional sewage infrastructure. *E. coli* counts point towards this deduction, as do the resultant high levels of nutrients and other physical and chemical variables. *E. coli* counts recorded downstream of Mpophomeni were consistently in excess of the target range (DWAF, 1996b), at levels posing a risk of serious gastrointestinal illness (DWAF, 1996b), in an area lacking in service delivery. This was especially alarming due to the observed abstraction of water for irrigation and the use of the waterway by the community dogs and livestock, all of which are potential hosts to a number of diseases.

The Gqishi sub-catchment is a system in which the water quality was governed by non-point source discharges as a result of run-off from mixed agricultural practices, accompanied by high nutrient (nitrogen and phosphorus) concentrations. Water quality in the up stream reaches of the Gqishi in areas of forestry was consistently good. Streams in forested areas are recognised to have exceedingly lower nitrogen and phosphorus levels in comparison to streams draining agricultural areas. The forestry industry makes use of fewer fertilizers as compared to agricultural practices, which could explain the differences in nutrient concentrations (Binkley *et al.,* 1999). The three sub-catchments all vary in size, flow and land use and variations in nutrient loads occur accordingly. The highest ammonia (NH_3) loads (kg/annum) were generated within the Mthinzima sub-catchment followed by the Gqishi and lastly the Khayalisha sub-catchment. In the case of NO_3 loads, the Gqishi produced the highest loads per annum followed by the Mthinzima and lastly that produced by the Khayalisha sub-catchment (Table 4.7). Nitrogen loads (NH_3 + NO_3) were greatest from the Mthinzima sub-catchment. A similar trend exists with regards to phosphorus loading with the largest loads (kg/annum) emanating from the Mthinzima followed by the Gqishi and lastly the Khayalisha sub-catchment (Table 4.7).

Although the Gqishi sub-catchment is 3.4 times larger than the Mthinzima, nitrogen (with the exception of NO_3) and phosphorus loads generated by the Mthinzima were in excess of those produced by the Gqishi. Water quality results at sites specifically located along the river gradient isolated areas responsible for nutrient inputs, with Mpophomeni as the source in the Mthinzima and agriculture the source in the Gqishi. Based on the size of the source land use, urban development in the Mthinzima produced higher nutrient loads as compared to agriculture per hectare land use. Although the Mthinzima discharges higher nutrient loads into Midmar Dam annually, the magnitude of the loads from the Gqishi are of concern. Nitrogen to phosphorus (N: P) ratios upstream of Mpophomeni (UM) illustrate that before the system flows adjacent to the settlement, phosphorus is the limiting nutrient, which suggests a system in better condition, which has already been established. N: P ratios downstream of Mpophomeni point towards a state under which nitrogen is becoming the limiting nutrient.

From a eutrophication perspective, nitrogen limitation is concerning as nitrogen is likely to be fixed resulting in additional available nitrogen (DWAF, 1996a). Cyanobacteria are one bacterium able to fix nitrogen in a nitrogen limited system; their growth is thus promoted and there is a threat of their toxins entering the aquatic environment (Van Ginkel, 2002). The concentrations of nutrients available in the Mthinzima coupled, with the potential nitrogen limitation, increases the risk of eutrophication. The Khayalisha-Midmar inflow site (LK) points towards a N: P ratio closer to nitrogen limitation as opposed to phosphorus limitation, however the nutrient concentrations recorded at this site are of negligible eutrophication concern, further solidified by the marginal nutrient loads discharged at the site. N: P ratios in the Gqishi were highest at forested sites, whereby phosphorus is the limiting nutrient, a desirable state from a eutrophication perspective (Van Ginkel, 2002). G-trib draining a large area of agriculture had an exceedingly low N: P ratio indicating nitrogen limitation (DWAF, 1996a; Van Ginkel, 2002). At the Gqishi-Midmar inflow site (LG) the system shifted towards a state tending to phosphorus limitation, however the N:P ratio cannot be considered of no concern, especially in light of the nutrient concentrations and loads entering Midmar at this site.

5.7. Upper uMngeni catchment implications

The Khayalisha sub-catchment is the smallest of the three sub-catchments and is under threat from land transformation in the form of the Khayalisha social housing project. Currently the land cover is dominated by natural grassland and cultivation (SANBI, 2009). The Khayalisha social housing project will transform the land cover in the sub-catchment with the addition of 178 hectares of high density urban development; an increase from 1.6 % of the catchment under urban land use to 18.4%. On completion, the development will be the second largest in the greater upper uMngeni catchment, after that of the adjacent Mpophomeni. Water quality analysis at sites downstream of Mpophomeni illustrate the detrimental nature of developing high density urban areas in close proximity to water courses, even more so when the water courses feed a principle drinking water resource. The nature of the Khayalisha development poses a threat of duplicating the issues and impacts witnessed at Mpophomeni, which themselves have not been fully addressed. Furthermore, the sewage contamination issues present at Mpophomeni, and sewage treatment plant upgrade, have not yet been addressed (Appendix A) (Douman, 2008; Beaver, 2011; Govender, 2011; Radebe, 2012). Presently the water quality, and the nutrient loads entering Midmar from the Khayalisha sub-catchment are of little concern in terms of eutrophication but evident from Mpophomeni, the presence of development could drastically alter this state. Both the Mthinzima and the Gqishi sub-catchments are producing nutrient levels of eutrophication concern, with the Mthinzima the more extreme of the two. Nutrient concentrations flowing into Midmar from the Gqishi were mesotrophic or eutrophic, whereas those from the Mthinzima were eutrophic to hypertrophic (DWAF, 1996a). The upper uMngeni catchment is representative of the land use practices occurring in the Gqishi sub-catchment, dominated by natural cover, plantation and cultivation (SANBI, 2009). In isolation the nutrient loads from the Mthinzima or that of the Gqishi may seem of marginal concern considering the scale of the catchments, however when viewing the broader scale implications, the compound effect of Mpophomeni, the nutrient inputs from the Gqishi and that of the greater upper uMngeni, coupled with the impact of the emerging Khayalisha development, a tipping point may be reached whereby a principle water resource could be compromised. This will come at a cost to all users both domestic and recreational and municipalities will bear the burden of increased purification costs or deficits in supply.

Pressure on the upper uMngeni resource unit is already emerging in the form of increases in demand from the eThekwini municipality, whereby areas of the eThekwini municipality are to be served by Midmar Dam instead of the lower uMngeni, in a load shifting exercise (Ramnath, 2010). The Mooi-uMngeni transfer scheme to be commissioned in 2013, aims to generate more yield from the upper uMngeni resource unit; however it has been realised that the scheme will not sustain the demand presented by the load shift for extended periods (Ramnath, 2010). It is evident that from a supply perspective, the upper uMngeni is under pressure from domestic demand; this, along with the emerging water quality threats poses both environmental and socio-economic issues in the catchment.

The desirability of an impoundments trophic status is dependent on the intended use of the water body. Oligotrophic systems are most desirable for domestic consumption as they require the least amount of treatment. At the opposite end of the scale, eutrophic and hypertrophic systems are the least desirable due to purification requirements (Hohls *et al.*, 2002). Currently Midmar Dam is in a mesotrophic state, between these extremes, which can be characterised by high productivity, high species diversity, and nuisance growth of aquatic plants and algae, although seldom toxic (DWAF, 1996a). Observed nutrient loads generated from the catchments under study have the potential to contribute to the shift of Midmar Dam into a eutrophic state, accompanied by high productivity, low species diversity and algal blooms that can prove toxic (DWAF, 1996a). The nutrient enrichment taking place promotes the growth of low order aquatic organisms such as macrophytes (Van Ginkel, 2002); this increase in productivity will be accompanied by large bacterial communities using available oxygen and increasing biological oxygen demand, while decreasing oxygen availability to other aquatic organisms (Correll, 1998). This will alter the structure of aquatic communities at the cost of aquatic biodiversity. Under enriched conditions, the growth of toxic species of algae will be favoured within the impoundment, toxins which will affect both terrestrial and aquatic biota and are transferred along trophic levels through bio-accumulation (Camargo and Alonso, 2006). In terms of the usability of the resource, extreme circumstances such as this will have far reaching impacts for this strategically significant resource, one already pressured by increases in domestic demand.

5.8. Conclusion

The impacts assessed in the upper uMngeni catchment pose a severe long-term risk to the state of Midmar Dam as a freshwater drinking resource, not only in terms of the elevated risks associated with nutrient inputs from Mpophomeni, but the compound impacts from agricultural practices in the greater upper uMngeni and the emergence of new developments such as Khayalisha in the future. The uMngeni catchment is of vital importance with regards to Kwazulu-Natal's water supply and needs to be managed accordingly, from source to river mouth. Midmar Dam supplies safe, clean drinking water to the eThekwini, uMgungundlovu and Msunduzi municipalities, with a current demand of 268 million litres per day (Ramnath, 2010). The importance of the impoundment as a primary water resource cannot be overstated. In a eutrophic state the strategic importance of Midmar Dam as a drinking water supply will be compromised, furthermore, of the four major impoundments along the uMngeni River, two (Albert Falls and Inanda) are moving to a eutrophic state (Hols, 2002). The importance of conserving a strategic water resource such as the uMngeni River in its headwaters is of vital importance due to its cumulative downstream affects.

CHAPTER SIX

CONCLUSIONS

6.1. Introduction

This chapter addresses the aim and objectives of the research, assessing if and how objectives were met. The chapter concludes by considering the general trends by addressing the outcome of each objective and the over-arching aim.

