AN INVESTIGATION OF ECOSYSTEM REGIME SHIFTS CAUSED BY REGULATED WATER RELEASE INTO PHONGOLO RIVER FROM THE PONGOLAPOORT DAM, KWAZULU-NATAL, SOUTH AFRICA.

BY

TIYISANI LINCON CHAVALALA

SUBMITTED IN THE FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTERS OF SCIENCE in ZOOLOGY

in the

Department of Zoology

School of Mathematical and Natural Sciences

at the

University of Venda

Thohoyandou

South Africa

Supervisor: Prof. PSO Fouché

Co-supervisor: Prof. SH Foord

March 2015

© University of Venda

University of Venda
Creating Future Leaders

Declaration

I, TL CHAVALALA hereby declare that the dissertation for the Masters of Science in Zoology degree at the University of Venda, hereby submitted by me, has not been submitted previously for a degree at this or any other university, that is my own work in designed in execution, and that all reference material contained therein been duly acknowledged.

Signature: _____ Date: 22 August 2015

© University of Venda

University of Venda
Creating Future Leaders

Dissertation outlay

Chapter one introduces the origin of rivers, variability of rivers and climate in South Africa, disturbances in ecosystem, regime shifts, effect of water quality in aquatic biota, primary productivity, organic matter, benthic macro-invertebrates and Phongolo River as a study area. A literature review on the effects of flood on aquatic biota is given. The research question, hypothesis, aims and objectives are mentioned in this chapter.

Chapter two describes the materials and methods used in the field and in the laboratory. This chapter includes the selected sites, sub-sites and the survey frequency. The instruments used to measure the *in situ* parameter are mentioned, how cobbles and benthic macro-invertebrates were collected and preserved, how nutrients concentration, water flow, chlorophyll-*a* were measured, how historical and current discharge obtained and how organic matter, Ash Free Dry Mass (AFDM) and how the benthic macro-invertebrates biomass were determined. The statistical tests used to analyze the data, how environmental factors will be correlated to benthic macro-invertebrates and nutrients are correlated to primary production were mentioned.

Chapter three describes the study sites and sub-sites, available habitats, survey dates and survey frequency and results. The results includes the following: 1) *in situ* parameters which are pH, dissolved oxygen (DO), total dissolved solids (TDS), electric conductivity (EC) and temperature, 2) the water flow, 3) discharge records, 4) nutrients concentration which are ammonium, nitrate, nitrite and phosphate, 5) chlorophyll-*a* concentration, 6) Ash Free Dry Mass, (7) SASS scores and average score per taxon (ASPT), 8) the group of recorded benthic macro-invertebrates based on body size and flow preference, 9) benthic macro-invertebrates diversity, seasonal variation of abundance using non-metric multidimensional scaling (nMDA), the correlation between environmental factors of the benthic macro-invertebrate and biomass using redundancy analyses (RDA), and 10) correlation between nutrients and chlorophyll-*a*.

Chapter four summarizes the results. The effect of flood on water chemistry, primary productivity, benthic organic matter and benthic macro-invertebrate diversity, abundance and biomass is discussed. The correlation between the nutrient and productivity is also

© University of Venda

University of Venda
Creating Future Leaders

discussed. SASS5, which was used to determine the condition of the sites are described and the environmental factors that will have an effect to the aquatic biota is discussed.

© University of Venda

University of Venda
Creating Future Leaders

ABSTRACT

Rivers have disturbance regimes of which flooding forms a major part. Scouring floods alters nutrient content, in-channel habitat, benthic macro-invertebrate assemblage structure and water quality in general. A novel macro-invertebrate regime or regime shift created by the artificial flood releases in the Phongolo River was determined by comparing the pre- and post-flood *in situ* physico-chemical aspects, primary production and benthic macro-invertebrate composition of two sites immediately downstream of the dam. nMDA results showed that there is no variation between the pre- and post-flood benthic macro-invertebrate composition of two sites immediately downstream but the sites were significantly difference ($P < 0.05$). The benthic macro-invertebrates were affected by the electric conductivity, oxygen level, ammonium concentration, nitrite concentration and pH when using RDA, and phosphate was correlated with the chlorophyll-*a* when using Person's correlation. It was found that flood reduced the standing stock producers, organic matter and benthic macro-invertebrates abundance, diversity and biomass and therefore a novel of macro-invertebrate regime or regime shift was created by the artificial flood releases in the Phongolo River.

Key words: Phongolo River, regime shift, periphyton, benthic macro-invertebrate and water quality

© University of Venda

University of Venda
Creating Future Leaders

ACKNOWLEDGEMENTS

The writing of this dissertation has been one of the most significant academic challenges I have ever had to face. Without the support, patience and guidance of the following people, this study would not have been completed. It is to them that I owe my deepest gratitude.

- Prof PSO Fouché who undertook to act as my supervisor despite his many other academic and professional commitments. His wisdom, knowledge and commitment to the highest standards inspired and motivated me.
- Prof SH Foord for helping with statistics to analyze data.
- The University of Venda for giving me the opportunity to study and supplying the necessary materials for conducting my research.
- Water Research Commission for funding this project as it forms part of a WRC major project.
- Special thanks to Jesus Christ who gave me an opportunity to be on this planet.
- I thank Pastor V.V Hlungwani and his church prayers which made my dreams to become true in my life
- I thank my parents for understanding that I must further my studies and contribute more knowledge to the society and their financial and moral support.
- I thank my sisters namely, Pessa, Hletelo, Dzunisani, Portia and Nomsa for their support and motivation towards my study.
- I would like to thank my dearly wife who was supportive and assisting me with data capturing.
- Friends and colleague, Lawrence, Aubrey, Dumisani, Silence and Rivers who inspired my final effort despite the enormous work pressures we were facing together.

© University of Venda

University of Venda
Creating Future Leaders

TABLE OF CONTENTS PAGE

DISSERTATION OUTLAY

ABSTRACT i

ACKNOWLEDGEMENTS ii

TABLE OF CONTENT iii

LIST OF FIGURES v

LIST OF TABLES viii

Chapter 1: Introduction 1

1.1. Literature review 1

1.2. Description of Phongolo River 10

1.3. Research question 12

1.4. Research hypothesis 13

1.6. Description of the major project 13

1.7. Reference list 14

Chapter 2: Materials and methods 18

2.1. Site selection 18

2.2. Historical flow data 18

2.3. Survey frequency 19

2.4. Site specific data 20

2.5. Water chemistry 20

2.6. Periphyton 20

2.7. Benthic macro-invertebrates 24

2.8. The ecological status of the sites 25

2.9. Data analyses 25

2.10. Reference list 26

Chapter 3: Results 28

© University of Venda

University of Venda
Creating Future Leaders

3.1. Reference Site 28
3.2. The survey area and selected survey sites 28
3.3. Site description 31
3.4.Discharge records 34
3.5. Survey frequency 36
3.6. Water quality 37
3.7. Biota 37
3.7.1.Periphyton 37
3.7.2. Benthic macro-invertebrates 41
3.7.2.1. Diversity 41
3.3.7.2. Abundance 43
3.3.7.3. Biomass 47
3.3.74. SASS 49
3.8. Reference list 50

Chapter 4: Discussion 51
4.1. Flood release from Pongolopoort Dam 51
4.2. SASS5 52
4.3. Water quality 52
4.4. Primary production 56
4.5. Organic matter 57
4.6. Benthic macro-invertebrates 57
4.7. Conclusion 58
4.8. Reference list 61

Appendix 64

UNIVERSITY OF VENDA
LIBRARY

© University of Venda

University of Venda
Creating Future Leaders

LIST OF FIGURES

PAGE

Figure 1.1. The average annual rainfall in South Africa (Adapted from Archer et al. 2010) 4

Figure 1.2. The average annual temperature in South Africa (Adapted from Archer et al. 2010) 4

Figure 2.1. Arial view of gauging station (W4H013) downstream of Pongolapoort Dam 20

Figure 2.2. A close-up view of gauging station W4H013 20

Figure 2.3. Determining nutrients concentration in water using Merck Pharo spectrophotometer and associated kits 22

Figure 2.4. Measuring cobbles surface area using aluminium foil. A: cobbles covered with aluminium foil, B: the unfolded foil marked into regular shapes and C: the regular shapes of the foil pasted on paper 23

Figure 2.5. Measuring the chlorophyll-a with the Labomed 22RS spectrophotometer 24

Figure 2.6. The Labcon Muffle Furnace used to determine Ash Free Dry Mass 25

Figure 2.7. Benthic macro-invertebrate sampling using a surber sampler 26

Figure 3.1. The location of study area showing the selected sites and two ecoregions (Site 1 located in Lebombo Upland and Site in Lowveld in Ecoregin) 30

Figure 3.2. Aerial view of surveyed sites in the Phongolo River 31

Figure 3.3. A general view of Site 1, the available habitat and sub-sites in the Phongolo River 33

Figure 3.4. The observed substrate in the sub-sites of Site 1 in the Phongolo River 33

Figure 3.5. A general view of Site 2, the available habitat and sub-sites in the Phongolo River 34

Figure 3.6. The observed substrate in the sub-sites of Site 2 in the Phongolo River 34

Figure 3.7. The discharge from Pongolapoort Dam recorded at gauging weir W4H013 in the period December 2012 to December 2013. The arrows on the graph indicate the four surveys and the graph is truncated in October 2013 to accommodate the magnitude of the flood release 36

© University of Venda

University of Venda
Creating Future Leaders

Figure 3.8. The mean and standard deviation of in situ physico-chemical parameters recorded during the surveys in the Phongolo River in 2013 39

Figure 3.9. The mean and standard deviation of water depth and velocity measured in the sub-sites during the surveys in the Phongolo River in 2013 40

Figure 3.10. The mean and standard deviation of nutrient concentration recorded in water samples collected at the Sites 1 and 2 in Phongolo River in 2013..... 40

Figure 3.11. The mean and standard deviation of Chlorophyll-a concentration per cm^2 recorded on the cobbles collected during the surveys in Phongolo River in 2013 41

Figure 3.12. The mean and standard deviation of Ash Free Dry Mass (AFDM) per cm^{-2} recorded on the cobbles collected during the surveys in Phongolo River in 2013 41

Figure 3.13. The most abundant families during the surveys (A = Baetidae, B= Simulidae, C = Thiaridae and D = Hydropsychidae) 44

Figure 3.14. The abundance of benthic macro-invertebrate families observed during the four surveys in the Phongolo River during the period of April to November 2013. 45

Figure 3.15. Non-metric multidimensional scaling (NMDS) plots of macro-invertebrate community composition based on abundance at two sites surveyed seasonally in the Phongola River. The prefix 1,2,3,4 indicate the survey number, S1, S2 site number, a,b,c,d sub-site and the circles shows the variation between the sites 46

Figure 3.16: Correlation tri-plot based on redundancy analyses (RDA) of benthic macro-invertebrates families and environmental factors at the two sites surveyed seasonally. Abbreviations: con = electric conductivity, P = Phosphate, 1 = Athericidae, 2 = Atydae, 3 = Baetidae, 4 = Chironomidae, 5 = Chlorocyphidae, 6 = Coenagrionidae, 7 = Elmidae, 8 = Gomphidae, 9 = Gyrinidae, 10 = Heptageniidae, 11 = Hydrophylidae, 12 = Hydropsychidae, 13 = Leptoceridae, 14 = Leptophlebiidae, 15 = Libellulidae, 16 = Naucoridae, 17= Oligocheata, 18 = Oligoneuridae, 19 = Philopotamidae, 20 = Physidae, 21 = Psychomidae, 22 = Pyralidae, 23 = Simulidae, 24 = Tabanidae, 25 = Thiaridae and, 26 = Tricorythidae 48

Figure 3.17. The total biomass in grams of benthic macro-invertebrates families observed during the four surveys in the Phongolo River during the period of April to November 2013.2013 49

© University of Venda

University of Venda
Creating Future Leaders

Figure 3.18. The total biomass in grams of benthic macro-invertebrates families observed at Sites 1 and 2 during the four surveys in the Phongolo River during the period of April to November 2013 50

© University of Venda

University of Venda
Creating Future Leaders

PAGE

LIST OF TABLES

Table 3.1. The location and characteristics of the survey sites in the Phongolo River 31

Table 3.2. The discharge records measured at gauging weir W4H013 downstream of Site 1 35

Table 3.3. The dates of four surveys conducted at Phongolo River in 2013 36

Table 3.4. Means, standard deviations and ranges of measured parameters (n=14), p-values are shown for only variables that showed significant differences between sites 38

Table 3.5. The correlation of Chlorophyll-*a* per surface area and nutrients concentration using Pearson correlation 42

Table 3.6. The average body size and flow preference (Gerber and Gabriel 2002) of the benthic macro-invertebrate observed at the two sites in the Phongolo River during the period of April to November 2013 (Flow = VS : very slow, S:slow, S-M: slow to moderate, MF : moderately Fast, F: fast, VF : Very fast) 43

Table 3.7. Grouping of benthic macro-invertebrate diversity, based on body on average size, observed in the Phongolo River during the period of April to November 2013 (P = present and A = absent) 43

Table 3.8. Grouping of benthic macro-invertebrate abundance, based on body on average size, observed in the Phongolo River during the period of April to November 2013 (N = no specimens) 46

Table 3.9. Grouping of benthic macro-invertebrate abundance, based on flow preference, observed in the Phongolo River during the period of April to November 2013 (N = no specimens) 47

Table 3.10. SASS scores of Sites 1 and 2 of the two surveys in the Phongolo River during the period of April and July 2013 50

© University of Venda

University of Venda
Creating Future Leaders

Chapter 1: Introduction

1.1 Literature review

Aquatic ecosystems worldwide are experiencing a change in natural conditions due to anthropogenic activities. These activities include the inflow of high nutrient concentrations from poorly managed sewage treatment plants and agriculture, pollution, overfishing and alien species introductions which result in biodiversity loss (Chapman 1992). River damming is also significant as it leads to loss in biodiversity caused by the change of natural conditions downstream of the dam (Haghighi *et al.* 2014). Dams change the downstream flow regime, reduce the mean annual flow and alter seasonal variation of flow regime. The purpose and the size of the dam also affect the composition and abundance of aquatic organisms (Haghighi *et al.* 2014).

Dallas and Day (2004) described rivers as "*longitudinal systems, driven largely by the flow of water, that are divided into zones, which are distinct with respect to their physical, chemical and biological characteristics*". A river is therefore characterised by its hydrology, habitat type, dissolved solutes, biota, sediments and the shape of the channel (Allan 1995). A river functions as an ecosystem which supports biota at different trophic levels and also provides resources to people living in the catchment. The water flowing in a river shapes the physical structure and flow relates to the gradient and the implication is that while fast flow occurs in the upper reaches, the flow velocity decreases downstream (Allan 1995). In addition, the volume of the water increases downstream as more tributaries join which implies that a river begins as a narrow channel and as more water is added, the channel gets wider through the process of erosion (Junk *et al.* 1989). Materials that are eroded from upper reaches, are transported downstream where it is deposited as the flow decreases (Davies and Day, 1998).

Rivers are divided into zones and Davies and Day (1998) recognises three zones namely the headwater, middle and lower zones. The headwater zone has fast flowing, well oxygenated, clear and nutrient poor water. Coarse alluvial material such as boulders and cobbles dominate the substrate and the dense canopy cover limits the penetration of light which lowers the productivity (Dallas and Day 2004). In the middle

© University of Venda

University of Venda
Creating Future Leaders

zone the river becomes wider and the oxygen concentration and water flow decreases while nutrient concentration, temperature and turbidity increase (Davies and Day 1998). The primary production is higher than in the headwater zone due to the opening of the canopy and the increased amount of light. The river is widest in the lower zone where flow decreases further and the substrate is dominated by fine alluvial material such as mud and silt. The canopy is open and the nutrient and mineral load increases while oxygen content decreases. The open canopy leads to high rate of photosynthesis.

Rivers experience different flow, flood, patterns, and floodplains, which vary from river to river. Floodplains assist rivers to accommodate floods and the larger the floodplain the better the ability of the river to accommodate a flood (Junk *et al.* 1989).