6.2. To undertake water quality assessment and SASS5 bio-monitoring to investigate the impact of Mpophomeni settlement and other land uses on water quality of stream networks draining into Midmar Dam

The site placement, sampling techniques and analytical methodology used allowed deductions to be made with regards to the impact of Mpophomeni settlement and other mixed land uses on water quality and ecosystem health of river networks.

6.3. Establish sites isolating areas of pollution concern

Sites in the Mthinzima and Gqishi systems were effective in isolating areas responsible for pollution inputs into the relative systems and the Khayalisha site acted as a baseline site for current water quality conditions in this sub-catchment. In the Mthinzima sub-catchment, the site upstream of the settlement provided a baseline against which sites downstream could be compared. Water quality and ecosystem health of sites downstream could be attributed to the presence of urban development in the form of Mpophomeni. In the Gqishi sub-catchment, sites located along the stream gradient recorded pollution inputs into the system by accounting for changes in land use and associated non-point source inputs from upstream in areas of forestry to downstream in areas of commercial agriculture. Physical, chemical and biological water quality analysis and SASS5 results, illustrated that site location proved successful in pointing towards land-based sources of water quality impacts.

6.4. Assess the impact of Mpophomeni settlement and other land uses on water quality and ecological integrity of the Mthinzima and Gqishi sub-catchments draining into Midmar Dam

The impact of Mpophomeni settlement on stream water quality and ecological integrity in the Mthinzima flowing into Midmar Dam was established through water quality and SASS5 monitoring. It was established that sewage discharges from broken and blocked sewage infrastructure was entering the Mthinzima main channel and the tributary that dissects Mpophomeni. This was evident through visual observation, backed-up by the elevated *E. coli* counts. Water quality was poor at sites immediately downstream of the settlement with some improvement before flowing into Midmar Dam. The most notable impact of the settlement was the increased concentrations of nitrogen and phosphorus compounds as a result of raw sewage. Excess nutrients (nitrogen and phosphorus) entering an aquatic environment can alter the trophic status of the system and cause a structural change in aquatic communities. Excess oxidisable organic matter entering the stream network causes decreases in dissolved oxygen and dominance of bacterial communities. The response of the Mthinzima ecological condition was evident in the SASS5 results, which responded in accordance to water quality, illustrating a system poor in invertebrate diversity, where only highly tolerant taxa were prevalent. This was the case for all sites downstream of Mpophomeni, a marked change from the upstream site which represented a diverse system of better quality and ecological condition.

Selected sites in the Gqishi system showed that prevailing stream water quality and ecological integrity could be attributed to surrounding land use activities. It was established that sites located in forestry had exceedingly better water quality and ecosystem health. Nutrient concentrations were lowest in forestry and dissolved oxygen was highest as a result, invertebrate communities were diverse and families with higher sensitivity were more prevalent. Agriculture had the most notable impact on stream water quality with a marked decline from areas of forestry. This decline was mirrored by declines in SASS5 indices, most notable by a shift to less sensitive invertebrates. In contrast to the Mthinzima sub-catchment, the nutrient concentrations were as a result of agricultural inputs rather than faecal matter entering the system, evident by relativity low *E. coli* counts but high nitrogen and phosphorus concentrations.

6.5. Assess the status of water quality entering Midmar from the Khayalisha sub-catchment

The Khayalisha inflow site was established as a means of assessing the current status of water quality originating from this sub-catchment in light of the Khayalisha social housing project. Currently the water quality is good and although not pristine, due to prevailing land uses, is of marginal water quality concern to Midmar Dam. Nutrient (nitrogen and phosphorus) concentrations and loads were sufficiently low to be of little concern in terms of eutrophication. Current land-based activities in the sub-catchment are not proving detrimental to the quality of water in Midmar Dam. The current state of water quality in this sub-catchment is under threat from land transformation in the form of the Khayalisha social housing project; which due to its placement could replicate the conditions prevailing at Mpophomeni.

6.6. Compare nutrient loads entering Midmar from the Mthinzima, Gqishi and Khayalisha sub-catchments

By establishing sites at the Midmar inflow of the three respective sub-catchments, nutrient (nitrogen and phosphorus) concentrations could be used to calculate nutrient loading by using simulated flow data (Warburton et al., 2010). The nutrient loads from the three sub-catchments varied, with the highest loads from the Mthinzima sub-catchment as a result of sewage inputs from inadequate sewage infrastructure in Mpophomeni. This was deduced by the high *E. coli* counts at sites downstream of Mpophomeni, as compared to sites upstream which were predominantly unaffected. As a result, nutrient concentrations were substantially high which resulted in high nitrogen and phosphorus loads entering Midmar Dam. Nutrient loads were sufficiently high to warrant eutrophication concern whereby Midmar Dam, a principle water resource, is under threat.

Nutrient loads from the Gqishi sub-catchment were lower than that of the Mthinzima; not sufficiently low enough, however, to be of no management concern, especially in the case of Nitrate (NO_3) loads. The level of *E. coli* counts established that faecal matter was not the primary source of nutrient loading. It was therefore deduced that fertilisers containing nitrogen and phosphorus compounds, used in commercial agricultural practices, were the source of the nutrient inputs. The most notable trend in nutrient loads was the nitrate loads which in contrast, to the other nutrient loads, were higher than those from the Mthinzima.

Loads entering Midmar from the Khayalisha sub-catchment were negligible in comparison to those produced by the Mthinzima and the Gqishi. This was both as a result of low nutrient concentrations and low stream discharge. Land use in the Mthinzima is dominated by urban development in the form of Mpophomeni, which was the source of the poor water quality in surrounding streams. Upstream in peri-urban/grassland areas, water quality and ecological integrity of the system was good. In the Gqishi sub-catchment water quality was governed by prevailing land activities, whereby upstream areas, dominated by forestry represented good quality water and ecological health. The change in land use to commercial agriculture was coupled by a decline in water quality and ecological health.

6.7. Evaluate the sampling and analysis techniques used

Site selection, sample strategy, and methods of analysis and interpretation proved successful in understanding the effects of the Mpophomeni settlement and other mixed land uses on water quality entering Midmar Dam. The multi-metric approach to the methods of analysis and interpretation allowed findings to reinforce each other and illustrate data interrelatedness. Furthermore, the use of bio-monitoring techniques alongside conventional physical, chemical and biological water quality analysis, illustrated the link between water quality and ecological integrity of freshwater systems. This resulted in a comprehensive understanding of the effects land use (such as development and agriculture) on various facets of the freshwater systems in the upper uMngeni.

6.8. Conclusion

The issues surrounding Mpophomeni are rooted in municipal service delivery based around solid waste and sewage infrastructural issues. The Khayalisha EIA (EIA-5349) stipulated (ROD 10.10) that the Mpophomeni wastewater treatment plant was to be upgraded if the project was to go ahead. The upgrade was commissioned in 2008 and has not yet been addressed. Currently domestic wastewater from Mpophomeni is piped to Howick for treatment, which itself is plagued by under performance and requires an upgrade. The justification for the development of the Khayalisha social housing project is to relocate informal settlers from areas in Howick. This is of undeniable importance in a country striving to eradicate past social inequalities and promote socio-economic development; however the lessons learned from the water quality analysis in Mpophomeni illustrate that further development in the area is unsustainable and poorly located, unless relevant services are adequately provided. In a rapidly developing country the issues raised herein illustrate the necessity of balancing development with environmental protection; whereby if one must supersede the other, the impacts must be minimised. This is of vital importance due to the transformation of land near waterways and requires integrated management of water resources whereby past lessons and proactive monitoring forms the basis of decisions. With freshwater supply deficits projected in South Africa by 2025, water quality must be managed to ensure available water is in a usable state for both humans and ecosystem functionality.

REFERENCES

Abdi, H. and Williams, L. J. 2010: *Principal Component Analysis*, computational statistica, Wiley Interdisciplinary Reviews, Texas.

Abonyi, J. and Feil, B. 2007: *Cluster analysis for data mining and system identification*, Birkhauser, Berlin.

Allan, D. J. 2004: Landscapes and Riverscapes: The Influence of Land Use on Stream Ecosystems, *Annual Review of Ecology, Evolution and Systematics*, 35, 257-84.

Aldendefer, M. S. and Blashfield, R.K. 1984: *Cluster analysis*, Sage publications, California.

Amisah, S. and Coux, I. G. 2000: Response of the fish populations of the River Don in South Yorkshire to water quality and habitat improvements, *Environmental Pollution*, 108, 191-199.

Azrina, M. Z., Yap, C. K., Rahim Ismail, A., Ismail, A. and Tan, S.G. 2006: Anthropogenic impacts on the distribution and biodiversity of benthic macroinvertebrates and water quality of the Langat River, Peninsular Malaysia, *Ecotoxicology and Environmental Safety*, 64, 337-347.

Batley, G. E. and Simpson, S. L. 2009: Development of guidelines for ammonia in estuarine and marine water systems, *Marine Pollution Bulletin*, 58, 1472-1476.

Barimo, J. F. and Walsh, P.J. 2005: The effects of acute and chronic ammonia exposure during early life stages of the gulf toadfish, *Opsanus beta*, *Aquatic Toxicology*, 75, 225-237.

Beaver, T. 2011: Threat to Midmar, the Witness Newspaper (03/01/2011).

Binkley, D., Burnham, H. and Allen, H. L. 1999: Water quality impacts of forest fertilization with nitrogen and phosphorus, *Forest Ecology and Management*, 121, 191 – 213.

Bilotta, G. S. and Brazier, R.E. 2008: Understanding the influence of suspended solids on water quality and aquatic biota, *Water Research*, 42, 2849-2861.

Camargo, J. A. and Alonso, 2006: Ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems: A global assessment, *Environment International*, 32, 831-849.

Carrero-colon, M., Wickham, G. S. and Turco, R. F. 2011: Taxonomy, phylogeny, and physiology of fecal indicator bacteria, in Sadowsky, M. J. and Whitman, R. L. (ed), *The fecal bacteria*, ASM press, Washington DC, p. 23-38.

Carson, R. L. 1962: *Silent spring*, Houghton Mifflin Company, New York.

Chapman, D. 1996: *Water quality assessment, a guide to the use of biota, sediments and water in environmental monitoring*, Taylor and Francis, New York.

Chutter, F. M. 1994: The rapid biological assessment of streams and river water quality by means of macroinvertebrate communities in South Africa. In Uys, M. C. (ed) Classification of Rivers and Environmental Health Indicators. Water Research Commission, Report No. TT 63/94, South Africa, p 217–234.

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

Collares-Pereira, M. J. 2004: The role of catchment scale environmental management in freshwater fish conservation, *Fisheries Management and Ecology*, 11, 303–312.

Correll, D. L. 1998: The role of phosphorus in the eutrophication of receiving waters: A review*, Journal of Environmental Quality*, 27, 261-266.

Dallas, H. F. 1997: A preliminary evaluation of aspects of SASS for the rapid bioassessment of water in rivers with particular reference to the incorporation of SASS in a national bio-monitoring Programme, *African Journal of Aquatic science,* 23, 79-84.

Dallas, H. F. 2005: River Health Programme: Site characterisation field-manual and field-data sheets, prepared for Resource Quality Services and the Department of Water Affairs and Forestry, Pretoria.

Dallas H. F. 2007: River Health Programme: South African Scoring System (SASS) Data Interpretation Guidelines, The Freshwater Consulting Group/Freshwater Research Unit, University of Cape Town, Prepared for Institute of Natural Resources and the Department of Water Affairs and Forestry, Pretoria.

Dallas, H. F. and Ketley, Z. A. 2011: Upper thermal limits of aquatic macroinvertebrates: Comparing critical thermal maxima with 96-LT50 values, *Journal of Thermal Biology,* 36, 322-327.

Department of Environmental Affairs and Tourism (DEAT). 1999: Accessed March 2011, from http://www.ngo.grida.no/soesa/nsoer/issues/water/index.html

Department of Environmental Affairs and Tourism (DEAT). 2006: South Africa Environment Outlook. A report on the state of the environment, Department of Environmental Affairs and Tourism, Pretoria.

Department of Environmental Affairs and Tourism (DEAT). 2009: South Africa's fourth national report to the convention on biological diversity, South African National Biodiversity Institute, Department of Environmental Affairs and Tourism, Pretoria.

Dickens, C. W. S. and Graham, M. P. 2002. The South African Scoring System (SASS) version 5, rapid bioassessment method for rivers, *African Journal of Aquatic Science,* 27, 1-10.

Douman, M. 2008: Midmar Dam will be contaminated, experts warn, The Witness Newspaper (30/07/2008).

Dudgeon, D., Arthington, A. H., Gessner, M. O., Kawabata, Z., Knowler, D. J., Leveque, C., Naiman, R. J., Prieur-Richard, A., Soto, D., Stiassny, M. L. J. and Sullivan, C. A. 2006: Freshwater biodiversity: importance, threats, status and conservation challenges, *Biol. Rev.* 81, 163-182.

Department of Water Affairs and Forestry (DWAF). 1996a: South African Water Quality Guidelines, Vol 7: Aquatic Ecosystems, Department of Water Affairs and Forestry, Pretoria.

Department of Water Affairs and Forestry (DWAF). 1996b: South African Water Quality Guidelines, Vol 2: Recreational Water Use, Department of Water Affairs and Forestry, Pretoria.

Department of Water Affairs and Forestry (DWAF). 2001: Quality of domestic water supplies, first edition. Vol 3: analysis guide, Institute for Water Quality Studies, Pretoria.

Department of Water Affairs and Forestry (DWAF). 2003: Management of Water-related Microbial Diseases, first edition. Vol 1: What in the problem? Disease Characteristics, Institute for Water Quality Studies, Pretoria.

Everitt, B. S., Landau, S., Leese, M. and Stahl. D. 2011: *Cluster analysis*, fifth edition. John Wiley and sons, Sussex.

Flint, K. P. 1987: The long-term survival of *Escherichia coli* in river water, *Journal of Applied Bacteriology,* 63, 261-270.

Gleick, P. H., A. Singh, and H. Shi. 2001: Emerging Threats to the World's Freshwater Resources. A Report of the Pacific Institute for Studies in Development, Environment, and Security, UNEP, Oakland, California.

Govender, D. S. 2011: Midmar Muck, Carte Blanche (22/05/2011).

Harwood, V. J., Ryu, H. and Domingo, J.S. 2011: Microbial source tracking, in Sadowsky, M. J. and Whitman, R. L. (ed), *The fecal bacteria*, ASM press, Washington DC, p. 189-216.

Hooda, P. S., Moynagh, M., Svoboda, I. F. and Miller, A. 2000: Macroinvertebrates as bioindicators of water pollution in streams draining dairy farming catchments, *Chemistry and Ecology*, 17(1), 17-30.

Hohls, B. C., Silberbauer, M. J., Kühn, A. L., Kempster, P. L. and van Ginkel, C. E. 2002: National water resource quality status report: Inorganic chemical water quality of surface water resources in SA, The big picture. Report No. N/0000/REQ0801. Institute for Water Quality Studies, Department of Water Affairs and Forestry, Pretoria.

Intergovernmental Panel on Climate Change (IPCC) (Kundzewicz, Z. W., Mata, L. J., Arnell, N. W., Döll, P., Kabat, P., Jiménez, B., Miller, K. A., Oki, T., Sen, Z. and Shiklomanov, I. A.). 2007: Freshwater resources and their management. *Climate Change 2007:* Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, in Parry, M. L., Canziani, O. F., Palutikof, J. P., van der Linden, P. J. and Hanson, C. E. (ed), Cambridge University Press, Cambridge.

Kalff, J. 2002: *Limnology: Inland water ecosystems*, Prentice Hall, New Jersey.

Karr, J. r., 1991: Biological Integrity: A long-neglected aspect of water resource management, *Ecological Applications,* 1 (1), 66-84.

Kidd, M. 2008: *Environmental law,* Juta, Cape Town.

Kirschner, A. K. T., Kavka, G. G., Velimirov, B., Mach, R. L., Sommer, R. and Farnleitner, A. H. 2009: Microbiological water quality along the Danube River: Integrating data from two whole-river surveys and a transnational monitoring network, *Water Research*, 43, 3673-3684.

Kleynhans, C. J. 1999: The development of a fish index to assess the biological integrity of South African rivers, Water SA, 25 (3), 265.

Kleynhans, C. J., Louw, M. D., Thirion, C., Rossouw, N. J., and Rowntree, K. 2005: River EcoClassification: Manual for EcoStatus determination (Version 1), Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. KV 168/05.

Kleynhans, C. J. 2007: Module D: Fish Response Assessment Index in River EcoClassification: Manual for EcoStatus Determination (version 2), Joint Water Research Commission and Department of Water Affairs and Forestry, Pretoria.

Lampert, W. and Sommer, U. 1997: *Limnoecology: the ecology of lakes and streams*, Oxford University Press, New York.

Landman, M. J. and van den Heuvel, M.R. 2003: An improved system for the control of dissolved oxygen in freshwater aquaria, *Water Research*, 37, 4337–4342.

Laurance, W. F., Albernaz, A. K. M., Schroth, G., Fearnside, P. M., Bergen, S., Venticinque, E. M. and Da Costa, C. 2002: Predictors of deforestation in the Brazilian Amazon, *Journal of Biogeography*, 29, 737-748.

Lushchak, V. 2011: Environmentally induced oxidative stress in aquatic animals, *Aquatic Toxicology*, 101, 13-30.

Malherbe, W., Wepener, V. and Vuren, J. H. J. 2010: Anthropogenic spatial and temporal changes in the aquatic macro invertebrate assemblages of the lower Mvoti River, KwaZulu-Natal, South Africa, *African Journal of Aquatic Science,* 35(1), 13–20.

McElhany, K. G. and Pillai, S. D. 2011: prevalence and fate of gut-associated human pathogens in the environment, in Sadowsky, M. J. and Whitman, R. L. (ed), *The fecal bacteria*, ASM press, Washington DC, p. 217-240.

McFarland, A. M. S. and Hauek, L. M. 200: Determining nutrient export coefficients & source loading uncertainty using in-stream monitoring data, Journal of the Amer. Water Res. Assoc. 37, 223-236.

McMillan, P. M 1998: An integrated Habitat Assessment System (IHAS v2), for the rapid biological assessment of rivers and streams. A CSIR research project, number ENV-P-1 98132 for the Water Resources Management Programme, CSIR.

Naidoo, N. 2008: Overhaul for sewage works, The Witness Newspaper (30/07/2008).