The water in rivers are from different precipitation sources such as rain and snow (Junk *et al.* 1989). Some rivers start as outflow from lakes or wetlands or as springs that bubble up from underground. The hydrology of rivers is determined by climate conditions which determine the seasonal precipitation and evaporation rate (Rowntree *et al.* 2000). During heavy rain, or if a large amount of water is added to rivers, they overflow their banks and flood the surrounding land resulting in floodplains (Davies and Day 1998). Rivers in the steep sloped headwater zone, near their source, flow very fast and the fast flowing water flushes away gravel, sand and mud leaving a rocky bottom. When tributaries join the main river the river gets wider (Paxton and King 2009). According to Chapman (1992), rivers change continuously as a result of erosion and sedimentation and this removes or replaces the river bed and can change the channel line. Over a period of time, water can cut through bedrock and rivers can cut deep gorges and canyons if the sedimentary rock is soft (Paxton and King 2009). Erosion caused by human activities in catchments leads to habitat loss and it is regarded as a disturbance in ecosystem (Chapman 1992).

In South Africa the climate variability has led to a landscape mosaic that includes semi-arid to arid areas as well as areas with a high rainfall (Schulze 2000). Rainfall in South

UNIVERSITY OF VENDA
LIBRARY

© University of Venda

Africa displays a decreasing gradient from east to west (Schulze 2000) and this results in very dry areas in the south-west, temperate and subtropical areas in the northeast and desert in a region of along parts of the north western area. The annual rainfall in the west of the country is below 200 mma^{-1} while the eastern highveld receives rainfall ranging from 500 to 900 mma^{-1} (Figure 1.1). The average annual rainfall in the centre of country is approximately 400 mma^{-1} (Figure 1.1). In addition to spatial differences there are also temporal differences with summer rainfall occurring from November to March in the central and northern parts of the country while in the southern part of the country winter rainfall occurs in the coldest month (Schulze 2000).

Temperature is *inter alia* influenced by elevation, terrain and ocean current (Schulze 2000). Climatic conditions vary from east to west in response to the warm Agulhas and the cold Benguela currents. The warm ocean current sweeps southward regions along the Indian Ocean coastline in the east for several months in a year and the cold current sweeps northward region along the Atlantic Ocean coastline in the west. In the narrow peninsula of the Cape of Good Hope, the effects of the warm and cold current is noticeable where the east side the water temperature of 4°C is higher than the west side. The variation in the average temperatures in South Africa is regarded as low and a comparison of the annual average temperatures of Cape Town and Pretoria serves as good example where Cape Town has annual average temperature of 17°C while that of Pretoria is 17.5°C (Archer *et al.* 2010). However based on minimums and maximums the variation is high with the maximum temperature recorded in the Northern Cape close to 48°C and the lowest minimum of -6.1°C recorded in the northeast of Northern Cape Province (Figure 1.2).

Because of the low rainfall South Africa has only a few large rivers when compared to the rest of Africa. In addition river flow is seasonal in the arid parts of the country and due to continental uplift many of the east-flowing rivers in South Africa are short and deeply incised (Paxton and King 2009). Many rivers in South African are ephemeral and they flow for a short period of time and often not on a regular basis. Ephemeral rivers are divided into two types namely: true ephemerals that flow during specific

© University of Venda

rainfall events and seasonal ephemerals that flow with a seasonal regularity. On the other hand there are number of perennial, or permanent flowing rivers that flow throughout all seasons but have low flow during the dry season and high flow during the wet seasons (Paxton and King 2009).

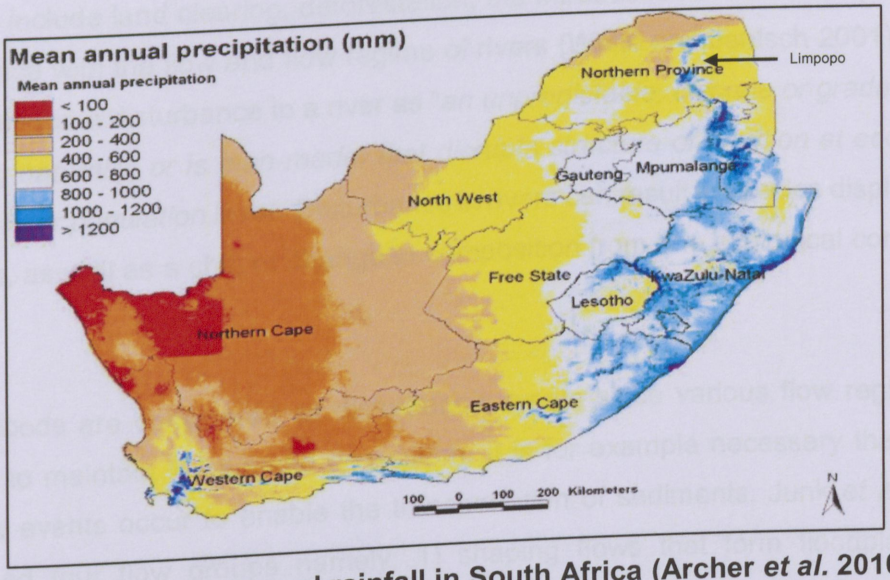


Figure 1.1: The average annual rainfall in South Africa (Archer *et al.* 2010).

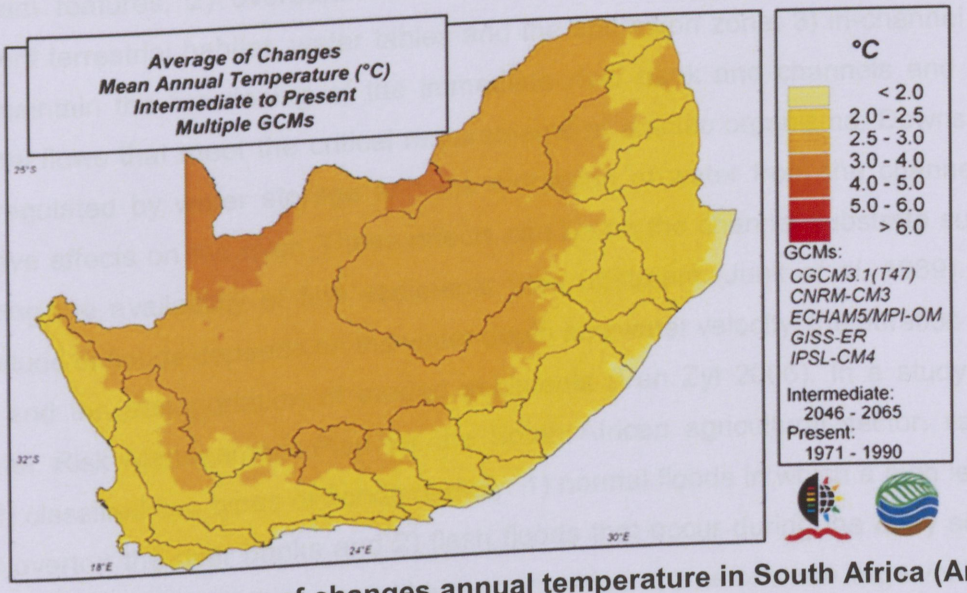


Figure 1.2: The average of changes annual temperature in South Africa (Archer *et al.* 2010).

© University of Venda

University of Venda
Creating Future Leaders

In ecology the concept disturbance is defined as any "natural or anthropogenic event that disrupts an ecosystem, community or population structure" (Fraterrigo and Ruska 2008; White and Pickett 1985). Ecological disturbance events include fire, flooding, earthquakes and human activities which have an impact on environments. Human activities include land clearing, deforestation, the introduction of invasive species and interference with the flow and flow regime of rivers (White and Jentsch 2001). Sparks (1990) defined a disturbance in a river as "*an unpredictable, discrete or gradual event, occurring naturally, or is man-made, that disrupts structure or function at ecosystem, community or population level*. Disturbance in rivers can result in species displacement or losses, as well as a shift or change in composition from one ecological condition to another.

Not all floods are considered as disturbance events since various flow regimes are required to maintain the aquatic ecosystem. It is for example necessary that natural high flow events occur to enable the transportation of sediments. Junk *et al.* (1989) recognised four flow groups namely: 1) shaping flows that form floodplains and instream features, 2) overbank flows that maintain surrounding riparian habitats, adjacent terrestrial habitat, water tables and the saturation zone, 3) in-channel flows that maintain the functioning of the immediate river bank and channels and 4) in-channel flows that meet the critical requirements of aquatic organisms. Downstream flow regulated by water storage and the extraction of water from the channel has negative effects on the river. These effects can be on the channel substrate such as reducing the availability of fine sediments from upstream (Junk *et al.* 1989). The magnitude of floods depends on the water depth and water velocity, the duration of the flood and the transportation of eroded sediments (Van Zyl 2006). In a study on a Disaster Risk Management Plan for the South African agricultural sector, van Zyl (2006) classified two types of floods namely: 1) normal floods in which a high level of water overtop the river banks and 2) flash floods that occur during the rainy season when an excess of rainfall occurs within a short period of time or when large volume of water is released from the dam into the rivers. The former is also referred to as a non-scouring flood and later as a scouring flood. Although scouring floods do not

© University of Venda

necessarily remove fish from the river, they alter resource availability and it has been shown that they can remove algae and macro-invertebrates (Franssen *et al.* 2006).

The effect of large scale perturbations on community structure has historically been an area of ecological research (Meffe 1984) and the work of Harrell (1978) is an example of a study on the effect of flooding on fish diversity. How ecosystems respond to environmental impacts, such as changes in the disturbance regime, is a central question in modern ecology and current models suggest that ecosystems can respond rapidly to such changes, causing regime shifts or the ecosystem switching to an alternative state (Robinson and Uehlinger 2008).

Water has a physical and chemical character that results mainly from the geology of the area through which the river flows (Dallas and Day 2004). The character variables include temperature, pH, electrical conductivity, total suspended substances, total dissolved solids, oxygen content, nutrient content, turbidity and salinity (Allan 1995). Collectively these variables contribute to what is referred to as water quality. The effects of water quality on aquatic biota are complex since the biota adapt to a wide range of environmental conditions (Dallas and Day 2004). Water quality in rivers naturally change on a temporal scale as a result of seasonal changes in the discharge regime, biological activities and inflow water, whereas human activities can change water quality permanently (Allan 1995).

Organisms exposed to abiotic perturbations responded over evolutionary time by developing morphological and physiological adaptations that minimize the impact (Meffe 1984). Franssen *et al.* (2006) pointed out that in addition to environmental variability, fish assemblage structure has also been shaped by biotic interactions which depend on the disturbance regime of the perennial as well as intermittent or seasonal rivers. The organisms in different zones in the river have developed morphological and physiological adaptation (Davies and Day 1998). The headwater zone is dominated by aquatic organisms which are adapted to fast flowing water and most of the invertebrates in this zone feed by shredding leaves that entered the system from the

© University of Venda

University of Venda
Creating Future Leaders

adjoining vegetation. In the middle zone the invertebrates are dominated by collectors and grazers who feed on fine particles of food and periphyton, while collectors and grazers are also abundant in the lower zone (Dallas and Day 2004). The rivers experience natural disturbances, of which flooding forms a major part, resulting in specifically adapted organisms (Fritz *et al.* 2002). Besides being adapted to harsh conditions many lotic organisms can, and do, recover and in some cases rapidly, from disturbances (Franssen *et al.* 2006).

The availability of resources and health condition in aquatic ecosystem are important for the survival, growth and production of organisms in the ecosystem (Jeffries and Mills 1990). For an ecosystem to function there must first of all be primary production, in the form of photosynthesis, and this is influenced by aspects such as the availability of nutrients and suitable temperature. If primary production is limited, it has a knock-on effect that affects secondary production by for example fish and macro-invertebrates (Davies and Day 1998).

Algae are multi- or uni-cellular, non-flowering aquatic "plants" of which a large number of species can photosynthesize. They lack the general morphological features of the "true" plants such as leaves, roots, stems and flowers. The colour of algae is a results of the dominant pigment in their cells (Monson 1992). The presence of chlorophyll causes algae to be green while the presence of carotene leads to an orange or red colour (Caduto 1990). The algae are divided into major groups such as green algae, blue-green algae, diatoms and euglenoids (Caduto 1990). Microscopic algae, known as phytoplankton, are suspended in the water body while periphyton on the other hand is attached to the coarse alluvial materials, sediments and organisms, such as plants, in the water body (Monson 1992). Algae have an important role in the aquatic ecosystem as they are all primary producers, but they also provide shelter for smaller organisms and play an important role in a process of absorbing nutrient and toxic substances (Monson 1992). Through photosynthesis algae also reduce the carbon dioxide in the atmosphere and increase the dissolved oxygen in the atmosphere and aquatic ecosystems (Monson 1992). The photosynthetic rate of algae fluctuate during

© University of Venda

the day depending on the available amount of radiant energy and it is observed that algae can create over-saturated oxygen conditions at midday while oxygen depletion occurs early at the morning and in the late evening (Monson 1992). Nitrogen and phosphate are primary nutrient required by algae in the production of organic food by the process of photosynthesis (Caduto 1990).

Periphyton is a source of organic food for inter alia benthic macro-invertebrates and fish in rivers (Carey 2001). Periphyton community structure and species composition respond to environmental condition changes. These changes can occur naturally or are caused by anthropogenic activities in the catchment (Saikia 2011). Hydrological drivers such as water depth and flow also have an effect on periphyton community structure and species composition. A change in periphyton growth can affect benthic macro-invertebrate abundance and species richness. McCormick *et al.* (1991) found that dams and flow regulation have an effect on downstream benthic periphyton richness and consequently the density of benthic macro-invertebrates. To determine algal growth, or primary production, two parameters, chlorophyll-*a* and phosphorus concentration can be used. Phosphorous is a limiting factor for plant growth and the quantity of phosphorous required by plants is lower than nitrogen with a general N:P ratio of 10:1 (Davies and Day 1998). Because of their growth reaction to nitrogen and phosphate levels, periphyton is regarded as a good indicator of ecological condition (Carey 2001).

Organic matter is a source of energy in a river system and it enters the system via two pathways (Heeg *et al.* 1980). The first is the allochthonous pathway where organic material from outside the instream environment, such as leaves from the terrestrial plants lands in the river. The autochthonous pathway, on the other hand, is the production of organic material in the river by primary producers in the river itself. The amount of organic matter, and therefore the amount of energy, in water can be determined by calculating the Ash Free Dry Mass (AFDM) (Dillard 1989). To determine the organic and inorganic portions of a sample it important to note that organic material is combusted, while inorganic material is not. Upon combustion, the organic carbon is

© University of Venda

University of Venda
Creating Future Leaders

burned off leaving a residue which is referred to as the AFDM. AFDM gives an idea of how much organic carbon was contained in a sample and AFDM includes the biomass of micro-organisms such as fungi, small fauna and detritus in a sample (Dillard 1989).

Benthic macro-invertebrates is a diverse and abundant group that play a vital role in the river as they cycle organic matter, purify water and serve as food source for vertebrates within and outside the stream (Thirion 2007). They are not as mobile as fish and therefore are less able to escape the effects of changes in water quality and flow (Covich *et al.* 1999). In-stream substrates and riparian characteristics also have an effect on benthic macro-invertebrates (Heino *et al.* 2005). For the macro-invertebrates to function, sufficient nutrient input and water flow is required and a change in community structure can occur if there is a nutrient or flow decrease or increase (Covich *et al.* 1999).

Floods have a disturbance effect on benthic macro-invertebrate assemblage structures and research conducted in the Luvuvhu River catchment by Fouché *et al.* (2005) showed that the assemblage structure of benthic macro-invertebrates was disturbed during the major floods of 2000 but recovered after the floods. The presence of macro-invertebrates relates to water quality and their distribution is determined by the availability of habitat, water flow and water quality (Thirion 2007). The impoundment of rivers has an effect on benthic macro-invertebrate composition structures downstream and dams regulate water flow and this affect the habitat and the environmental factors which are required by the benthic macro-invertebrate species (Mantel *et al.* 2010). Some macro-invertebrates species are more sensitive to pollution while some are tolerant to pollution an in the polluted rivers the tolerant species dominate (Tripole 2007). An index known as the South Africa Scoring System version 5 (SASS5) has been developed to determine the condition or health status of the river (Dickens and Graham 2002). This index is primarily based on sensitivity and tolerance ratings of the benthic macro-invertebrates.