Noble, R. T., Moore, D. F., Leecaster, M. K. and McGee, C. D., Weisberg, S. B. 2003: Comparison of total coliform, faecal coliform, and enterococcus bacterial indicator response for ocean recreational water quality testing, *Water Research*, 37, 1637–1643.

Oberholster, P. J., and Ashton, P. J. 2008: State of the nation report: An overview of the current status of water quality and eutrophication in South African rivers and reservoirs, parliamentary grant deliverable, publisher unavailable.

Omar, K. B. and Barnard, T. G. 2010: The occurrence of pathogenic *Escherichia coli* in South African wastewater treatment plants as detected by multiplex PCR, *Water SA*, 36(2), 172-176.

PRIMER v. 6. 2009: PRIMER-E Ltd, Plymouth.

Radebe, M. 2012: Sewage seeps into Midmar, the Witness Newspaper (12/07/2012).

Ramnath, A. 2010: Umgeni Water infrastructure masterplan, planning services, engineering & scientific services division, Umgeni Water, Pietermaritzburg.

Republic of South Africa (RSA). 1996: Constitution of the Republic of South Africa Act No. 108, Government printers, Pretoria.

Republic of South Africa (RSA). 1997: Water Services Act No. 108, Government printers, Pretoria.

Republic of South Africa (RSA). 1998 b: Municipal Structures Act No.117, Government printers, Pretoria.

Republic of South Africa (RSA). 1998a: National Environmental Management Act No. 107, Government printers, Pretoria.

Republic of South Africa (RSA). 1998c: National Water Act No. 36, Government printers, Pretoria.

Republic of South Africa (RSA). 2008: National Environmental Management: Waste Act No. 59, Government printers, Pretoria.

Saunders, D. L., Meeuwig, J. J. and Vincent, A. C. J. 2002: Freshwater Protected Areas, Strategies for Conservation, *Conservation Biology*, 16 (1), 30-41.

Shortle, J. S., and Abler, D. G. 2001: *Environmental policies for agricultural pollution control*, CABI publishing, Wallingford.

Singh, K. P., Malik, A., Mohan,D. and Sinha, S. 2004: Multivariate statistical techniques for the evaluation of spatial and temporal variations in water quality of Gomti River (India)-a case study, *Water Research*, 38, 3980–3992.

South African National Biodiversity Institute (SANBI) 2009: National land cover database, South African National Biodiversity Institute.

Srivastava J., Singh, N., Chandras, H., Singh, D. and Nautiyal, A.R. 2009: Removal of soluble reactive phosphorus (SRP) from water by aquatic macrophytes, *Research in Environment and Life Sciences*, 2(3), 167-172.

Strydom, H. A. and King, N. D. 2009: *Environmental management in South Africa*, second edition, Juta Law, Cape Town.

Swatuk, L. A. 2002: The new water architecture in Southern Africa: Reflections on current trends in the light of 'Rio + 10', *International Affairs*, 78(3), 507-530.

ter Braak, C. and Šmilauer, P. 1997: Canoco for windows. Plant Research International, Wageningen, Netherlands.

Terry, S. 2011: Personal Communication, Umgeni Water, Pietermaritzburg.

Thirion, C. 2007: Module E: Macroinvertebrate Response Assessment Index in River EcoClassification: Manual for EcoStatus Determination (version 2), Joint Water Research Commission and Department of Water Affairs and Forestry report, Resource quality services, Pretoria.

Tong, S. T. Y., and Chen, W. 2002: Modelling the relationship between land use and surface water quality, *Journal of Environmental Management*, 66, 377-393.

Umgeni Water. 2010: Accessed 25 February 2011, from www.umgeni.co.za/profile/wqi.asp

United Nations. 2003: International Decade for Action, "Water for Life", UN Documents: Gathering a body of global agreements, Fifty-eighth session, Agenda item 95.

United Nations Environmental Programme. 2011: Accessed August 2011, from vital water graphics, http://www.unep.org/dewa/vitalwater/article69.html

United Nations-water. 2011a: Accessed August 2011, from http://www.unwater.org/downloads/waterquality_policybrief.pdf

United Nations - Water. 2011b: Accessed September 2011, from http://www.unwater.org/statistics.html

Van Ginkel, C. E. 2002: Trophic status assessment, Institute for Water Quality Studies, Department of Water Affairs and Forestry, Pretoria.

Van Ginkel, C. E. 2011: Eutrophication: Present reality and future challenges for South Africa, *Water SA*, 37(5), 693-702.

Vitousek, P. M., Aber, J., Howarth, R.W., Likens, G.E., Matson, P.A., Schindler, D. W., Schlesinger, W. H. and Tilman, G. D. 1997: Human Alteration of the Global Nitrogen Cycle: Causes and Consequences, *Issues in Ecology - Ecological Society of America*, 1, 1-16.

Vorosmarty, C.J., McIntyre, P.B., Gessner, M.O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S.E., Sullivan, C. A. Liermann, C.R. and Davies, P.M. 2010: Global threats to human water security and river biodiversity, *Nature*, 467, 555–561.

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

Warburton, M L., Schulze, R. E. and Jewitt, G. P. W. 2010: Confirmation of *ACRU* model results for applications in land use and climate change studies, *Hydrology and Earth System Sciences*, 14, 1 – 16.

Wcisło, R., and Chróst, R. J. 2000: Survival of *Escherichia coli* in Freshwater, *Polish Journal of Environmental Studies,* 9(3), 215-222.

Welch, E. B. 1992: *Ecological effects of wastewater: Applied limnology and pollutant effects*, Chapman and Hall, London.

Water Research Commission (WRC). 2002: State-of-Rivers Report: uMngeni River and neighbouring rivers and streams, WRC report no. TT 200 /02, Water Research Commission, Pretoria, ISBN No: 1 86845 899 7.

Yost, C. K., Diarra, M. S. and Top, E. 2011: Animals and humans as sources of fecal indicator bacteria, in Sadowsky, M. J. and Whitman, R. L. (ed), *The fecal bacteria*, ASM Press, Washington DC, p. 67-92.

Young, M. P., Scannell, J. W., O'Neill, M. A., Hilgetag, C. C., Burns, G. and Blakemore, C. 1995: Non-metric multidimensional scaling in the analysis of neuroanatomical connection data and the organization of the primate cortical visual system, *Philosophical Transactions: Biological Sciences*, 348(1325), 281-308.

Appendix A – The Witness Newspaper (2008, 2011, 2012) and Carte Blanche (2011)

THE WITNESS

Overhaul for sewage works

30 Jul 2008

Nalini Naidoo

A R30 million project is to be launched before the end of this year to solve Mpophomeni's sewage problems and deal with increased effluent from the new housing developments being established in the Howick/Merrivale area.

It involves the opening and upgrading of the Mpophomeni waste water treatment works, which were decommissioned by the Transitional uMngeni Council in 1996. Umgeni Water, Umgungundlovu District Municipality and uMngeni Municipality are working jointly on the project.

Umgungundlovu acting municipal manager Sbu Khuzwayo said Umgeni Water will be the service provider for the project on the basis of BOTT (build, operate, train and transfer): they will build the waterworks, operate it, train municipal staff and transfer the complex to the municipality within 10 or 15 years. He said capital will be provided by Umgeni Water and the municipalities will repay it on a monthly basis.

uMngeni municipal manager Dumisani Vilakazi says the Mpophomeni waste treatment plant was decommissioned because in the apartheid era, effluent from blacks and whites was not allowed to mix, so townships had their own waterworks.

When the transitional council came into being it was felt this was a huge waste of water and resources as both the Mpophomeni and Howick waterworks were running at half-capacity. The Mpophomeni plant was decommissioned and the Howick plant served both areas.

Vilakazi said that with developments in the Howick and Merrivale area, it became clear that there was an urgent need to re-open the Mpophomeni plant.

THE WITNESS

Midmar Dam will be contaminated, experts warn

30 Jul 2008

Melissa Douman

Despite doubts over funding, poor location, a land ownership dispute and the potentially disastrous effect on water quality of building 4 000 low-cost houses too close to Midmar Dam, the uMngeni Municipality says the project has been approved and will commence as soon as they have the budget for it.

"We have got very astute ... people who have approved building, and as soon as we are ready we will go ahead," said uMngeni municipal manager Dumisani Vilakazi.

The municipality started the Khayelisha Housing Project six years ago with plans to build 4 000 low-cost houses on Hollywood Farm, situated on the Boston road between Mpophomeni and Howick. The farm is about 500 metres from wetlands, small dams and Midmar Dam.

Each house will accommodate about five people. If all the houses are occupied, this will translate into 20 000 people staying on a few acres of land close to natural sites that need to be conserved.

Environmentalists object that building so many houses so close to the dam and other wetlands will seriously affect the quality of water in the dam and contaminate the drinking water of residents from Howick all the way down to Durban.

Vilakazi said a new settlement has to be built as Mpophomeni has reached its limits and cannot be expanded.

Lin Gravelet-Blondin, deputy director of water quality management at the Water Affairs and Forestry Department, said: "Although we fully support citing of development further away from the dam, the implications of a sewage spill or storm- and rainwater runoff into either the wetlands or the dam are that the quality of the water will be spoiled.

"The dam will become as unclean as the Duzi, only the negative consequences will be on a much larger scale ... swimming in the dam will not be safe and this will rule out annual events like the Midmar Mile."

Vilakazi reacted to criticism that the municipality has failed to maintain sewage systems in Mpophomeni and the Prospect road settlement, saying: "We have had occasional bursts and leakages; you cannot call that failure."

Another obstacle is funding.

Nottingham Road councillor Moira Grueneberg said the uMngeni Municipality already owes uMgungundlovu District R23,9 million.

"In order for the building to be approved, they need to upgrade sewerage facilities. They do not have this money and will have to borrow it from the district.

"But the district will not loan them any more money until they repay the money that is still outstanding," said Grueneberg.

Advocate and bird lover Rob McCarthy says Hollywood Farm was unlawfully acquired by the municipality.

Advocate Keith Khoza, who was also head of the KZN Housing Department four years ago, is alleged to have acquired 17 properties without the department's authority.

Hollywood Farm, a former dairy farm, was allegedly one of them. Though Khoza was arrested, Hollywood Farm is now owned by the department. "The transaction was unlawfully acquired with the help of advocate Khoza ... I don't see how they can build land on property that isn't lawfully theirs," McCarthy said.

Local Government and Housing Department spokesman Lennox Mabaso told The Witness that he would have to check on the legal ownership of the land, but said that issues relating to properties acquired by Khoza are currently being dealt with.

"I don't want to talk about it, but building has been approved and I can promise you that we are definitely going ahead," he said.

THE WITNESS

Threat to Midmar

03 Jun 2011

Trish Beaver

MIDMAR Dam may become a stinking pool of sewage if a new housing development nearby is allowed to go ahead, says Rob McCarthy, a fiery environmental lawyer, who has fought this development tooth and nail.

McCarthy has been watching the plans for Khayelisha become reality with ground being broken recently to lay foundations for the low-cost houses planned by uMgungundlovu Municipality, 300 metres from the shore of the fresh-water dam.

Environmental experts, as well as the Department of Water Affairs have expressed grave concerns about the future of the wetlands surrounding the dam, and, more importantly, say that the development could poison the main water supply, affecting towns downstream like Howick and the greater Pietermaritzburg area.

If Midmar becomes polluted, events like the Midmar Mile, which attracts visitors to the dam and injects income into the local economy, will be severely compromised. Leisure activities centred around the Midlands Meander will also be negatively affected.

McCarthy, who grew up enjoying the beauty of the dam, is horrified by the unfolding disaster. He says poor water and sanitation management of the nearby township of Mpophomeni has already caused significant sewage seepage into the dam.

Drains are blocked, rubbish has been thrown into manholes and broken sewerage pipes have been left unattended. This is all due to poor maintenance by uMngeni Municipality.

Mpophomeni is two kilometres from Midmar, and the filth is carried to the dam by a small tributary. "This second housing development will cause complete and utter devastation of the fauna and flora — and that is not just what I think — the environmentalists said it in their report," said McCarthy.

The Khayelisha site was chosen from one of several sites, reportedly because the municipality wishes to utilise and extend the existing sewerage infrastructure.

McCarthy alleges the land (Hollywood Farm) is also contentious as it belonged to a former politician, who never went through official tender processes when he sold it to the Department of Housing.

Dr Mark Graham, a scientist working for GroundTruth, an environmental consultancy, told The Witness that an environmental assessment impact (EIA) was done as part of the process.

"The Department of Water Affairs [DWA] gave the go-ahead, but with very stringent conditions imposed, which were put into the Record of Decision [RoD].

He said: "Construction work has begun on the site, but the RoD issues have not been met. If we look at other areas like Mpophomeni, which is adjacent to Khayelisha, and in the same catchment area, there is a poor record of environmental management, and there is ongoing faecal and nutrient pollution into Midmar Dam."

KwaZulu-Natal Department of Water Affairs acting director Manisha Maharaj, said they would be constantly monitoring the water-catchment areas to see if the development would negatively affect Midmar Dam.

She said: "Although the DWA supports uMngeni Municipality's efforts to supply low-cost housing, we do not support its choice of location. Other locations downstream of Midmar would have been more suitable."

Research has shown Mpophomeni contributes almost 51% of the E. coli loads that are found in Midmar Dam. The sewage also increases the concentration of phosphates in Midmar Dam causing the development of blue-green algae, which has devastated other dams like Hartebeespoort Dam (see box).

uMgungundlovu Municipal Manager Sibusiso Khuzwayo gave his side of the story to The Witness.

"Development of this nature is the outcome of an intensive community participation. Community needs are articulated and expressed. A social, environmental and technical assessment is performed to assist communities to make informed choices. The site location is the culmination of a long-winded process."

Khuzwayo admitted there was a need for the entire uMngeni sanitation and sewerage system to be upgraded. "We have just completed our Water Services Development Plan and quantified all the new capital works and upgrades to be done over the next five years.

"Then a systematic but comprehensive process to respond to the water services issues will roll out on a phased implementation basis."

Khuzwayo denied that housing got more priority than water and environmental affairs. "We have a legal and moral obligation to uphold the environment health of all areas in our jurisdiction. But housing is also a priority, from the uMngeni Municipality's point of view. We therefore have a constitutional obligation to support one another as organs of state."

Khuzwayo agreed they were currently experiencing a staff problem in the water and sanitation department. He said: "We have increased our capacity through maintenance contracts from the private sector, as well as the Development Bank of Southern Africa (DBSA). With the re-constitution of the new council, the freezing of posts will be revisited."

"The Department of Water has created a support-funding programme to help municipalities pay for upgrades. DWA's Manisha Maharaj said R75 million had been allocated for the next three years and was prioritised for municipalities like uMngeni."

But McCarthy remains unconvinced that the district municipality or the DWA will be able to prevent a disaster from happening.

"It's a time bomb waiting to explode! We'll all be buying drinking water — how will the poor afford that?"

ACCORDING to Dr Mark Graham, phosphate loading of water sources is the primary cause of eutrophication of water in which blue-green algae multiplies, producing a serious toxin known as cyanotoxin, which has been linked to neurological disorders. The Hartebeespoort Dam experience has shown that under extreme conditions, the water becomes extremely difficult to treat for drinking water. Many of South Africa's water resources are already polluted by this algae.

Scientists have established that these cyanotoxins can be linked to Alzheimer's disease and Parkinson's disease. People and animals that are exposed to these at low doses over a long time suffer from nerve and liver damage.

High phosphate loads were detected in 2006 on satellite images of Mpophomeni on Google Earth.

DUZI uMngeni Conservation Trust (Duct) volunteer, Liz Taylor, who along with other team members, carries out water-quality tests, said there are many contributing factors to the deterioration of the uMngeni municipal water and sanitation services.

• Water purification systems need to be upgraded, especially outlying water pumps that break down regularly after rain storms. The estimated cost of this would be R25 million for the uMngeni area.

• The recruitment of plumbing staff. There are allegedly only 18 qualified plumbers on the municipal payroll due to a wage dispute created by the previous administration. No new staff can be hired until this is resolved. There are 62 open vacancies in the sanitation department.

• Due to a manpower shortage, broken pipes and sewage spills cannot be attended to, and the end result is filth and poor hygiene.

• Informal settlements and townships have no access to regular refuse removal and no landfill or dumping site near their homes. Consequently, they resort to burning their rubbish or leaving it in the street, where it gets washed into the rivers by rain storms.

Midmar Muck

Date: 22 May 2011 07:00
Producer: Nguni Productions
Presenter: Devi Sankaree Govender
Show: Carte Blanche

Busy attorney Rob McCarthy and high school head boy Gareth Gardiner have never met.

But both have a similar goal - to protect one of KwaZulu-Natal's primary water sources from potential disaster.

Midmar Dam in the KwaZulu-Natal Midlands provides water to Pietermaritzburg and Durban. That's 374 million kilolitres of water to 4.8 million people every year.

Now this vital water source could be severely compromised by a new low cost housing development.

Rob McCarthy (Lawyer): "The research and the opinions of the experts are clear: do not do this project."

Gareth Gardiner (Howick High School Head boy): "That is completely crazy - if you are going to put in another housing development like that, when you haven't even sorted out current issues."

Devi Sankaree Govender: "In an attempt to relocate squatters from the informal settlements near Howick, local authorities have begun building the first phase for 1 500 unit low cost housing development right here at Midmar Dam."

Even the Department of Water Affairs thinks the plan is foolhardy - it's siding with residents against the local uMngeni Municipality.

Manisha Maharaj is acting assistant director for Water Resource Management.

Manisha Maharaj (Department of Water Affairs): "The location is unsuitable, mainly because it is in such close proximity to a strategic water resource such as Midmar Dam."

Mark Graham is a water quality scientist and knows all about the appalling condition of KZN's waterways.

His Rivers report shocked viewers in 2008 when he exposed that only three of the 61 rivers in greater Durban were still in a natural condition.

He also tested water from the Umsindusi River, site of the annual Duzi Canoe Marathon. He revealed an E.coli count an astounding 7 000 times higher than the acceptable level.

Forty percent of the field had either chronic diarrhoea or vomiting.

[Carte Blanche 3 February 2008] Dr Mark Graham (Aquatic Scientist, Ground Truth): "The canoeists are the red flag to indicate there are problems and issues around water and contamination that many of our rivers suffer from in the country."

Mark warns that contamination of the Midmar would pose an even greater risk because of its key position.