UNIVERSITY OF VENDA
LIBRARY

© University of Venda

Mendonca *et al.* (2005) demonstrated that fish community structure is correlated to the physical and chemical characteristics of a river and that change in river morphology can lead to change in these characteristics, which in turn affect fish assemblage. Lotic fish populations are influenced by flows and water level and where low water levels can for example limit fish movement, high water levels might provide more suitable habitat for fish (Kleynhans 2007). Floods also change the nutrient status and cycling in rivers and this has an effect on the aquatic biota. During a flood the abundance of resistant species in a river are not affected or can even increase, while the abundance of non-resistant species decrease during and remain low after the flood event (Rogers *et al.* 2005).

Mäler *et al.* (2003) defined a regime as "*a characteristic behaviour of a system, which is maintained by mutually reinforced processes or feedbacks*" and considered a regime as persistent relative to the time period over which they occur. A change of regimes is regarded as a "regime shift" and usually occurs when a change in an internal process or disturbance completely changes system behaviour (Carpenter 2003). To manage a freshwater ecosystem it is important to understand the hydrological regime (Botter 2014). In rivers a flow regime is the flowing pattern of a river and change in this pattern is considered as regime shift (Carpenter 2003). The major body of data regarding ecosystem regime shift comes from the terrestrial environment and from shallow lakes in the freshwater environment but little is known of lotic systems (Robinson and Uehlinger 2008). This data paucity is in particular applicable to South African rivers. Knowledge regarding regime shifts and their duration is critical for environmental management to take decisions. Human activities in an environment can result in a regime shift and this has an effect on ecosystem services for the human population (Robinson and Uehlinger 2008).

1.2 Description of Phongolo River

The Phongolo River is located in an area of the KwaZulu-Natal Province historically referred to as Maputoland (Heeg *et al.* 1980). At low altitudes, in the Lowveld Ecoregion, the river forms a floodplain of approximately 10000 ha with numerous

© University of Venda

shallow pans that receive their water from the river during floods. The Phongolo Floodplain ecosystem has unique physical characteristics and a high biodiversity consisting of northern tropical biota as well migrant and rare species (Heeg *et al.* 1980). The human settlements adjacent to the river, and specifically the Thonga people, depend on the floodplain for food, such as fish, and cultivate crops in the enriched soil which results after flooding (Heeg *et al.* 1980). The Phongolo Floodplain includes two local municipalities in the Umkhanyakude District namely, Umhlanbuyalingana and Jozini local municipalities and people in these municipalities depend on the untreated water resources from pans and floodplains to meet their domestic needs (Lankford *et al.* 2011). In the period following winter, the evaporation rate exceeds the precipitation rate and the water levels of the pans drop and salts accumulate. The summer floods, starting in December during high rainfalls, dissolve the accumulated salts and production increases due to nutrient enrichment. In winter, the water levels drop and a decrease in production, due to low light intensity occurs and the aquatic biota depend on energy input from riparian vegetation (Heeg *et al.* 1980).

The catchment of the Phongolo River covers an area in excess of 7000 km^2 in the eastern side of South Africa. The river originates at 2200 m.a.s.l. and flows in the valley between the Lebombo and Ubombo Mountains.The Phongolo River is situated in a warm, humid, subtropical climate with summer rainfall occurring from December to March (Lankford *et al.* 2011). The South African Government constructed the Pongolapoort Dam in 1973 with the main purpose to store water for irrigation and to regulate floods (Lankford *et al.* 2011). The Pongolapoort Dam forms part of the Pongolapoort-Makatini Flats Government Water Scheme, which was proposed and developed in an effort "*to utilise the water resources of the Pongolo River, for the irrigation of sugar cane in Zululand in the area east of the Lebombo Mountains.*" (DWAF 1996). The water from the dam is supplied for irrigation to the farmers through canals (Lankford *et al.* 2011). According to the original planning the annual water releases from the dam, which included a single event to fill the pans, were intended to stimulate the natural flow regime and to maintain the floodplain (Smit 2014). This is however not the case and the release of water from the dam is driven by the needs of agriculture

© University of Venda

which leads to the release of large volumes of water to meet needs (Smit 2014). In addition, a single large flow release is done that do not coincide with the expected high flows at the peak of the rain season. The annual flood released in the Phongolo River can be classified as an erosive flood (Jurajda *et al.* 2006) as it consists of fast moving turbulent water that move substrates and change the physical in-channel habitat. This flood release has potentially changed natural conditions in the Phongolo River with a resultant decrease in resources for the human population (Lankford *et al.* 2011). The study by McCartney *et al.* (2003) showed that local communities were not satisfied with the poorly timed flood release and reported a decrease in resources harvested from the floodplain. Concerns regarding the incorrect releases from the Pongolapoort Dam led to the initiation of a Water Research Commission (WRC) funded project that investigated the ecosystem functioning, sustainable utilization and management of aquatic resources of the Lower Phongolo River and its associated floodplains (Smit 2014). In the initial surveys of this WRC project it was observed that the fish biodiversity of the river reach immediately downstream of the dam wall was lower than the expected diversity derived from historic data (Khosa 2012).

1.3 Research question

The question now arises whether the floods released from the Pongolapoort Dam, and the changes in biodiversity, resulted in a regime shift in the river section after the dam wall. Based on the observed changes in the fish community structure it can be asked whether these shifts are permanent or not. In addition it can be asked that whether flood release affected the benthic algae and benthic macro-invertebrate assemblage structure. Although it is predicted that the physical habitat ecosystem properties would change, it is expected that the flood will have little effect on the physico-chemical aspects. It is furthermore predicted that benthic matter decreases because alluvial bed material are mobilised and benthic particulates are flushed out of the system which will lead to reduced benthic macro-invertebrate density, biomass and taxon richness and higher proportions of smaller sized organisms (Robinson and Uehlinger 2008). As stated by Robinson and Uehlinger (2008) it is expected that "a regime shift will be

© University of Venda

manifested by a change in mean values and an increase in variation which will decrease after the shift".

1.4 Research hypothesis

It is hypothesized that the flood will not affect the water chemistry or temperature regime of the river but that the flood will reduce the transported and benthic organic matter and reduce the standing stock of the primary producers. The flood will lead to a decrease in the abundance of disturbance-prone macro-invertebrates while disturbance-resistant taxa would increase.

1.5 Aims and objectives

The aim of the study was to determine whether a novel macro-invertebrate regime, or regime shift, is created by the flood release in the Phongolo River and if it occurs, what the duration is.

The objective of this study was to compare the pre- and post-flood physico-chemical aspects, primary production and benthic macro-invertebrate composition of two sites immediately downstream of the Pongolapoort Dam.

1.6 Description of the major project

This study formed part of a larger Water Research Commission funded project that is investigating the "Ecosystem functioning, sustainable utilization and management of aquatic resources of the Lower Phongolo River and floodplain" (Smit 2014). This current major project is assessing the ecological status of Phongolo River and floodplain using fish health and macro-invertebrates community structure as indicators of ecological integrity to establish conservation plans for the major aquatic fauna which includes fish, birds and amphibians. The findings of this project could be used by the Ezemvelo-KZN wildlife conservation authority to establish conservation plans for the threatened species in the Phongolo River and floodplain and maintain the unique ecosystem services which is socio-economical important to the local communities.

© University of Venda

1.7 Reference list

Allan JD. 1995. *Stream Ecology: Structure and functioning of running waters.* London: Chapman and Hall.

Archer E, Engelbrecht F, Landman W, Landman W, Le Roux A, Van Huyssteen E, Fatti C, Vogel C, Akoon I, Maserumule R, Colvin C, Le Maitre D, Lotter D, Olwoch J, Wright C, Meyer AA, Theron A, Diedericks G, Maherry A, Rossouw M, Midgley G, Davis C, Stevens N, Sinden LA, Warburton M, Nkambule C. 2010. *South African Risk and Vulnerability Atlas.* Department of Science and Technology. Report No. 5940.

Botter G. 2014. Flow regime shifts in the Little Piney creek (US). *Advanced in Water Resources* 71: 44-54.

Caduto MJ. 1990. *Pond and Brook: A Guide to Nature in Freshwater Environments.* Englewood Cliffs: Prentice Hall.

Carey R. 2001. The effect of nutrient enrichment on stream peryphyton growth in the southern coastal plain of Georgia: Implementation for low dissolved oxygen. Unpublished PhD thesis, University of Georgia.

Carpenter, S.R. 2003. Regime Shifts in Lake Ecosystems: Pattern and Variation. Volume 1: Excellence in Ecology Series. Germany: *Ecology Institute.*

Chapman D. 1992. *Water Quality Assessments – A guide to Use of Biota, Sediments and Water in Environmental Monitoring.* (2nd edn). Cambridg: University Press.

Covich AP, Palmer AMA, Crowl TA. 1999. The role of benthic invertebrate species in freshwater ecosystem: Zoobenthic species influence energy flows and nutrient cycling. *BioScience* 49: 31-44.

Dallas HF, Day JA. 2004. *The effect of water quality variables on aquatic ecosystems: A review.* Water Research Commission Technical Report 224/O4. Pretoria: Water Research Commission.

Davies BR, Day JA 1998. *Vanishing Waters.* Cape Town: University of Cape Town Press.

Dickens CWS, Graham PM. 2002.The South African Scoring System (SASS) version 5 rapid bio-assessment method for rivers. *African Journal of Aquatic Science* 27:1-10.

Dillard G.E. 1989. Freshwater algae of the Southeastern United States. Part 2. Chlorophyceae: Ulotrichales, Microsporales, Cylindrocapsales,

© University of Venda

University of Venda
Creating Future Leaders

Sphaeropleales, Chaetophorales, Cladophorales, Schizogoniales, Siphonales, and Oedogoniales. *Bibliotheca Phycologica* 83: 1-63.

DWAF (Department of Water Affairs and Forestry). 1996. *South African Water Quality Guidelines*. Volume 7: Aquatic Ecosystem.

Fouché PSO, Foord SH, Potgieter N, Vander Waal BCW, Van Ree T. 2005. *Towards understanding of factors affecting the biological integrity of rivers in the Limpopo Province: Niche partitioning, habitat preference and microbiological status in rheophilic biotopes of the Luvuhvu and Mutale rivers.* WRC Report no. 1197/105. Pretoria: Water Research Commission.

Franssen NR, Gido KB, Guy CS, Tripe JA, Shrank SJ, Strakosh TR, Bertrand KN, Franssen CM, Pitts KL, Paukert GP. 2006. Effects of floods on fish assemblages in an intermittent prairie stream. *Freshwater Biology* 51: 2072-2086.

Fraterrigo JM, Rusak JA. 2008. Disturbance-driven changes in the variability of ecological patterns and processes. *Ecology Letters* 11: 756-770.

Fritz KM, Tripe JA, Guy CS. 2002. Recovery of three fish species to flood and seasonal drying in a tall grass prairie stream. *Transactions of the Kansas Academy of Science* 3: 209-218.

Haghighi AT, Marttila H, Kløve B. 2014. Development of a new index to assess rivers regime impacts after dam construction. *Global Planetary Change* 122: 186-196.

Harrell HL. 1978. Response of the Devil's River (Texas) fish community to flooding. *Copeia* 978: 60-68.

Heeg J, Breen CM, Rogers KH. 1980. The Pongolo Floodplain: A unique ecosystem threatened. In: Bruton MN, Cooper KH (eds), *The ecology of Maputoland*. University of Kwazulu Natal. pp 374-381.

Heino J, Paavola R, Virtanen R, Muotka T. 2005. Searching for biodiversity indicators in running waters: do bryophytes, macro-invertebrates, and fish show congruent diversity patterns? *Biodiversity and Conservation* 14: 415-428.

Jeffries M, Mills D. 1990. *Freshwater Ecology Principles and Applications*. London: Belhaven Press.

Junk W J, Bayley PB, Sparks RE. 1989. The flood pulse concept in river floodplain systems. In: Dodge DP (eds), *Proceedings of the International Large River Symposium (LARS)*, Canada: Canadian Special Publication of Fisheries and Aquatic Sciences.

© University of Venda

University of Venda
Creating Future Leaders

Jurajda P, Reichard M, Smith C. 2006. Immediate impact of an extensive summer flood on the adult fish assemblage of a channelized lowland river. *Journal of Freshwater Ecology* 3: 493-501.

Khosa D. 2012. The impact of water control measures on the fish biodiversity of the lower reaches of the Phongolo River, KwaZulu-Natal. Unpublished Honours report, Zoology Department, University of Venda.

Kleynhans CJ. 2007. Module D: *Fish Response Assessment Index in River EcoClassification: Manual for EcoStatus Determination (version 2).* WRC Report No. TT330/08. Pretoria: Water Research Commission and Department of Water Affairs and Forestry.

Lankford B, Pringle C, Dickens C, Lewis F, Mander M, Chhotray V, Goulden M, Nxele Z, Quayle L. 2011. Hydrological modelling of water allocation, ecosystem services and poverty alleviation in the Pongola floodplain, South Africa. *Journal of Environmental Planning and Management* 54: 1237-1260.

Mäler KG, Xepapadeas A, de Zeeuw A. 2003. The Economics of Shallow Lakes. *Environmental and Resource Economics* 26: 603-624.

Mantel SK, Muller NWJ, Hughes BA. 2010. Ecological impacts of small dams on South African rivers Part 2: Biotic response – abundance and composition of macroinvertebrate communities. *Institute for Water Research* 36: 55-76.

McCartney M, Jugani J, Mkhize S. 2003. *Comprehensive options assessment: the Pongolo case* study (eds), Proceeding of comprehensive options assessment for dams Workshop, 22–24 September. Geneva, Switzerland.

McCormick PV, Stevenson RJ. 1991. Mechanisms of benthic algal succession in lotic environments. *Ecology* 72: 1835-1848.

Meffe GK. 1984. Effects of abiotic disturbance on coexistence of predator-prey fish species. *Ecology* 68: 1525 – 1534.

Mendonca FP, Magnusson WE, Zuanon J. 2005. Relationship between habitat characteristics and fish assemblage in small streams of Central Amazon. *American Society of Ichthyologists and Herpetologists* 4: 751-764.

Monson BA. 1992. *A Primer on Limnology* (2nd edn). College of Natural Resources. Cleveland Avenue: University of Minnesota.

Paxton BR, King JM. 2009. *The influence of hydraulics, hydrology and temperature on the distribution, habitat use and recruitment of threatened cyprinids in a Western Cape River, South Africa.* WRC No. 1483/1/09. 170. Cape Town: Water Research Commission Report.

© University of Venda

University of Venda
Creating Future Leaders

Robinson CT, Uehlinger U. 2008. Experimental floods cause ecosystem regime shift in a regulated river. *Ecological Applications* 18: 511-526.

Rogers MW, Allen MS, Jones MD. 2005. Relationship between rivers surface and fish assemblage in the Oklawaha River, Florida. *Rivers Research and Application* 3: 43-51.

Rowntree K, Wadeson R, O'Keeffe J. 2000. Geomorphological zonation for ecological river typing. *South African Geographical Journal* 83: 163-172.

Saikia SK. 2011. Review on periphyton as mediator of nutrient transfer in aquatic ecosystems. *Ecologia Balkanica* 3: 65-78.

Schulze RE. 2000. Modelling Hydrological Responses to Land Use and Climate Change: A Southern African Perspective. *Ambio* 29: 12-22.

Smit NJ. (ed). 2014. *Ecosystem functioning, sustainable utilization and management of aquatic resources of the Lower Phongolo River and floodplain*". Progress report, Project K5-2185 of the WRC. Pretoria: Water Research Commission.

Sparks R E, Bayley PB, Kohler SL, Osborne LL. 1990. Disturbance and recovery of large floodplain rivers. *Environmental Management* 14: 699-709.

Thirion C. 2007. Module E: *Macroinvertebrate Response Assessment Index in River EcoClassification: Manual for EcoStatus Determination (version 2)*. WRC Report No. TT 332/08. Pretoria: Joint Water Research Commission and Department of Water Affairs and Forestry report.

Tripole S, Vallania EA, Corigliano MC. 2007. Benthic macroinvertebrates tolerance to water acidity in Grande river sub-basin (San Luis, Argentina). *Lemnetica* 27: 28-38.

Van Zyl K. 2006. *A study on a disaster risk management plan for the South African agricultural sector*. Pretoria: Agric SA, NAFU SA and TAU SA.

White AS, Pickett STA. 1985. *Natural disturbance and patch dynamics: an introduction. In: The Ecology of Natural Disturbance and Patch Dynamics*. New York: Academic Press.