Dr Graham (Water quality expert): "Midmar is the top-end of this cascade of dams [on screen] going down the Umgeni River system. It cascades from here down to Albert Falls [Dam], which is Durban's main water supply; and then from Albert Falls down to Nagel Dam, and on from there to Inanda Dam. So we have got this sequence of cascading of key dams. We want to preserve quality and quantity at the top, rather than to deal with it as problematic downstream."

Treating polluted water is a costly exercise and of course ratepayers will have to cough up.

As it is, there are already two low cost housing projects in the area with outdated and overloaded sewage systems, polluting Midmar and its rivers.

Mpophomeni is a 6 000 house settlement built in the '60s, three kilometres above Midmar Dam.

Siphumele is a 357 low cost housing unit development completed four years ago - built 1.4 kilometres downstream from Midmar and just 100 metres from the Umgeni River's edge.

Khayelisha will be built below Mpophomeni.

Devi: "The fear is that the new controversial 'slum clearage' project will only add to the problem."

Rob says he got involved in 2002 when authorities first announced plans to build Khayelisha.

He grew up on the banks of the dam and says recreational activities will be a thing of the past if plans go ahead. It's also host to the famous Midmar Mile.

Rob: "Sailing, swimming, fishing.... it is a tremendously beautiful area."

Today he is meeting a young ally with similar concerns.

Gareth goes to school in Howick. Asked to do a project on pollution in the area, he was shocked at what he found.

Gareth: "You come here and it is really revolting... it's a stench!"

Devi: "Gareth started his investigation here at Siphonomela, which is a low cost housing development just below Midmar Dam."

Here he met Cyril Hlele, a local resident who has had to deal with a burst manhole in his yard and raw sewage flowing out of his toilet.

Cyril Hlele (Siphonomela resident): "... Coming straight into the house."

These cellphone video clips of the muck were part of Gareth's project. The overflow included human faeces.

Gareth: "It covered the issue of the sewerage spilling out of his house and then flowing into the Umgeni River, which is located a hundred metres away."

He says if sewage leaks into the river here - then Midmar is doomed, with Khayelisha built metres from the shore.

Devi: "We are going up in the air to see the proximity of Khayelisha to Midmar Dam."

Not only will houses be built just under 800 metres from the shores of Midmar, the plan is for more houses to be built only 150 metres from a cascade of smaller dams on the site.

Dr Graham: "They would be the first receptacle. They would hold the water for some time, but ultimately that water drains from there into Midmar Dam, which is now our primary drinking water source."

He says it's inevitable that any sewerage spills or litter from Khayelisha will contaminate the water.

Gareth: "I am no expert on sanitation or anything like that, but I can't see why the municipality can't see it, when I can easily see it on a couple of visits to a place like Siphonomela."

Things aren't much better at Mpophomeni.

Devi: "This is a typical example of what exactly is going on here at Mpophomeni: you have got the sewerage pipe here and an overflowing manhole just over the little bush there, and, straight line in the distance, Midmar Dam. I can't even begin to describe what it smells like."

Manisha: "Currently Mpophomeni is... okay, I can't think of any nice word... it is a disaster. We have a failing sanitation system, a failing waste disposal management system."

Dr Graham: "If the waste hasn't been collected, often it lands up in the sewerage system."

And it blocks the pipes. As a result, burst storm water drains overflow, polluting streams and the water table, then all flow into Midmar...

Rob: "There are condoms, sanitary pads, dead animals and the like flowing through the water systems there. It really is a disgraceful situation."

Dr Graham: "Midmar has increased by about 82% in terms of its phosphate loading in the last ten years."

Phosphates are a by-product of human and animal faeces. They can cause an explosion in algae growth.

Carte Blanche has highlighted the dangers associated with algae blooms before. Hartebeespoort Dam in Gauteng has been poisoned with phosphate overloading.

Dr Graham: "We are going to end up with Midmar looking like Hartebeespoort. And that will be wall to wall covered in water hyacinth, blue-green algae particularly."

Studies show that toxins in blue-green algae can cause liver disease, especially in children.

Manisha: "A special study was conducted by the Institute of Natural Resources and those studies show that from the Khayelisha development a 50% increase of phosphorous will emanate from that development alone."

Eric Svensson from the uMngeni Municipality disputes the research.

Eric Svensson (uMngeni Municipality): "The advice from our scientists has indicated that the majority of phosphate loading is actually from farm lands."

He says only a small amount of Mpophomeni's waste lands up in the dam and that it's not necessary to calculate Khayelisha's potential phosphate contribution.

Devi: "So are you refuting what the Department of Water Affairs is saying?"

Eric: "I'm not aware exactly of their study that they are referring to."

Manisha says the studies she is referring to were done last year, studies backed up by Eric's own water management team - Umgeni Water.

Their March 2011 Water Quality Report on Rivers and Dams marks Midmar as having poor water quality status 'due to high algal counts' as a result of 'phosphate concentrations arising from sewer problems in Mpophomeni'.

Eric: "Well, we would have to have a look at that study and how detailed that study was."

Residents say there are other places to put much-needed housing.

Rob: "We have made the municipality aware of seven different sites that we considered more appropriate."

And it's not as if people are dying to move to Khayelisha...

Devi: "Not only is the Khayelisha development far away from town, but they say there aren't any employment opportunities, or transport facilities."

Devi: "What was wrong with the other proposed locations?"

Eric: "There were no services available. In other words 'bulk services'."

Devi: "i.e.?"

Eric: "The water supply was inadequate. There was no waterborne sewerage, or the waterborne sewerage was inadequate."

One wonders when last councillors visited Mpophomeni or Siphumele.

Even the Record of Decision giving permission to go ahead recognises the problem.

According to the RoD, Khayelisha can only be built if the Mpophomeni Waste Water Works is upgraded.

The Works were decommissioned 10 years ago.

Rob: "And that is a 25-million to 30-million rand exercise."

No upgrade has started, yet building of the first 500 units is bulldozing ahead. And there's no way the Howick Treatment Works will cope with these additional houses.

Manisha: "Therefore the Department has recommended that the Howick waste water works be upgraded as well as Mpophomeni."

The sewage systems of the remaining thousand units will have to form part of the upgrade.

But, the municipality wants them to be built in the meantime - provided they remain unoccupied.

Eric: "Obviously there is nobody can move in because there won't be any sanitation services provided."

And not everyone believes that the municipality will eventually upgrade the system.

Manisha: "Promises are not good enough. We want to see physical action. Our major concern is, if whatever is happening in Mpophomeni happens in Khayelisha, we will have a disaster in Midmar Dam."

THE WITNESS

Sewage seeps into Midmar

12 Jul 2012

Mlondi Radebe

THE main sewage pipe coming from Mpophomeni has burst, and has not only created a foul smell near the township along the R617, but is seeping into a stream that feeds Midmar Dam.

Umgeni Water discovered only on Monday that the pipe had burst and then began isolating the pipe, resulting in the valves being shut off to stop the flow of sewage, said the utility's corporate stakeholder manager, Shami Harichunder.

Contractors were sent to repair the pipe and it was expected that the work would be completed by last night.

Harichunder said there was no risk to the quality of the water supply to Pietermaritzburg and Durban because the water underwent treatment as normal before it was supplied in bulk to municipalities.

The pipe burst near the road a kilometre away from the dam and water leaked into the stream that flows into the dam.

It is believed that the pipe has been faulty since last week.

The stench leads one to a stream with foamy water and signs of pollution.

Duzi-uMngeni Conservation Trust spokesperson Liz Taylor, said that if the sewage flowed into the dam all the time, it would cause a problem.

Taylor said: "We are working with uMgungundlovu Municipality and are trying to identify the nature of the blockage.

"We are mapping all the sewage pump stations and manholes in Howick, Howick West, Merrivale and Mpophomeni to set up a surveillance system that will hopefully ensure early detection."

Taylor said there were two problems that could cause the pipe to burst: excessive pressure or misuse.

"Residents flush plastic and other things that block the pipes like nappies, which should not be put in toilets."

She said poor water and sanitation management in Mpophomeni had already caused significant sewage seepage into the dam.

uMgungundlovu municipal manager Sbu Khuzwayo said he would respond to questions from *The Witness* today.

- *mlondi.radebe@witness.co.za*

Appendix B – SASS5 score sheet

SASS Version 5 Score Sheet

Date: / /200__

Collector: . .

Grid Reference: WGS-84 | Cape datum

S: ° ' , " E: ° ' , "

Site code:

River:... ... .

Site description:...

Weather Condition:...

Temp:................°C pH:....................

DO:....................mg/l Cond:...........mS/m

Biotopes sampled:

SIC .... Time..................minutes

SOOC.................. Time..................minutes

Average size of stones.......................cm

Bedrock...............

Aquatic veg'n......... Dom. sp.....................................

MvegIC.............. Dom. sp.....................................

MvegOOC............Dom. sp.....................................

Gravel.................. Sand.................

Mud.........................

Hand picking/Visual observation................

Flow: Low/Medium/High/Flood

Turbidity: Low/Medium/High

Riparian land use:

Disturbance in the river: eg. sandwinning, cattle drinking point, floods etc.

Observations: eg. smell and colour of water, petroleum, dead fish, etc.

Taxon		S	Veg	GSM	TOT
PORIFERA	5				
COELENTERATA	1				
TURBELLARIA	3				
ANNELIDA					
Oligochaeta	1				
Leeches	3				
CRUSTACEA					
Amphipoda	13				
Potamonautidae*	3				
Atyidae	8				
Palaemonidae	10				
HYDRACARINA	8				
PLECOPTERA					
Notonemouridae	14				
Perlidae	12				
EPHEMEROPTERA					
Baetidae 1sp	4				
Baetidae 2 sp	6				
Baetidae > 2 sp	12				
Caenidae	6				
Ephemeridae	15				
Heptageniidae	13				
Leptophlebiidae	9				
Oligoneuridae	15				
Polymitarcyidae	10				
Prosopistomatidae	15				
Teloganodidae SWC	12				
Tricorythidae	9				
ODONATA					
Calopterygidae ST,T	10				
Chlorocyphidae	10				
Chlorolestidae	8				
Coenagrionidae	4				
Lestidae	8				
Platycnemidae	10				
Protoneuridae	8				
Aeshnidae	8				
Corduliidae	8				
Gomphidae	6				
Libellulidae	4				
LEPIDOPTERA					
Pyralidae	12				

Taxon		S	Veg	GSM	TOT
HEMIPTERA					
Belostomatidae*	3				
Corixidae*	3				
Gerridae*	5				
Hydrometridae*	6				
Naucoridae*	7				
Nepidae*	3				
Notonectidae*	3				
Pleidae*	4				
Veliidae/M...veliidae*	5				
MEGALOPTERA					
Corydalidae	8				
Sialidae	6				
TRICHOPTERA					
Dipseudopsidae	10				
Ecnomidae	8				
Hydropsychidae 1 sp	4				
Hydropsychidae 2 sp	6				
Hydropsychidae > 2 sp	12				
Philopotamidae	10				
Polycentropodidae	12				
Psychomyiidae/Xiphocen	8				
Cased caddis:					
Barbarochthonidae SWC	13				
Calamoceratidae ST	11				
Glossosomatidae SWC	11				
Hydroptilidae	6				
Hydrosalpingidae SWC	15				
Lepidostomatidae	10				
Leptoceridae	6				
Petrothrincidae SWC	11				
Pisuliidae	10				
Sericostomatidae SWC	13				
COLEOPTERA					
Dytiscidae*	5				
Elmidae/Dryopidae*	8				
Gyrinidae*	5				
Haliplidae*	5				
Helodidae	12				
Hydraenidae*	8				
Hydrophilidae*	5				
Limnichidae	10				
Psephenidae	10				

Taxon		S	Veg	GSM	TOT
DIPTERA					
Athericidae	10				
Blepharoceridae	15				
Ceratopogonidae	5				
Chironomidae	2				
Culicidae*	1				
Dixidae*	10				
Empididae	6				
Ephydridae	3				
Muscidae	1				
Psychodidae	1				
Simuliidae	5				
Syrphidae*	1				
Tabanidae	5				
Tipulidae	5				
GASTROPODA					
Ancylidae	6				
Bulininae*	3				
Hydrobiidae*	3				
Lymnaeidae*	3				
Physidae*	3				
Planorbinae*	3				
Thiaridae*	3				
Viviparidae* ST	5				
PELECYPODA					
Corbiculidae	5				
Sphaeriidae	3				
Unionidae	6				
SASS Score					
No. of Taxa					
ASPT					

Sample collection effort exceeds method? .....

Other biota including juveniles:

Comments:

Procedure: 'Kick SIC & bedrock for 2 mins, max. 5 mins; Kick SOOC & bedrock for 1 min; Sweep marginal vegetation (IC & OOC) for 2m total and aquatic veg $1m^2$; Stir & sweep gravel, sand, mud for 1 min total; * = airbreathers; Hand picking & visual observation for 1 min — record in biotope where found; Score for 15 mins/biotope but stop if no new taxa seen after 5 mins; 'Estimate abundances: 1 = 1, A = 2–10, B = 10–100, C = 100–1 000, D = >1 000; S = Stone, rock & solid objects; Veg = All vegetation; GSM = Gravel, sand, mud; SWC = South Western Cape; T = Tropical; ST = Sub-tropical; Rate each biotope sampled: 1 = very poor (i.e. limited diversity), 5 = highly suitable (i.e. wide diversity)

Appendix C – Physical, chemical and biological water quality parameters

		NH_3 (mg N/ℓ)	NO_2 (mg N/ℓ)	NO_3 (mg N/ℓ)	TKN (mg N/ℓ)	SRP (µg P/ℓ)	TP (µg P/ℓ)	TOC (mg C/ℓ)	COND (mS/m)	SS (mg/ℓ)	pH	TEMP (°C)	DO(% saturation)	*E. coli* (counts/100mℓ)
	25/10/2010	0.52	0.5	1.29	3	5.3	24.5	1.95	10.2	10	7.86	17.84	83.75	620
	20/12/2010	0.04	0.05	0.33	1.4	3.15	26.28	1.19	5.4	10.4	7.68	18.8	94.6	160
UM	15/03/2011	0.06	0.05	1.14	1	3.4	25.5	1.9	6.4	9.2	7.64	22.53	87.65	649
	23/05/2011	0.05	0.05	0.55	1	3.36	15	1.23	6.5	4	7.35	12.85	77.59	160
	14/07/2011	0.05	0.05	0.95	1	3	15	1.23	6.6	4	7.66	8.1	90.38	6
mean		**0.144**	**0.14**	**0.852**	**1.48**	**3.642**	**21.256**	**1.5**	**7.02**	**7.52**	**7.638**	**16.024**	**86.794**	**319**
	25/10/2010	17.33	0.5	0.5	18.81	880	1180	12.8	42.4	34	7.67	22.85	67.86	540000
	20/12/2010	4.8	0.05	6.38	5.79	178.23	397.31	4.93	26.9	51.2	7.56	22.88	53.12	816000
MM	15/03/2011	6.6	0.05	0.07	13	1360	1670	12.6	31.2	17.6	7.3	25.27	66.2	173300
	23/05/2011	0.72	0.12	1.91	1.03	79.23	164	2.42	15.1	28.4	7.14	13.94	71.41	12030
	14/07/2011	3.54	0.43	1.23	5.87	183.87	341	4.17	18.5	14	7.59	10.77	82.98	51700
mean		**6.598**	**0.23**	**2.018**	**8.9**	**536.266**	**750.462**	**7.384**	**26.82**	**29.04**	**7.452**	**19.142**	**68.314**	**318606**
	25/10/2010	20.05	0.5	0.5	26.72	1310	1510	12.9	43.9	39	7.47	22.38	53.98	365000
	20/12/2010	6.84	2.29	2.54	8.95	285.31	1341.25	5.06	29.8	24.4	7.35	22.93	48.21	816000
M-Trib	15/03/2011	6.7	0.05	0.05	19	1745	2500	16.8	30.3	21.6	7.18	25.79	57.58	24190
	23/05/2011	0.46	0.28	2.61	1.97	116.4	229	3.44	21.6	16	7.31	13.8	53.2	24190
	14/07/2011	6.27	0.6	0.89	13.27	401.48	738.32	6.64	26	10.4	7.46	10.27	78.43	241900
mean		**8.06**	**0.74**	**1.32**	**13.98**	**771.64**	**1263.71**	**8.97**	**30.32**	**22.28**	**7.35**	**19.03**	**58.28**	**294256**
	25/10/2010	3.59	0.5	1.53	3	280	580	8.86	27.6	51	7.19	25.51	62.07	1150
	20/12/2010	1.2	0.05	3.74	3.14	98.27	349.87	4.65	18.2	68	7.85	20.82	50.19	126000
LM	15/03/2011	4.2	0.24	1.09	4.8	463	595	6.93	23.4	12.8	7.34	21.02	68.97	1203
	23/05/2011	0.04	0.05	3.4	1	89.5	170	3	14.6	15.6	7.19	12.68	77.54	1960
	14/07/2011	2.45	0.05	3.56	3.22	207.2	300.4	4.74	18.3	4.8	7.44	9.1	79.13	1034