White PS, Jentsch A. 2001. The search for generality in studies of disturbance and ecosytems dynamics. *Progress in Botany* 62: 399-449.

© University of Venda

Chapter 2: Materials and methods.

2.1 Site selection

Two of the sites downstream of the Pongolapoort Dam, that were also used as survey sites in the major Water Research Commission Project (Smit 2014), were selected as the survey sites in this study. Site 1 was immediately downstream of the dam wall and Site 2 a further 12 km downstream. Although the sites were selected because they had similar geomorphological features, due to the fact that they were both in a Lower Foothill Zone (Rowntree and Wadeson 2000), they were in different ecoregions. A third site was selected upstream of the Pongolapoort Dam to serve as a "reference" site. Sampling was spatially replicated four times at each site. Each sub-site was in a rheophilic biotope and care was taken to select sub-sites that were similar in depth and substrate composition.

2.2 Historical flow data

Historical and current discharge data was obtained from the official records on the website (www.dwa.gov.za/Hydrology/Weekly) of the Department of Water Affairs and Sanitation. An official departmental flow gauging station, W4H013, is situated below the dam wall approximately 500 meters downstream of Site 1 (Figure 2.1) and has been in operation since 1985. The gauge consists of a weir (Figure 2.2) that is equipped and operated to measure and record discharges (Wessels and Rooseboom 2009).

2.3 Survey frequency

Surveys were scheduled to take place during the high and low flow scenarios in the period of April to November 2013. Care was taken to ensure that a scheduled high flow release was included in the survey period. Historic records show that these releases are not scheduled for a specific date but usually occurs in the period from October to November.

© University of Venda



Figure 2.1: Arial view of gauging station (W4H013) downstream of Pongolapoort Dam.



Figure 2.2: A close-up view of gauging station W4H013.

2.4 Site specific data

All organisms have a temperature range which is favourable for their optimal growth and production and the survival and is therefore important to determine water temperature. The dissolved oxygen was measured to determine if the dissolved oxygen saturation was conducive for the survival of aquatic biota. Benthic macro-invertebrates have a pH tolerance range and therefore pH was measured to determine if the conditions in the river was suitable for aquatic biota. At each site the following *in situ*

© University of Venda

UNIVERSITY OF VENDA

physico-chemical parameters were determined with handheld Eutech Cyberscan meters: Electrical conductivity (EC), dissolved oxygen (DO) concentration and saturation, total dissolved solids (TDS), temperature and pH.

In each sub-site the water depth was measured, using a meter rod at five randomly selected points and the average depth for each sub-site was calculated. At the same points the velocity was measured in $msec^{-1}$, using a PASCO PS 2130 velocity meter, in the water column 10 cm above the river bed. The average velocity for each sub-site was calculated. At each point the alluvial material on the bed was investigated, classified, the amount assessed and recorded (Appendix 1).

2.5 Water chemistry

Water samples were collected in pre-cleaned 500ml plastic bottles, refrigerated and transported to the laboratory. In the laboratory a Merck Pharo spectrophotometer (Figure 2.3) and associated kits were used to determine the concentrations of PO_4-P, NO_3-N, NO_2-N and NH_4. The Merck Pharo spectrophotometer is designed to measure the amount of light absorbed by the sample due to the colour change resulting from the chemical reactions in the test kit. The concentrations of PO_4-P, NO_3-N, NO_2-N and NH_4 were measured as they are limiting factors to primary production and consequently benthic macro-invertebrate assemblage structure (Dallas and Day 2004).

2.6 Periphyton

The periphyton growing on the substrates are a major part of the primary producers in an aquatic ecosystem and by determining the amount of periphyton the primary production is determined. Chlorophyll-*a* concentration was measured to determine primary productivity and Ash Free Dry Mass (AFDM) to calculate the organic matter content (Dillard 1989). At each sub-site, ten-fist sized cobbles were randomly collected, placed in plastic bags and refrigerated. In the laboratory the bags with the cobbles were kept frozen until analyses could be done. Periphyton was removed from all ten cobbles, which were allowed to thaw, with a wire brush into a beaker containing 200 ml water. The sample was then thoroughly mixed and a 10ml aliquot removed with a Labcon

© University of Venda

micro-pipette and filtered through a Whatman GF/F filter paper. After filtration the macro-invertebrates were physically removed from filter paper under 10X magnification using a Kyowa SE-L stereo microscope. The filter paper was then cut into two equal halves. One half of the filter paper was used for chlorophyll- *a* determination and the other for AFDM determination according to Robinson and Uehlinger (2008).



Figure 2.3: Determining nutrient concentration in water using Merck Pharo spectrophotometer and associated kits.

It is important that the surface area of each cobble is measured to determine the chlorophyll-*a* concentration and AFDM per surface area (Robinson and Uehlinger 2008). Because of the irregular form of the cobbles a method to calculate the surface area was devised. The cobble was carefully covered with aluminium foil (Figure 2.4A) and all overlapping sections of foil were cut away. The foil was then carefully unfolded and flattened. The surface area of the foil was then marked out in regular shapes (Figure 2.4B) and the shapes cut out and pasted on paper (Figure 2.4C). The surface areas of the regular shapes were calculated and surface areas added to obtain the total area of the cobble. Although it is not precise method the same procedure was repeated and it is accepted that the error factor was similar throughout.

The chlorophyll-a concentration in the samples was spectrophotometrically determined from hot ethanol (95%) extracts according to the method of Sartory (Swanepoel et al. 2008). The one half of the filter paper was boiled at 78°C for five minutes in 10 ml 95% ethanol cooled in the dark and poured into cuvette. Absorbance of the extracted chlorophyll-a was read with a Labomed Spectro 22RS spectrophotometer at a

© University of Venda

University of Venda
Creating Future Leaders

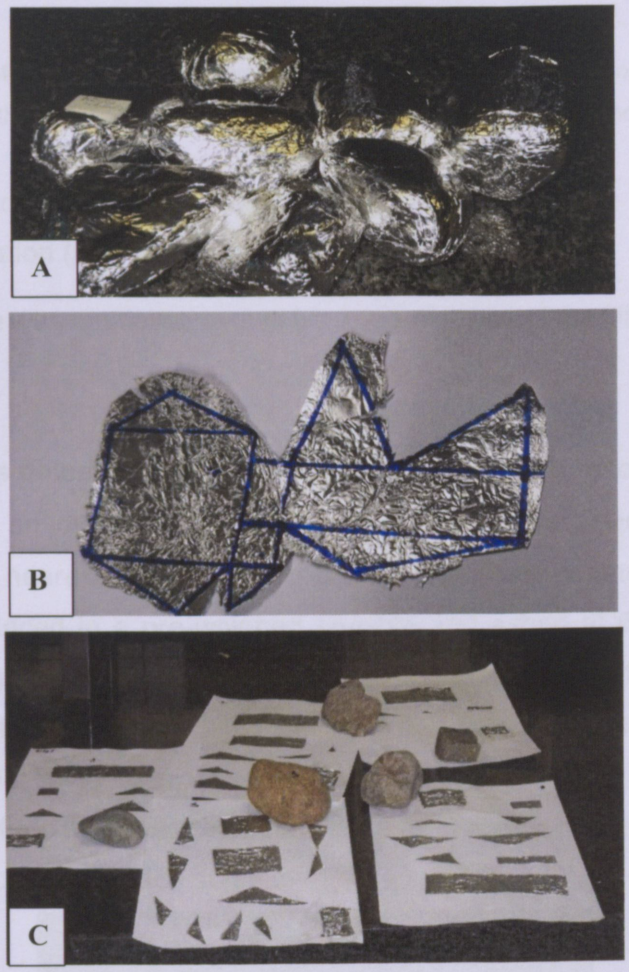


Figure 2.4: Measuring cobbles surface area using aluminium foil. A: cobbles covered with aluminium foil, B: the unfolded foil marked into regular shapes and C: the regular shapes of the foil pasted on paper.

wavelength of 665 nm (Figure 2.5). Then 100 µl of 0.1N HCl was added directly to the cuvette, which was inverted once to mix the extract, and the absorbance was read again at 665 nm after three minutes. Background absorbance for both samples were read at 750 nm and subtracted from the readings obtained at 665 nm. The calculation of chlorophyll-*a* mass was done using the formula used by Swanepoel *et al.* (2008):

$$\textit{Chlorophyll-a}\ \text{mass}\ (\mu g) = (A_{665} - A_{665a}) \times 28.66$$

© University of Venda

Where:

A_{665} = absorbency of ethanol extract at 665nm before it was acidified minus absorbency at 750 nm.

A_{665a} = absorbency of the acidified ethanol extract at 665nm minus the absorbency at 750 nm.

The concentration of chlorophyll-*a* was calculated as:

$$\text{Concentration } (\mu gL^{-1}) = \text{Chlorophyll-}a \text{ mass X } 100$$

The obtained value was multiplied by two because only half of the filter paper was used to calculate.

Ash Free Dry Mass determination was done by first drying the second half of the filter paper at 60°C in an oven for 24 hours. The mass of the dried filter paper was determined to the nearest milligram on a Citizen electronic balance. The dried filter paper was then placed in a pre-weighed crucible and ashed at 650°C in a Labcon muffle furnace (Figure 2.6) after which the mass of the ash was determined. Because only half of the filter paper was used the recorded mass was multiplied by two to determine the AFDM in the 10 ml aliquot according to Robinson and Uehlingher (2008). The AFDM per surface area was calculated to determine how much the organic matter produced by the cobbles at each sub-site.



Figure 2.5: Measuring the chlorophyll-*a* with a Labomed 22RS spectrophotometer.

© University of Venda



Figure 2.6: The Labcon muffle furnace used to determine Ash Free Dry Mass.

2.7 Benthic macro-invertebrates

A region of a habitat associated with fast moving water and coarse alluvial substrate, known as rheophilic biotope, is a recognized habitat for benthic macro-invertebrates. At each site and during each survey all four sub-sites were sampled. Following Robinson and Uehlingher (2008) the benthic macro-invertebrates were collected from the rheophilic biotopes using a surber sampler. The surber sampler had surface area of 0.045 m^2 and was covered with 250 µm mesh net. The sampler tapered towards the downstream end where it was closed off with removable cap (Figure 2.7). The open end of the surber sampler's metal frame was placed onto the substrate, the substrate disturbed for 60 seconds and the benthic macro-invertebrates were swept into the net by the current. To collect the sample the net was inverted and the cap at the end opened to decant the collected material into a sample bottle.

The collected specimens were preserved in 4% formalin and later handpicked in the laboratory using a Kyowa SE-L stereo-microscope at 10X magnification. Each specimen was identified to family level using the field guide of Gerber and Gabriel (2002) and the specimens counted. The biomass of each taxon was determined by drying the organisms at 60°C for a period of 48 hours and then weighed in milligram using a Citizen electronic balance.

© University of Venda



Figure 2.7: Benthic macro-invertebrate sampling using a surber sampler.

2.8 The ecological status of the sites

The SASS5 was used to determine the ecological health of the sites before and after flood release. Sampling was done using the standard SASS5 protocol and the SASS scores and ASPT were calculated according to Dickens and Graham (2002). The data was recorded on SASS5 field data sheet (Appendix 15).

2.9 Data analyses

The mean values and standard deviation of each measured parameter was determined. To test whether a regime shift had occurred, values of measured parameters before and after the flood were compared using a paired t-test and coefficients of variation. The change in periphyton and benthic macro-invertebrate biodiversity, total abundance and total biomass were determined with ANOVA. The regime shift in ecosystem properties of the data were tested with one-way ANOVA. Non-metric multidimensional scaling (NMDS) plots was used to determine the benthic macro-invertebrate community composition based on abundance.

To establish the correlation between nutrients content and chlorophyll-*a* concentration the Pearson correlation coefficient was determined (Millar 2001). Redundancy

© University of Venda

analyses (RDA) tri-plot was used to determine the effect of environmental factors measured on the abundance and diversity of benthic macro-invertebrates.

© University of Venda

University of Venda
Creating Future Leaders

2.10 Reference list

Dallas HF, Day JA. 2004. *The effect of water quality variables on aquatic ecosystems*: A review. Water research Commission Technical Report 224/O4. Pretoria: Water Research Commission.

Dickens CWS, Graham PM. 2002.The South African Scoring System (SASS) version 5 rapid bio-assessment method for rivers. *African Journal of Aquatic Science* 27:1-10.

Dillard G.E. 1989. Freshwater algae of the Southeastern United States. Part 2. Chlorophyceae: Ulotrichales, Microsporales, Cylindrocapsales, Sphaeropleales, Chaetophorales, Cladophorales, Schizogoniales, Siphonales, and Oedogoniales. *Bibliotheca Phycologica* 83: 1-63.

Gerber A, Gabriel MJM. 2002. *Aquatic Invertebrates of South African Rivers, Field Guide* (1st edn). Pretoria: Institute for Water Quality Studies, Department of Water Affairs and Forestry.

Millar N. 2001. Biology statistics made simple using excel. *School Science Review* 83: 23-34.

Robinson CT, Uehlinger U. 2008. Experimental floods cause ecosystem regime shift in a regulated river. *Ecological Applications* 18: 511-526.

Rowntree K, Wadeson R. 2000. *Field manual for channel classification and condition assessment.* NAEBP Report Series No. 13 Institute for Water Quality Studies. Pretoria: Department of Water Affairs and Forestry.

Smit NJ. (ed). *2014. Ecosystem functioning, sustainable utilization and management of aquatic resources of the Lower Phongolo River and floodplain*". Progress report, Project K5-2185 of the WRC. Pretoria: Water Research Commission.

Swanepoel A, Du Preez H, Schoeman C, Janse Van Vuuren S, Sundram A. 2008. *Condensed Laboratory Methods for the Monitoring of phytoplankton, including Cyanobacteria, in South African Freshwaters*. WRC Report: TT 323/08. Pretoria: Water Research Commission.

Wessels P, Rooseboom. 2009. Flow-gauging structures in South African rivers Part 1: An overview. *Water SA* 35: 22-32.

© University of Venda

University of Venda
Creating Future Leaders

Chapter 3: Results

3.1 Reference Site

The site above the dam was selected to serve as a reference to the sites below the dam. The selected Reference Site proved to be unsuccessful. At this site the channel was deep and wider and rheophilic biotopes scarce. Because it lacked sufficient habitat the site was sampled only once during April and the data of this survey is regarded as insufficient to be compared with two sites downstream of the Pongolapoort Dam that were surveyed four times.

3.2 The survey area and the selected survey sites

The two sites were downstream of the Pongolapoort Dam with Site 1 located in the Lebombo Uplands Ecoregion and Site 2 in the Lowveld Ecoregion (Figure 3.1 and Table 3.1). Site 1 is approximately 200 m downstream of the dam wall while Site 2 is approximately 12 km from the dam (Figure 3.2).

Where the terrain morphology in the Lebombo Uplands Eoregion consists of closed hills and mountains with a moderate to high relief, the Lowveld Ecoregion is dominated by plains with a moderate relief (Kleynhans *et al.* 2005). Both ecoregions have Bushveld vegetation and where the lowveld ecoregion is dominated by Mopane Bushveld and Mixed Lowveld Bushveld the Lembobo Uplands is dominated by Lebombo Arid Mountain Bushveld. Both ecoregions do however have Sweet Lowveld Vegetation present (Kleynhans *et al.* 2005).

Lower Foothill zones has characteristic alluvial material, that forms the river substrate and also has a distinctive hydrology based on the gradient (Rowntree *et al.* 2000). The river bed substrate is mostly coarse alluvial material, such as boulders and cobbles, and when the flow is high there is very little fine alluvial material, such as sand and silt. The water velocity in a Lower Foothill zone is generally higher than in for example a Lowland River zone. Based on the composition of the bed material, sites 1 and 2 were typical of a Lower Foothill zone.

© University of Venda

University of Venda
Creating Future Leaders

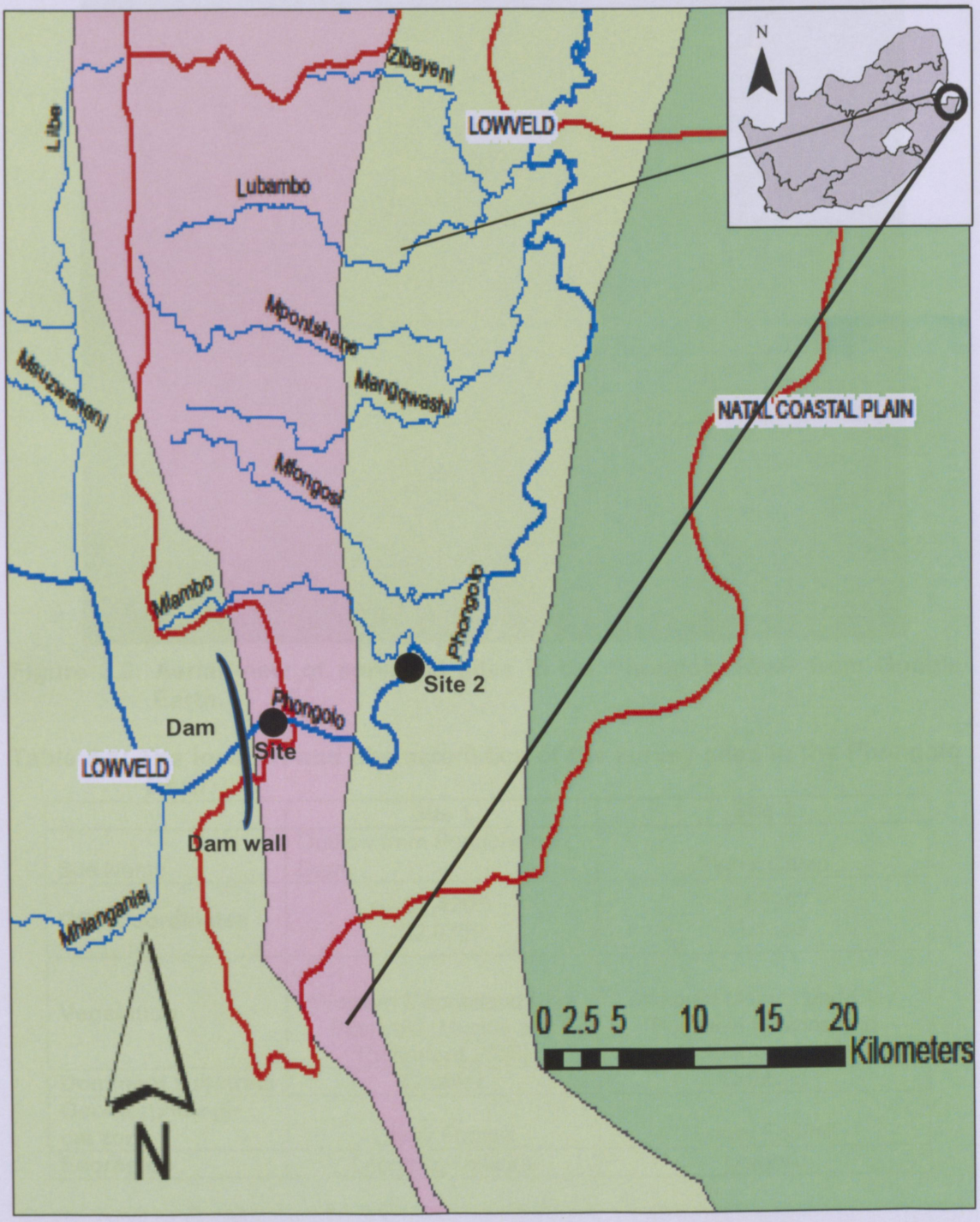


Figure 3.1: The location of study area showing the selected sites and two ecoregions (Site 1 was lcated in Lebombo Upland and Site 2 in Lowveld in Ecoregion).

© University of Venda



Figure 3.2: Aerial view of surveyed sites in the Phongolo River from Google Earth.

Table 3.1: The location and characteristics of the survey sites in the Phongolo River.

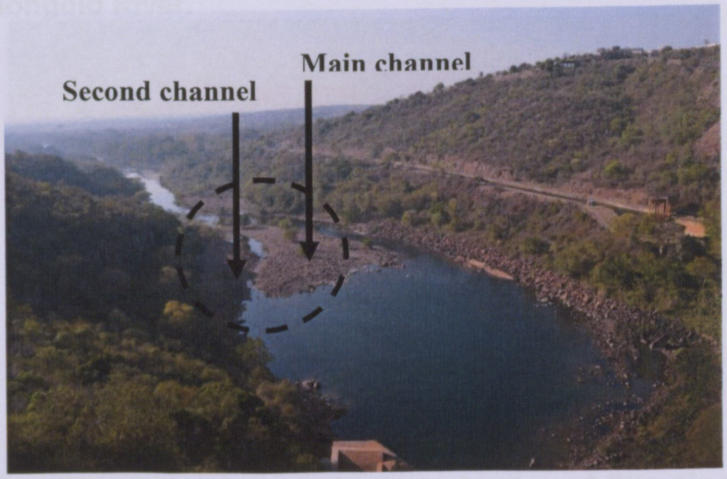
	Site 1	Site 2
Site Name	Outflow from Pongolapoort Dam	Pete's Camp
GPS Coordinates	-27.4207 32.0759	-27.3997 31.1383
Vegetation	Western Maputaland Clay Bushveld (Mucina and Rutherford 2006)	Western Maputaland Clay Bushveld (Mucina and Rutherford 2006)
Dominant substrate	Cobbles	Cobbles
Geomorphological zone	Lower Foothill	Lower Foothill
Ecoregion	Lebombo Uplands	Lowveld

© University of Venda

3.3 Site description

Site 1 has a main channel with a fast flowing cobble riffle flowing out of a deep channel (Figure 3.3). The riverbed is dominated by cobbles and boulders with little sedimentation observed (Figure 3.4). The four sub-sites that were sampled were located at the edge of the riffle and are located in the circled area marked as circles in Figure 3.3. A backwater pool was connected via a deep pool to the main channel. A vegetated island the separates the two channels and instream aquatic vegetation occurs only in the backwaters. At the site the river valley is narrow and confined which could result in high water velocity during water release.

Site 2 is also a single channel with a fast flowing riffle (Figure 3.5.) flowing out of a deep pool. The river slope is gentle and pools, riffles and bars are present and the riverbed is alluvial consisting of cobbles and boulders (Figure 3.6). There is overhanging vegetation at the edges of both the pools and the riffle. Instream vegetation is present in the pool. At the upstream end of the sampling area there is a cobble riffle that forms the hydraulic control. The sub-sites, in the cobble riffle, where periphyton and benthic macro-invertebrates were sampled, are shown in Figure 3.5. The valley at this site is wider than at Site 1 which could imply that water levels during a flow release would be lower.



© University of Venda

University of Venda
Creating Future Leaders

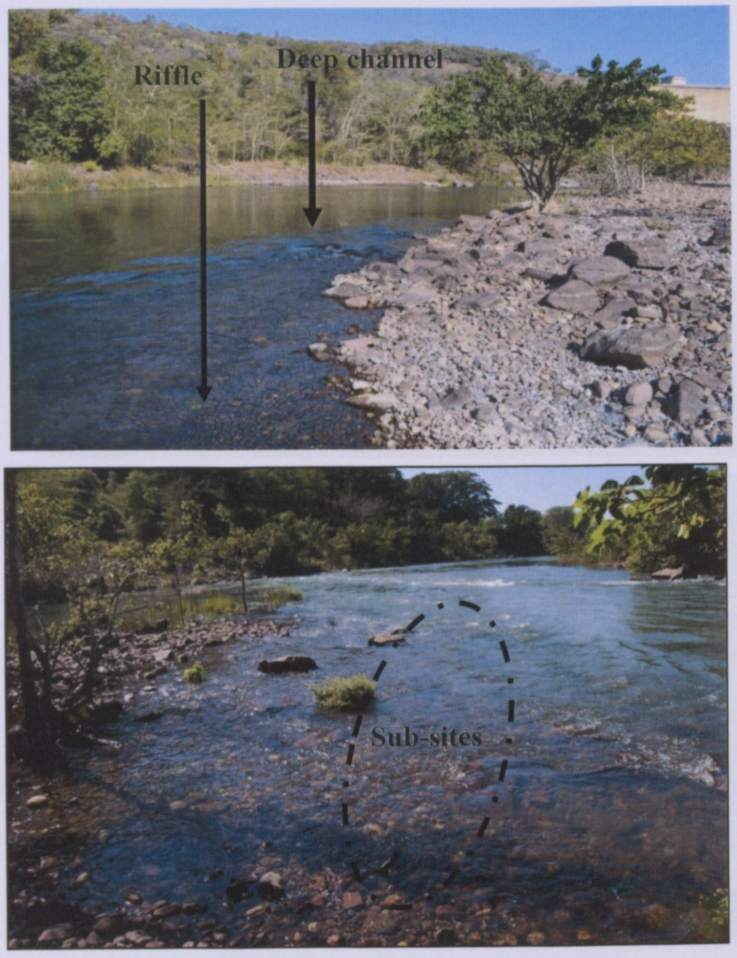


Figure 3.3: A general view of Site 1, the available habitat and sub-sites in the Phongolo River.



Figure 3.4: The observed substrate in the sub-sites of Site 1in the Phongolo River.

UNIVERSITY OF VENDA
LIBRARY

© University of Venda

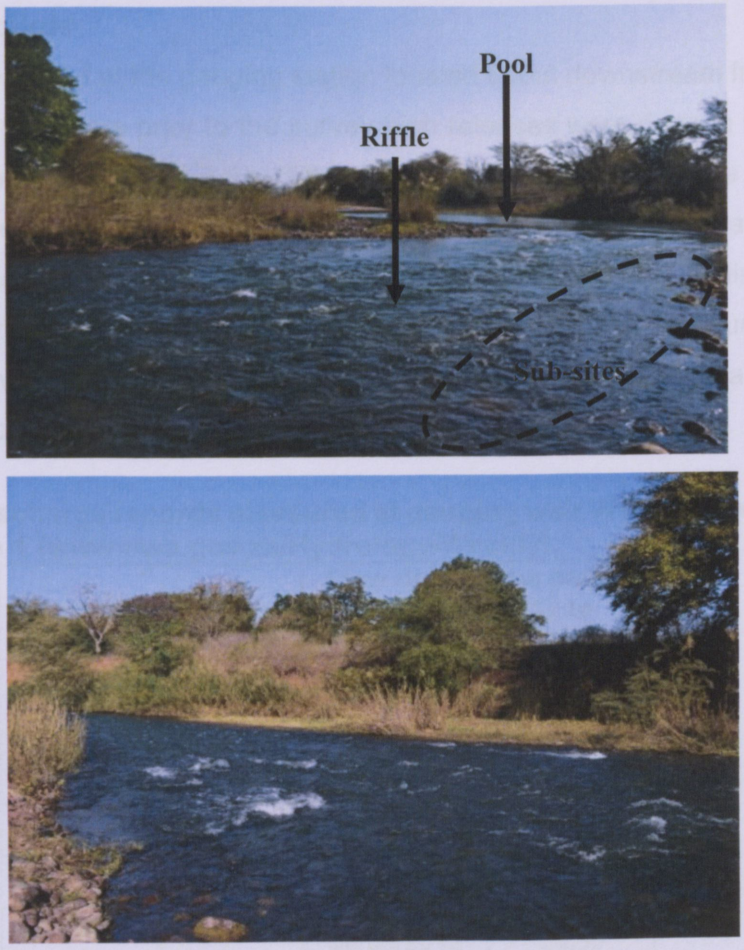


Figure 3.5: A general view of Site 2, the available habitat and sub-sites in the Phongolo River.



Figure 3.6: The observed substrate in the sub-sites of Site 2 in the Phongolo River.

© University of Venda

University of Venda
Creating Future Leaders

3.4 Discharge records

The discharge measured at the gauging station located 500m downstream from Site 1, shows that in the two years prior to the survey high releases were done in November 2011 and October 2012 (Table 3.1). After the 2012 flood release there were four months, from November 2012 to February 2013, with low flows followed by an increase in flow that commenced in March, prior to the first survey in April and continued up to May. The flow decreased in the two months before survey 2 decreased. Survey 3 was also in this low flow period but in October, between third and fourth survey a discharge in excess of 720 cumec was released (Table 3.2 and Figure 3.7).

Table 3.2: The discharge records measured at gauging weir W4H013 downstream of Site 1 (www.dwa.gov.za/Hydrology/Weekly).

Peak flow data prior to 2013		Flow data for the period December 2012 to December 2013	
Date	Peak Flow (cumec)	Date	Flow (cumec)
		6/12/2012	6.584
		6/01/2013	6.706
5/11/2011	685	12/02/2013	12.224
		30/03/2013	38.85
5/10/2012	481	27/04/2013	32.344
		3/05/2013	32.728
		2/06/2013	23.107
		3/07/2013	12.087
		26/08/2013	7.958
		4/09//2013	16.761
		11/10/2013	**724.368**
		12/11//2013	8.918
		26/12/2013	8.997

© University of Venda

UNIVERSITY OF VENDA

University of Venda
Creating Future Leaders

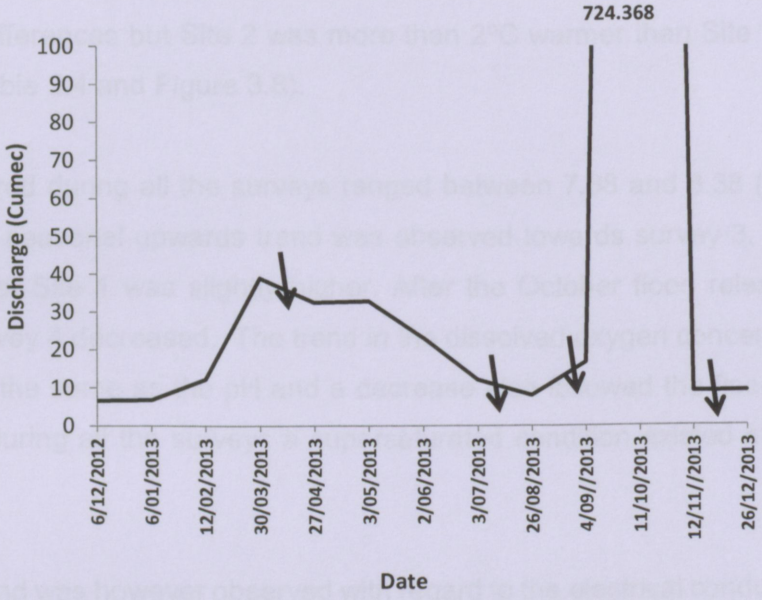


Figure 3.7: The discharge from Pongolapoort Dam recorded at gauging weir W4H013 in the period December 2012 to December 2013. The arrows on the graph indicate the four surveys and the graph is truncated in October 2013 to accommodate the magnitude of the flood release.

3.4 Survey frequency

Four surveys were conducted (Table 3.3) at the two sites in Phongolo River from April to November 2013. Based on the discharge records (Table 3.2) it is observed that the first three surveys were during low flows in a period of a decrease in flow occurring from April to September, while the fourth survey followed the annual discharge in October, which in this study is regarded as disturbance event.

Table 3.3: The dates of four surveys conducted at Phongolo River in 2013.

Survey number	First survey	Second survey	Third survey	Fourth survey
Date	16 April 2013	28 July 2013	09 September 2013	20 November 2013

© University of Venda

University of Venda
Creating Future Leaders

3.6 Water quality

As could expected the temperature recorded at the sites during the surveys reflected the seasonal differences but Site 2 was more than 2°C warmer than Site 1 during all the surveys (Table 3.4 and Figure 3.8).

The pH measured during all the surveys ranged between 7.38 and 8.38 (Figure 3.9) and although a seasonal upwards trend was observed towards survey 3. During this period the pH at Site 1 was slightly higher. After the October flood release the pH recorded in survey 4 decreased. The trend in the dissolved oxygen concentration and saturation was the same as the pH and a decrease also followed the flood. It should be noted that during all the surveys a supersaturated condition existed at both sites (Figure 3.8).

A distinctive trend was however observed with regard to the electrical conductivity (EC) and total dissolved solids (TDS) (Figure 3.8). This trend shows a spatial difference with both EC and TDS that was higher at Site 2 in all four surveys. In addition there was a temporal change with an increase at both sites from survey 1 to survey 2, this was followed by a decrease in survey 3 but contradictory to the pH, the EC and TDS values were higher following the October flood. The difference between the sites and the difference between surveys 1 and 4 were statistically different ($p < 0.05$).