mean		**2.3**	**0.18**	**2.66**	**3.03**	**227.59**	**399.05**	**5.64**	**20.42**	**30.44**	**7.4**	**17.83**	**67.58**	**26269.4**
	25/10/2010	0.5	0.5	0.5	3	6.99	31.2	7.22	10.2	8	7.8	16.34	101.65	130
	20/12/2010	0.04	0.05	1.31	1.18	8.22	60.94	2.57	8.2	30.8	7.56	17.38	104.93	330
UG	15/03/2011	0.07	0.05	0.05	1	10	30	2.09	9.4	12.4	7.95	18.68	101.2	687
	23/05/2011	0.04	0.05	0.33	1	7.49	19.19	1.68	8	4	7.24	11.26	79.46	60
	14/07/2011	0.08	0.05	0.18	1	3	15	1.2	7	4	7	5.59	104.66	22
mean		**0.15**	**0.14**	**0.47**	**1.44**	**7.14**	**31.27**	**2.95**	**8.56**	**11.84**	**7.51**	**13.85**	**98.38**	**245.8**
	25/10/2010	0.5	0.5	0.5	3	3.5	24.5	3.13	11.7	14	7.78	18.78	92.64	50
	20/12/2010	0.06	0.05	0.09	1.62	3	30.02	3.4	11	5.6	7.82	20.85	85.31	160
MG	15/03/2011	1	0.05	0.09	1.3	8.8	26	4.96	27.1	8.4	7.61	22.13	84.75	148
	23/05/2011	0.23	0.05	0.61	1	4.75	26.6	2.79	10	10.4	7.31	11.95	70.43	1110
	14/07/2011	0.05	0.05	0.88	1.32	3	33.3	2.96	8.3	16.8	7.05	6.25	88.21	1034
mean		**0.368**	**0.14**	**0.434**	**1.648**	**4.61**	**28.084**	**3.448**	**13.62**	**11.04**	**7.514**	**15.992**	**84.268**	**500.4**
	25/10/2010	1.96	0.05	1.26	3.72	123.25	500	3.84	13.3	4	8.01	21.8	92.57	1380
	20/12/2010	0.19	0.05	1.51	1.25	32.62	128.27	3.97	10.4	65.6	7.82	20.14	91.72	930
G-Trib	15/03/2011	0.15	0.05	0.83	1	47	124	5.22	11.2	57.6	7.81	19.92	90.98	579
	23/05/2011	0.04	0.05	1.3	1	16.9	121.5	2.34	10.4	82.4	7.45	12.54	84.88	310
	14/07/2011	0.08	0.05	0.88	1.28	15.52	29.89	1.7	9.6	8.4	7.66	8.42	91.54	114
mean		**0.48**	**0.05**	**1.16**	**1.65**	**47.06**	**180.73**	**3.41**	**10.98**	**43.6**	**7.75**	**16.56**	**90.34**	**662.6**
	25/10/2010	0.5	0.5	0.5	3	12.11	73.7	6.97	14.8	41	7.8	20.51	93.61	1080
	20/12/2010	0.07	0.05	1.66	3.05	31.91	107.92	4.38	11.4	48	7.8	19.41	86.63	980
LG	15/03/2011	0.32	0.05	0.05	1	12.4	87.6	4.24	14.4	91.2	7.12	20.17	85.84	411
	23/05/2011	0.04	0.05	1.95	1	12.5	46.3	2.71	11	13.2	7.2	13.03	77.75	190
	14/07/2011	0.07	0.05	1.53	1.36	11.72	26	2.29	10.4	8	7.73	8.12	91.55	56
mean		**0.2**	**0.14**	**1.14**	**1.88**	**16.13**	**68.3**	**4.12**	**12.4**	**40.28**	**7.53**	**16.25**	**87.08**	**543.4**
	25/10/2010	0.5	0.5	0.5	3	6.58	15	7.22	17.5	24	7.4	19.5	84.71	640
	20/12/2010	0.08	0.05	0.21	2.07	3	53.34	5.61	18	14	7.65	25.91	71.62	170

LK	15/03/2011	0.07	0.05	0.05	1	3.6	44.6	4.75	11.5	11.6	7	25.53	81.46	74
	14/07/2011	0.04	0.05	0.05	1.23	3	55.88	4.99	12.7	27.2	7.66	11.03	78.43	60
mean		**0.17**	**0.16**	**0.2**	**1.83**	**4.05**	**42.21**	**5.64**	**14.93**	**19.2**	**7.43**	**20.49**	**79.06**	**236**

Appendix D – Presence and absence of macroinvertebrate taxa (1: present, 0: absent)

	Mthinzima sub-catchment														
	UM					MM					LM				
	25/10/10	20/12/10	15/03/11	23/05/11	14/07/11	25/10/10	20/12/10	15/03/11	23/05/11	14/07/11	25/10/10	20/12/10	15/03/11	23/05/11	14/07/11
Turbellaria	0	0	0	0	0	0	1	1	0	0	1	1	0	0	0
Oligochaeta	0	1	0	1	0	0	1	0	1	1	1	1	1	1	1
Leeches	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1
Potamonautidae	1	1	1	1	1	0	0	0	0	0	1	1	1	1	1
Atyidae	1	1	1	1	1	0	0	0	0	1	1	1	1	0	1
Hydracarina	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Perilidae	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0
Baetidae	1	1	1	1	1	0	0	0	1	1	0	0	1	1	1
Caenidae	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0
Leptophlebiidae	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0
Polymitarcyidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Teloganodidae	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Tricorythidae	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0
Chlorolestidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coenagrionidae	1	1	1	1	1	0	0	0	1	0	0	0	0	1	0
Protoneuridia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aeshnidae	1	1	1	1	1	0	0	0	1	0	0	0	0	1	0
Corduliidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gomiphidae	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0
Pyralidae	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
Corixidae	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0
Gerridae	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0
Naucoridae	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0

Nepidae	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Notonectidae	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0
Pleidae	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Veliidae	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Ecnomidae	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydropsychidae	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0
Philopotamidae	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Psychomyiidae	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Barbarochthonidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroptilidae	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Leptoceridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sericostomatidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dytiscidae	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Elmidae*/*Dryopidae	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0
Gyrinidae	1	1	1	1	1	0	0	0	0	1	0	0	0	0	0
Helodidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydraenidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrophilidae	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0
Psephenidae	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0
Athericidae	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Chironomidae	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1
Culicidae	0	0	0	1	1	0	0	1	1	1	0	0	0	0	1
Dixidae	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Muscidae	0	0	0	0	1	0	0	0	1	0	0	0	0	1	1
Psychodidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Simulidae	0	1	0	1	1	0	1	0	1	1	0	1	1	1	1
Tabanidae	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Tipulidae	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
Ancylidae	1	0	1	1	0	0	0	1	1	0	0	0	0	0	0

Lymnaeidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Physidae	0	0	0	0	0	1	1	1	1	1	1	1	0	1	0
Corbiculidae	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Sphaeriidae	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Unionidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	Gqishi sub-catchment														
	UG					**MG**					**LG**				
	25/10/10	**20/12/10**	**15/03/11**	**23/05/11**	**14/07/11**	**25/10/10**	**20/12/10**	**15/03/11**	**23/05/11**	**14/07/11**	**25/10/10**	**20/12/10**	**15/03/11**	**23/05/11**	**14/07/11**
Turbellaria	1	1	0	0	1	1	1	0	0	0	1	1	1	1	0
Oligochaeta	1	1	1	1	0	0	0	1	0	0	1	1	0	1	1
Leeches	0	0	1	1	0	0	0	0	0	0	1	1	0	1	1
Potamonautidae	1	0	1	1	1	1	0	1	1	1	1	0	1	1	0
Atyidae	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Hydracarina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perilidae	1	1	1	1	1	0	0	0	0	0	0	0	0	0	1
Baetidae	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Caenidae	1	1	1	0	1	1	1	1	1	0	1	1	1	1	1
Leptophlebiidae	1	0	1	1	1	1	1	1	1	1	1	0	0	1	1
Polymitarcyidae	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Teloganodidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tricorythidae	1	1	1	1	1	1	1	1	0	0	1	1	1	0	0
Chlorolestidae	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
Coenagrionidae	1	1	1	1	0	1	0	1	1	1	1	1	1	0	0
Protoneuridia	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Aeshnidae	1	1	1	0	1	1	1	0	1	1	1	1	1	1	1
Corduliidae	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0

Gomiphidae	1	1	1	0	1	1	0	0	0	0	0	0	1	0	0
Pyralidae	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
Corixidae	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Gerridae	1	0	1	1	0	0	0	1	1	0	0	1	1	0	0
Naucoridae	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1
Nepidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Notonectidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pleidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Veliidae	0	0	1	1	0	1	0	1	1	0	0	1	1	0	0
Ecnomidae	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Hydropsychidae	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Philopotamidae	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Psychomyiidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Barbarochthonidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroptilidae	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Leptoceridae	1	0	0	0	1	0	1	0	0	1	1	0	1	0	1
Sericostomatidae	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Dytiscidae	0	0	0	0	0	0	0	1	0	0	1	1	1	0	0
Elmidae/Dryopidae	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1
Gyrinidae	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Helodidae	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0
Hydraenidae	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0
Hydrophilidae	0	0	1	0	1	0	1	1	1	1	0	0	1	1	1
Psephenidae	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0
Athericidae	1	0	1	1	1	0	0	0	0	0	0	0	0	1	0
Chironomidae	1	0	1	1	1	1	1	0	0	1	0	0	0	1	1
Culicidae	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0
Dixidae	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Muscidae	0	1	0	0	0	0	0	0	0	1	0	1	0	1	0

Psychodidae	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Simulidae	0	0	0	0	1	0	1	0	1	1	0	1	0	1	1
Tabanidae	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0
Tipulidae	1	1	1	1	0	1	1	1	1	1	0	1	0	0	0
Ancylidae	1	1	1	1	0	0	0	0	1	1	1	0	0	1	1
Lymnaeidae	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Physidae	0	1	0	0	0	0	1	0	1	1	0	0	1	1	0
Corbiculidae	0	0	1	0	0	0	1	0	1	0	1	1	1	1	1
Sphaeriidae	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Unionidae	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0

Appendix E - Map disclaimer

FIGURE 3.3: Study sub-catchments within the upper uMngeni catchment

FIGURE 3.5: Land cover and study sites in the three sub-catchments under study, study sites illustrated

Ross van Deventer and/or Colin Holmes make no warranty, representation, or guarantee of any kind regarding either any maps (Figures stated above) or other information provided herein or the sources of such maps or other information. Ross van Deventer and/or Colin Holmes specifically disclaim all representations or warranties, express or implied, including, without limitation, the implied warranties or merchantability and fitness for a particular purpose.

Ross van Deventer and/or Colin Holmes assume no liability either for any errors, omissions, or inaccuracies in the information provided regardless of the cause of such or for any decision made, action taken, or action not taken by the user in reliance upon any maps or information provided herein.

Colin Holmes

Ross van Deventer