The average depth in the sub-sites was deeper at Site 1 and, with the exception of survey 1, these differences were not statistically different ($p > 0.05$) (Figure 3.9). Based on the maximum velocity the water flowed faster at Site 1 and as is the case with depth, with the exception of survey 1 (Figure 3.9), these differences were not statistically different ($p > 0.05$).

The ammonium and phosphate concentrations, with exception of survey 4, were the highest at Site 2 (Figure 3.10). This pattern has not observed for nitrate concentrations where Site 1 was the highest. Seasonally, the only increasing trend was observed in

© University of Venda

the nitrate concentration which increased from survey 1 to 3 and the high values of survey 3 was followed by a decrease following the October flooding event.

Table 3.4: Means, standard deviations and ranges of measured parameters (n=14), p-values are shown for only variables that showed significant differences between sites.

	Site 1				Site 2				
	Mean	Stand. dev	Min	Max	Mean	Stand. dev	Min	Max	p-Value
pH		0.27	7.38	8.14		0.25	7.6	8.38	
Electrical conductivity (μScm^{-1})	258.29	2.4	254	261	345.57	32.66	281	375	0.001
Water temp. (°C)	19.96	2.5	17.4	23.7	22.36	2.36	20.1	25.3	0.011
Dissolved Oxygen concentration (mgL^{-1})	9.83	1.12	8.62	11.13	11.13	2.1	8.6	13.3	0.001
Dissolved Oxygen saturation (%)	114.77	6.16	110.3	128.6	116.66	4.81	110.1	121.9	0.004
TDS (mgL^{-1})	128.29	1.54	126	130	173	16.06	141	187	
Depth (cm)	26.57	8.66	16	50	23	5.88	12	33	
Velocity (ms^{-1})	0.48	0.26	0.01	0.9	2.76	8.13	0.23	31	
Ammonium (mgL^{-1})	0.14	0.05	0.08	0.2	1.04	1.46	0.11	3.27	0.003
Phosphate (mgL^{-1})	0.13	0.05	0.09	0.21	0.16	0.09	0.05	0.28	
Nitrate (mgL^{-1})	1.49	0.57	0.93	2.3	1.13	0.72	0.5	2.7	
Nitrite (mgL^{-1})	0.05	0.05	0.02	0.13	0.04	0.01	0.03	0.05	

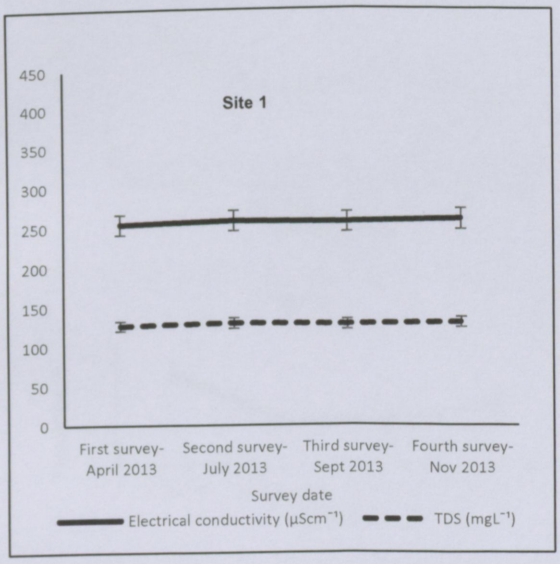
3.7 Biota

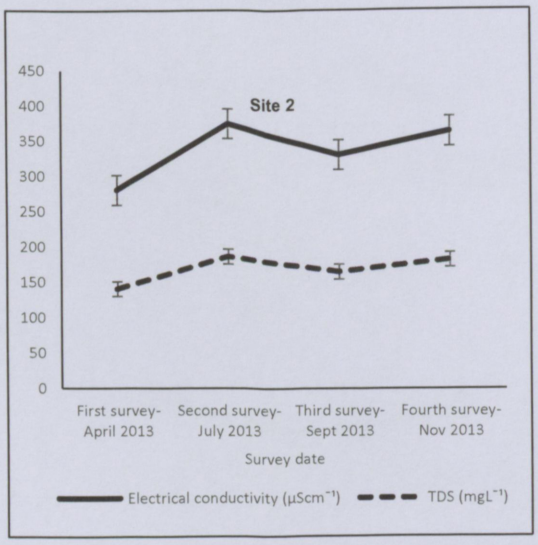
3.7.1 Periphyton

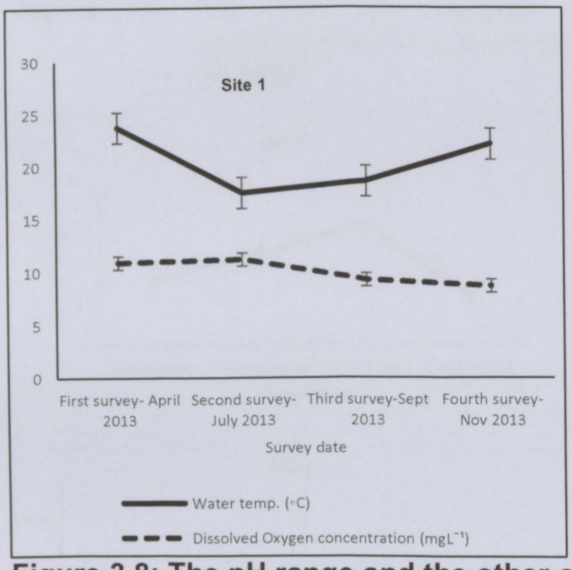
The chlorophyll-*a* concentration showed an increase from survey 1 to survey 3 (Figure 3.11). In the first two surveys the chlorophyll-*a* concentration of the two sites were similar but in survey 3 a distinct increase occurred at Site 2 (Figure 3.11). The chlorophyll-*a* at both sites was negatively impacted by the October 2013 flow release and this decrease was statistically significant at both sites ($p < 0.05$). At Site 1 the decrease is approximately 60% while at Site 2 it is calculated as 38%. Both were found to be statistically significant ($p < 0.05$).

With the exception of survey 1, the chlorophyll-*a* was the highest at Site 2 and the increase that occurred from survey 1 to survey 3 was the most pronounced at Site 2.

© University of Venda







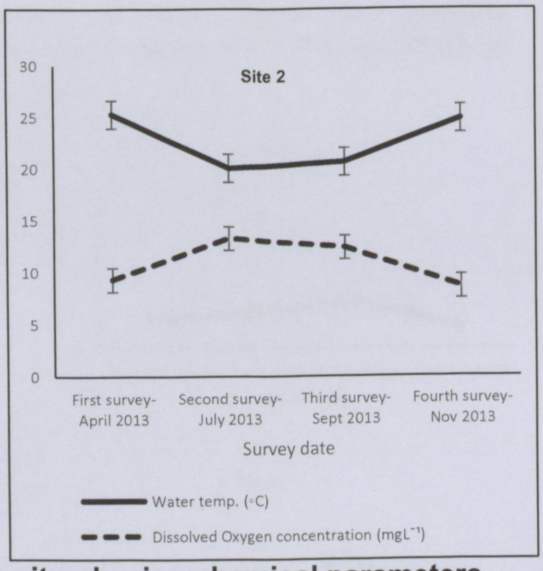


Figure 3.8: The pH range and the other of in situ physico-chemical parameters mean and standard deviation recorded during the surveys in the Phongolo River in 2013.

© University of Venda

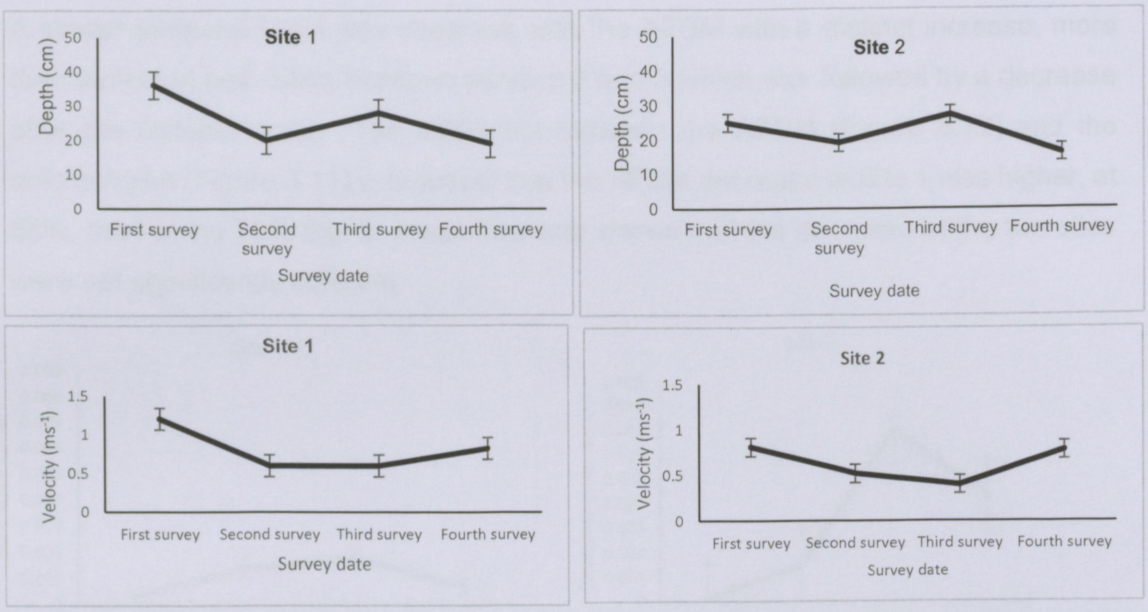


Figure 3.9: The mean and standard deviation of water depth and velocity measured in the sub-sites during the surveys in the Phongolo River in 2013.

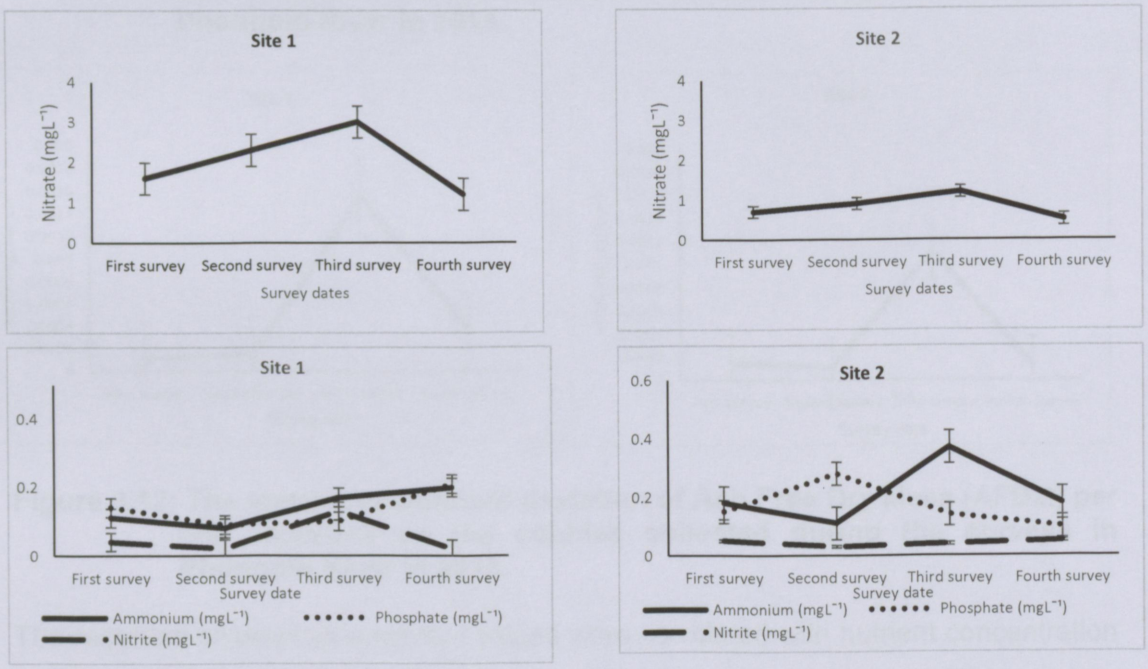


Figure 3.10: The mean and standard deviation of nutrient concentration recorded in water samples collected at the Sites 1 and 2 in Phongolo River in 2013.

© University of Venda

A similar temporal trend was observed with the AFDM with a distinct increase, more than tenfold at both sites, between surveys 2 and 3 which was followed by a decrease after the October flood. The difference between the AFDM (Figure 3.12) and the chlorophyll-*a* (Figure 3.11) is however that the AFDM decrease at Site 1 was higher, at 88%, than at the 76% Site 2. It was however shown that the decrease at the two sites were not significantly different.

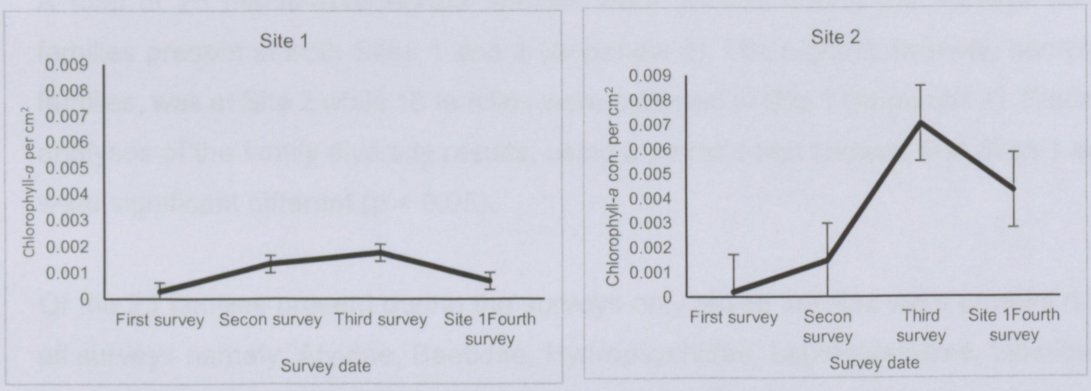


Figure 3.11: The mean and standard deviation of chlorophyll-*a* concentration per cm² recorded on the cobbles collected during the surveys in Phongolo River in 2013.

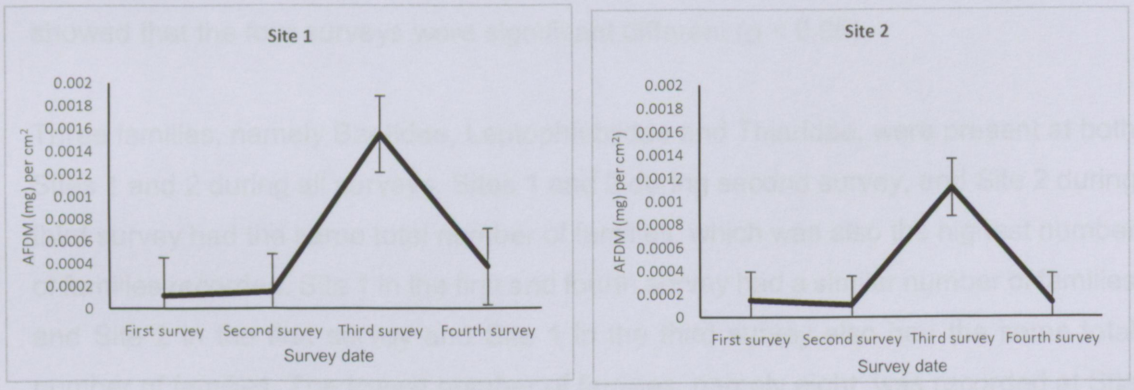


Figure 3.12: The mean and standard deviation of Ash Free Dry Mass (AFDM) per cm² recorded on the cobbles collected during the surveys in Phongolo River in 2013.

The recorded chlorophyll-*a* content values were correlated with nutrient concentration (Table 3.5) and the Pearson correlation coefficient was then calculated. Chlorophyll-*a* was positively correlated with phosphate concentration (r = 0.672) but there was no correlation between nitrate, ammonium, nitrite and chlorophyll-*a*.

© University of Venda

Table 3.5: The correlation of Chlorophyll-*a* per surface area and nutrients concentration using Pearson correlation.

	Phosphate	Nitrate	Nitrite	Ammonium
Pearson correlation coefficient was (r)	0.672	0.035	0.001	0.003

3.7.2 Benthic macro-invertebrates

3.7.2.1 Diversity

A total of 25 macro-invertebrate families were present during the surveys with 16 families present at both Sites 1 and 2 (Appendix 4). The highest diversity, namely 23 families, was at Site 2 while 18 families were collected at Site 1 (Appendix 4). Statistical analyses of the family diversity results, using a paired t-test showed that Sites 1 and 2 were significant different ($p < 0.05$).

Of the 25 families present during the surveys only seven families were present during all surveys namely, Atyidae, Baetidae, Hydropsychidae, Leptophlebiidae, Libellulidae, Physidae and Thiaridae. The highest total number of families, namely 18, was recorded during the second survey and lowest total number of families was recorded in the fourth survey (Appendix 5). Statistical analysis of the family diversity results, using ANOVA, showed that the four surveys were significant different ($p < 0.05$).

Three families, namely Baetidae, Leptophlebiidae and Thiaridae, were present at both Sites 1 and 2 during all surveys. Sites 1 and 2 during second survey, and Site 2 during third survey had the same total number of families, which was also the highest number of families recorded. Site 1 in the first and fourth survey had a similar number of families and Site 2 in the first survey and Site 1 in the third survey also had the same total number of families. The lowest number of families, namely eight, was recorded at Site 2 in the fourth survey (Appendix 6).

The average size and velocity preference, adapted from Gerber and Gabriel (2002) of the macro-invertebrate families, with the exception of the Oligochaeta, the two snails and the freshwater shrimps, are shown in Table 3.6. The results when using the average body size to group the macro-invertebrates of the four surveys were inconclusive (Table 3.7).

© University of Venda

Table 3.6: The average body size and flow preference (Gerber and Gabriel 2002) of the benthic macro-invertebrate observed at the two sites in the Phongolo River during the period of April to November 2013 (Flow = VS : very slow, S:slow, S-M: slow to moderate, MF : moderately Fast, F: fast, VF : Very fast).

Family	Average size (mm)	Flow preference	Family	Average size (mm)	Flow preference
Baetidae	8	MF	Leptophlebiidae	11	S
Chironomidae	10	S	Libellulidae	15	VS
Chlorosyphidae	20	S	Naucoridae	9.5	VS
Coenagriidae	24	S	Oligoneuridae	26	VF
Elmidae	6.5	F	Philopotamidae	12	F
Gomphidae	17	S	Psychomyiidae	12	F
Gyrinidae	20	S - MF	Pyralidae	23	F
Heptageniidae	8	MF	Simulidae	8	F
Hydrophilidae	8	S	Tabanidae	30	S
Hydropsychidae	12	F	Tricorythidae	10	F
Leptoceridae	28	S			

Table 3.7: Grouping of benthic macro-invertebrate diversity, based on body on average size, observed in the Phongolo River during the period of April to November 2013 (P = present and A = absent).

Family	First survey- April 2013	Second Survey- July 2013	Third survey- Sept 2013	Fourth survey- Nov 2013
Average size 6 - 15 mm				
Elmidae	A	P	P	P
Heptageniidae	P	P	P	A
Hydrophilidae	A	P	A	A
Simulidae	A	A	P	P
Baetidae	P	P	P	P
Naucoridae	P	A	A	A
Chironomidae	A	P	A	P
Tricorythidae	P	A	A	A
Leptophlebiidae	P	P	P	P
Hydropsychidae	P	P	P	P
Philopotamidae	A	A	P	A
Psychomyiidae	P	P	P	A
Average size > 15mm				
Libellulidae	P	P	P	P
Gomphidae	A	A	P	A
Chlorocyphidae	A	P	A	A
Gyrinidae	A	P	A	A
Pyralidae	P	A	A	P
Coenagriidae	A	P	A	A
Atyidae	P	P	P	P
Oligoneuridae	P	A	A	A
Leptoceridae	A	P	A	A
Tabanidae	A	P	P	A

© University of Venda

3.7.2.2 Abundance

The total abundance at Site 1, namely 1276, was higher than at Site 2 where only 604 individuals were collected. At Site 1, Thiaridae was the most abundant family, followed by Simulidae and Baetidae. At Site 2 Baetidae was the most abundant family, followed by Hydropsychidae and Simulidae (Appendix 7). Statistical analyses of the abundance results, using a paired t-test showed that Sites 1 and 2 were significantly different ($p < 0.05$).

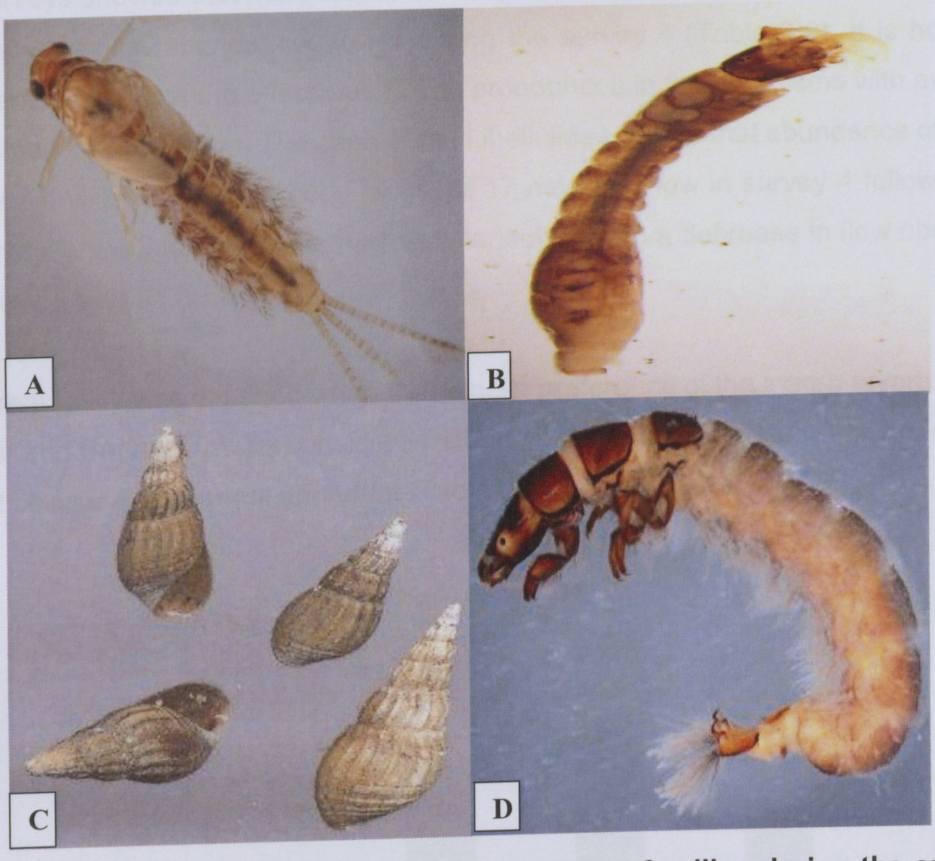


Figure 3.13: Representatives of the most abundant families during the surveys (A = Baetidae, B= Simulidae, C = Thiaridae and D = Hydropsychidae)

With regard to seasonality the highest abundance was recorded during the third survey and the lowest abundance in the first survey (Figure 3.14 and Appendix 8). Non-metric multidimensional scaling (NMDS) plots of macro-invertebrate community composition based on abundance of the various families at two sites surveyed seasonally showed

© University of Venda

University of Venda
Creating Future Leaders

that there was no variation between the surveys but sites were significantly different (Figure 3.15). Members from the Baetidae was the most abundant in the first survey, Thiaridae in the second and Simulidae in the third and fourth survey. The family Thiaridae was the second most abundant in the first survey, Baetidae in the second survey, Thiaridae in the third and fourth survey (Appendix 8).

The results when using the average body size to group the macro-invertebrates of the four surveys showed that the October flood releases affected the abundance in all the families which the abundances lower during the survey 4 (Table 3.8). It is however important to note that the effect was not as pronounced in the organisms with average sizes smaller than 15 mm. The case of the Libellulidae shows that abundance of these organisms, with an average body length of 17 mm, was low in survey 4 following an increase in abundance that occurred simultaneously with a decrease in flow observed in surveys 2 and 3 (Table 3.8).

A different result was obtained when the velocity preference of the macro-invertebrates (Gerber and Gabriel 2002) is considered. During survey 3 the families with a preference for fast flows were the most abundant (Table 3.9).

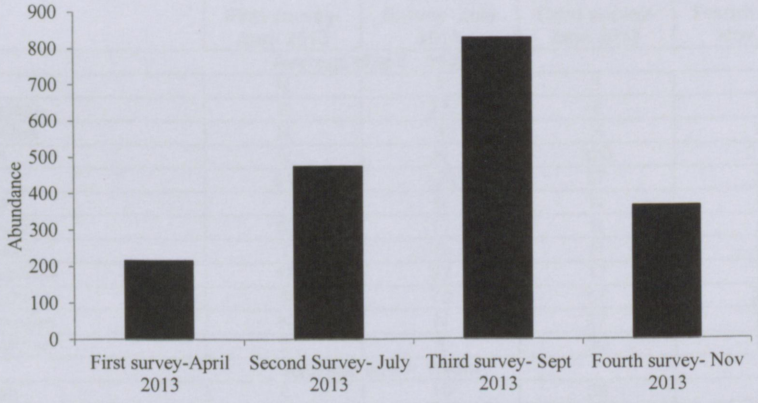


Figure 3.14: The abundance of benthic macro-invertebrate families observed during the four surveys in the Phongolo River during the period of April to November 2013.

© University of Venda

UNIVERSITY OF VENDA
LIBRARY

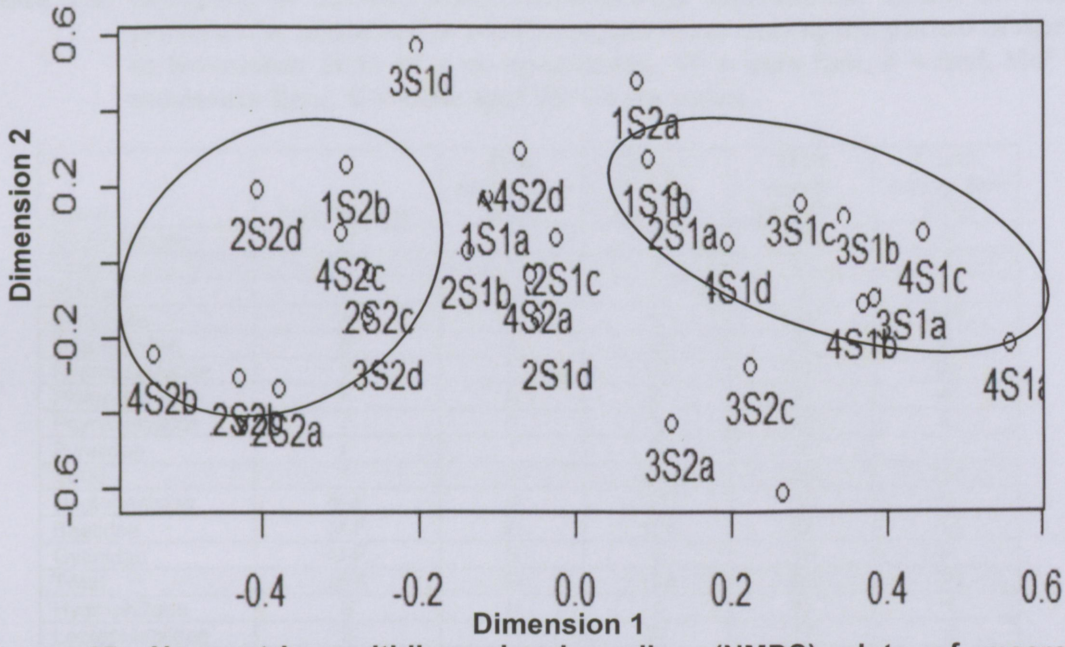


Figure 15: Non-metric multidimensional scaling (NMDS) plots of macro-invertebrate community composition based on abundance at two sites surveyed seasonally in the Phongola River. The prefix 1,2,3,4 indicate the survey number, S1, S2 site number, a,b,c,d sub-site and the circles shows the variation between the sites.

Table 3.8: Grouping of benthic macro-invertebrate abundance, based on body on average size, observed in the Phongolo River during the period of April to November 2013 (N = no specimens).

Family	First survey- April 2013	Second Survey- July 2013	Third survey- Sept 2013	Fourth survey- Nov 2013
Average size 6 - 15 mm				
Elmidae	N	1	3	1
Heptageniidae	3	27	3	N
Hydrophilidae	N	4	N	N
Simulidae	N	N	320	215
Baetidae	91	129	57	38
Naucoridae	1	N	N	N
Chironomidae	N	12	N	5
Tricorythidae	1	N	N	N
Leptophlebiidae	17	27	17	2
Hydropsychidae	3	79	57	24
Philopotamidae	N	N	27	N
Psychomyiidae	2	1	20	N
Average size > 15mm				
Libellulidae	4	19	38	4
Gomphidae	N	N	1	N
Chlorosyphidae	N	1	N	N
Gyrinidae	N	2	N	N
Pyralidae	1	N	N	1
Coenagriidae	N	1	N	N
Oligoneuridae	1	N	N	N
Leptoceridae	N	1	N	N
Tabanidae	N	1	2	N

© University of Venda

Table 3.9: Grouping of benthic macro-invertebrate abundance, based on flow preference, observed in the Phongolo River during the period of April to November 2013 (N = no specimens, VF = very fast, F = fast, M-F = moderate flow, S = slow and VS = very slow).

Family	Velocity class	First survey-April 2013	Second Survey-July 2013	Third survey-Sept 2013	Fourth survey- Nov 2013
Oligoneuridae	VF	1	N	N	N
Total	VF	1	0	0	0
Elmidae	F	N	1	3	1
Simulidae	F	N	N	320	215
Tricorythidae	F	1	N	N	N
Hydropsychidae	F	3	79	57	24
Philopotamidae	F	N	N	27	N
Psychomyiidae	F	2	1	20	N
Pyralidae	F	1	N	N	1
Total	F	7	81	427	241
Heptageniidae	M-F	3	27	3	N
Baetidae	M-F	91	129	57	38
Gyrinidae	M-F	N	2	N	N
Total	M-F	94	158	60	38
Hydrophilidae	S	N	4	N	N
Leptophlebiidae	S	17	27	17	2
Gomphidae	S	N	N	1	N
Chlorosyphidae	S	N	1	N	N
Coenagriidae	S	N	1	N	N
Total	S	17	33	18	2
Naucoridae	VS	1	N	N	N
Chironomidae	VS	N	12	N	5
Libellulidae	VS	4	19	38	4
Leptoceridae	VS	N	1	N	N
Tabanidae	S	N	1	2	N
Total	S	5	33	40	9

Redundancy analyses (RDA) results showed that the environmental factors measured during the four surveys were strongly related to the families observed (Figure 3.16). Thiaridae was positively correlated to high concentration of nitrite, Simulidae was positively correlated with high pH and ammonium concentration while Hydropsychidae and Libellulidae were negatively correlated with high electric conductivity and oxygen concentration in water (Figure 3.16).

© University of Venda

University of Venda
Creating Future Leaders

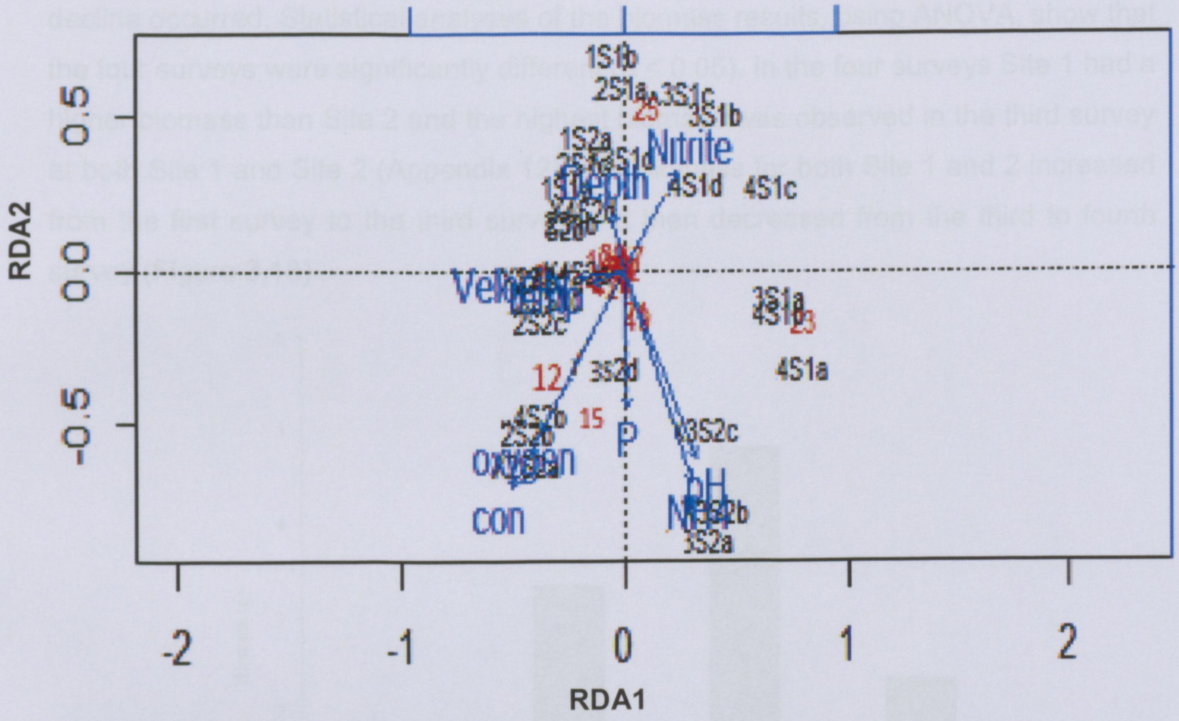


Figure 3.16: Correlation tri-plot based on redundancy analyses (RDA) of benthic macro-invertebrates families and environmental factors at the two sites surveyed seasonally. Abbreviations: con = electric conductivity, P = Phosphate, 1 = Athericidae, 2 = Atydae, 3 = Baetidae, 4 = Chironomidae, 5 = Chlorocyphidae, 6 = Coenagrionidae, 7 = Elmidae, 8 = Gomphidae, 9 = Gyrinidae, 10 = Heptageniidae, 11 = Hydrophylidae, 12 = Hydropsychidae, 13 = Leptoceridae, 14 = Leptophlebiidae, 15 = Libellulidae, 16 = Naucoridae, 17= Oligocheata, 18 = Oligoneuridae, 19 = Philopotamidae, 20 = Physidae, 21 = Psychomidae, 22 = Pyralidae, 23 = Simulidae, 24 = Tabanidae, 25 = Thiaridae and, 26 = Tricorythidae.

3.7.2.3 Biomass

It was observed that the combined biomass for the four surveys was highest at Site 1 (Appendix 10). Statistical analyses of the biomass results, using a paired t-test showed that Sites 1 and 2 were significantly different ($p < 0.05$).

The highest biomass of benthic macro-invertebrate families, namely 4.809 g, was observed in the third survey and the lowest during the first survey (Appendix 11). Figure 3.17 shows that the biomass steadily increased from April to September after which a

© University of Venda

decline occurred. Statistical analyses of the biomass results, using ANOVA, show that the four surveys were significantly different ($p < 0.05$). In the four surveys Site 1 had a higher biomass than Site 2 and the highest biomass was observed in the third survey at both Site 1 and Site 2 (Appendix 12). The biomass for both Site 1 and 2 increased from the first survey to the third survey and then decreased from the third to fourth survey (Figure 3.18).

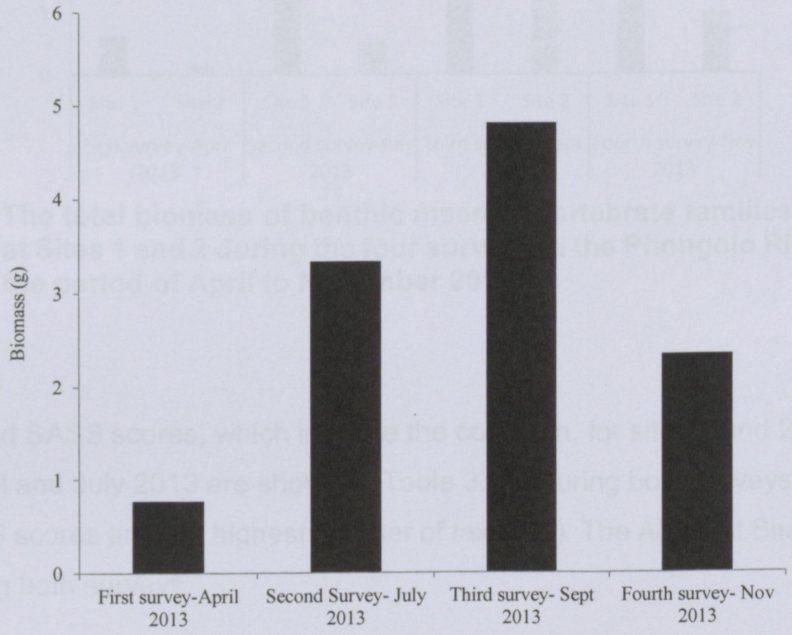


Figure 3.17: The total biomass in grams of benthic macro-invertebrate families observed during the four surveys in the Phongolo River during the period of April to November 2013.

© University of Venda

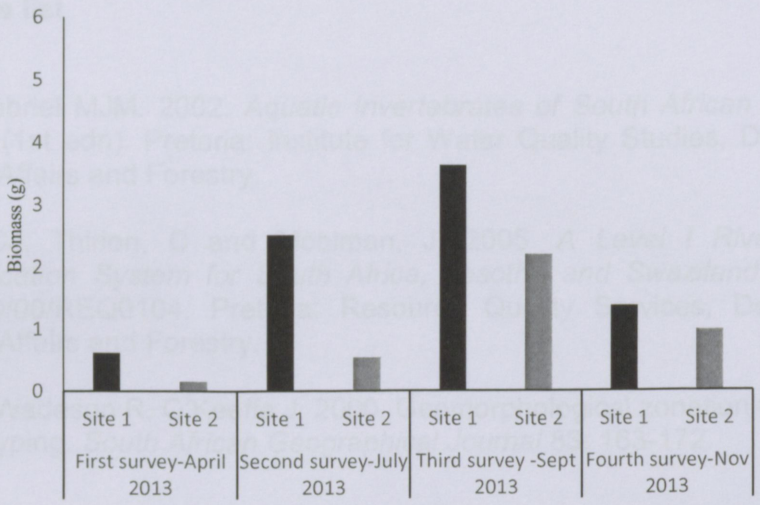


Figure 3.18: The total biomass of benthic macro-invertebrate families observed at Sites 1 and 2 during the four surveys in the Phongolo River during the period of April to November 2013.

3.7.2.4 SASS

The calculated SASS scores, which indicate the condition, for sites 1 and 2 during the period of April and July 2013 are shown in Table 3.10. During both surveys Site 2 had highest SASS scores and the highest number of taxa (30). The ASPT at Site 2 was the highest during both surveys.

Table 3.10: SASS scores of Sites 1 and 2 of the two surveys in the Phongolo River during the period of April and July 2013.

	Apr-2013		Jul-2013	
	Site 1	Site 2	Site 1	Site 2
SASS score	124	135	158	193
No. of taxa	25	21	26	30
ASPT	5	6.4	6.1	6.4

© University of Venda

University of Venda
Creating Future Leaders

3.8 Reference list

Gerber A, Gabriel MJM. 2002. *Aquatic Invertebrates of South African Rivers, Field Guide* (1st edn). Pretoria: Institute for Water Quality Studies, Department of Water Affairs and Forestry.

Kleynhans, CJ, Thirion, C and Moolman, J. 2005. *A Level I River Ecoregion classification System for South Africa, Lesotho and Swaziland*. Report No. N/0000/00/REQ0104. Pretoria: Resource Quality Services, Department of Water Affairs and Forestry.

Rowntree K, Wadeson R, O'Keeffe J. 2000. Geomorphological zonation for ecological river typing. *South African Geographical Journal* 83: 163-172.

© University of Venda

Chapter 4: Discussion

4.1 Flood release from Pongolopoort Dam

At the onset of this study the question was asked whether the erosive flood released annually from the Pongolapoort Dam has an effect on water quality, primary productivity, benthic organic matter and benthic macro-invertebrates assemblage structure and whether this resulted in a regime shift in the river. Although it was predicted that physical properties would change, it was expected that the flood will have little effect on the physico-chemical aspects. It was furthermore predicted that benthic matter decreases because alluvial bed material are mobilised and benthic particulates are flushed out of the system, which will lead to reduced benthic macro-invertebrate density, biomass and taxon richness and result in higher proportions of smaller sized organisms.

It was hypothesized that the flood would not affect the water chemistry of the Phongolo River but will reduce the benthic organic matter, the primary productivity and benthic macro-invertebrates abundance. The aim was to determine whether a novel regime shift is caused by the release of the flood and its duration. This was done by comparing the pre- and post-flood physico-chemical parameters, primary production and benthic organic matter and macro-invertebrate compositions at two sites immediately downstream of the Pongolapoort Dam.

The annual major release of water from the Pongolapoort Dam is done every year in October and in October 2013 flood was released between the third and fourth survey. The high volume of water, which was in excess of 720 cumec at its peak, lasted for three days and is regarded as an erosive flood that has an effect to the aquatic ecosystem. A number of studies have been done to determine the effect of dams on the flow regime, water quality and aquatic biota and they have shown that dams for example reduce the flow variability downstream of the dam (Marzolf 1999: Webb *et al* .1999). The size and structure of the dam and how the dam is managed has an effect on the river (Haghighi *et al.* 2014). The discharge from a dam, and particularly from an

© University of Venda

impoundment with a large flood-storage capacity, reduces available macro habitat, nutrient and water quality to a larger extent than smaller dams (Marzolf 1999).

4.2 SASS5

There are several studies that demonstrated the relationship between aquatic invertebrates and water quality (Chutter 1994; Chutter 1998; Dallas and Day 2004; Dickens and Graham 2002; Thirion *et al.* 1995). Since aquatic invertebrates are sensitive to change in water quality and because they can be used for bio-assessment, Chutter (1994) developed the South African Scoring System (SASS) protocol to assess the health status or condition of a river and this protocol was refined by Dickens and Graham (2002). In the SASS method each benthic macro-invertebrate taxon is allocated a tolerance score according to the water quality conditions it is known to tolerate (Chutter 1998) and the higher the score, the greater the organism's sensitivity and the lower its tolerance. In this study the SASS score and the Average Score per Taxon (ASPT) were calculated to determine the ecological status of the sites (Dickens and Grahams 2002). A low SASS score shows that the river is polluted or highly impacted and vice versa. The ASPT score on the other hand reflects the average sensitivity of the taxa and the higher the score the more sensitive the taxa that occur. The SASS scores and ASPT were higher at Site 2 during both first and second survey and Site 2 had highest number of taxa during the second survey (Table 3.10). The high SASS scores, ASPT and number of taxa at Site 2 indicate that Site 2 was in a better condition compared to Site 1.

4.3 Water quality

Environmental variables such as pH, electrical conductivity, temperature, dissolved oxygen and total dissolved solids have an effect on aquatic ecosystems. The nutrients required for primary production includes, phosphate, nitrate and nitrite. Ammonium, on the other hand, relates more to the breakdown processes and to pollution in general.

The temperature of a water body varies daily and seasonally along with climatic fluctuations. The surface water temperature is influenced by latitude, altitude, period of

© University of Venda

University of Venda
Creating Future Leaders

the day, weather and the water flow and depth. An increase in temperature speeds up the rate of chemical reactions in water and decreases the solubility of gases in water such as oxygen, carbon dioxide and nitrogen (Chapman 1996). Change in temperature has an effect the species community level of aquatic biota and each species has a temperature at which the growth and production is at its peak (Dallas and Day 2004). According to DWAF (1996) the Target Water Quality Range (TWQR) of water temperature should not differ from the background average daily water temperature by more than 10%. The recorded temperature during the four surveys ranged from 17.1 to 25.3 °C and reflects seasonal changes with the lowest water temperatures recorded in the coldest months. Site 2 in general had higher temperatures than Site 1 and this can be ascribed to the geographic location of the site and not to the flow releases. The temperature of water released downstream could also have an effect.

The pH of water has an effect on the physiological processes, such as osmoregulation and respiration, of aquatic biota (Dallas and Day 2004, Robertson-Bryan 2004). The pH in water changes rapidly over time and the rate of change is related to the dissolved substances in the water (Dallas and Day 2004). Carbonate and bicarbonate ions serve as a buffer in freshwater and most South African freshwaters are well buffered with a neutral pH ranging from 6 to 8 (Dallas and Day 2004). Eutrophication, which results in a high photosynthesis rate, leads to an increase in pH in lotic ecosystems and this is caused by high rate of consumption of high carbon dioxide which leads to low carbonate and bicarbonates ions in the water and a reduced buffering capacity (Dallas and Day 2004). The pH measured during the study was alkaline at both Site 1 and 2 and ranged between 7.38 and 8.38 (Table 3.6). The pH TWQR prescribed by DWAF (1996), EIFAC (1964) and ANZECC (1992) ranges between 6.5 and 9.0 and the acceptable pH values listed by USEPA (1993) ranges between 6.5 and 8.5. These values were not exceeded during the study and therefore the measured pH were suitable for aquatic ecosystem. There was no spatial trend observed but the pH changed as flow decreased and the decrease observed after the flood suggesting that the flood did have an effect.

© University of Venda

University of Venda
Creating Future Leaders

The total concentration of materials dissolved in freshwater determines the quality of water (Dallas and Day 2004) and can be measured as the Total Dissolved Solids (TDS) and the Electrical Conductivity (EC). The TDS is the total quantity of dissolved materials, including both the organic and inorganic molecules in a water body. The EC is a measure of the ability of water to conduct electric current and it is influenced by the amount of ionized solutes (DWAF 1996). The TDS and EC are directly related and the EC increases with an increase in TDS and both variables can be used as an indication of pollution levels. An increase in the values can be regarded as an indication of increased pollution (Dallas and Day 2004). According to ANZECC (1992), the EC for aquatic life should not exceed the target value of 500 μScm^{-1}. There is a lack of information regarding the TDS tolerance ranges of freshwater biota but according to WHO (1984) the acceptable TDS values should be below 1000 mgL^{-1} for drinking water and TWQR values (DWAF 1996) states that the TDS should not be changed by more than 15% of natural conditions. The TDS values measured from April to November 2013 at that ranged between 126 to 187 mgL^{-1} (Table 3.4) and the recorded EC during the surveys that ranged from 254 to 375 μScm^{-1}. This indicates that conditions regarding the EC were favourable for aquatic organisms throughout the study. This study showed a spatial difference with both EC and TDS that was higher at Site 2 in all four surveys, which could be regarded as an indication that concentration levels of EC and TDS increased downstream. In addition, there was a temporal change with an increase at both sites from survey 1 to survey 2 that was followed by a decrease in survey 3 but contradictory to the pH the EC and TDS values were higher following the October flood.

The concentration of dissolved oxygen in water is important to the survival and the functioning of the aquatic organisms. Oxygen in water originates directly from the atmosphere or can be a by-product of the photosynthesis by aquatic plants (Allan 1995). The dissolved oxygen concentration in water fluctuates during the day depending on the rate of photosynthesis and respiration under the normal conditions (Dallas and Day 2004). The availability of radiant energy from the sun, which is a limiting factor for photosynthesis, influence the dissolved oxygen concentration in the

© University of Venda

UNIVERSITY OF VENDA

aquatic ecosystem and the dissolved oxygen concentration varies seasonal daily and seasonally (Allan 1995). If the oxygen saturation is below 80% in water body the condition could be harmful and can lead to physiological and behavioural stress (DWAF 1996). The TWQR of oxygen saturation prescribed by DWAF (1996) and USEPA (1986) ranges between 80% to 120% and oxygen saturation above 100% is considered as super-saturation. Super-saturation can be a result of eutrophication (Dallas and Day 2004; DWAF 1996). It should be noted that during all the surveys a supersaturated condition existed at both sites (Table 3.4) as shown by the recorded oxygen saturation of between 110.1% and 128.6% during the four surveys.

The ammonium, and ammonia, in natural water bodies is a result of the break-down of organic and inorganic matter in the sediments and the water column, excretion from aquatic biota as well as nitrogen related processes of micro-organisms (Chapman 1996). The high concentration of ammonia in water is toxic to aquatic biota and the toxicity relates to the pH level with ammonia being more toxic at a high pH (Dallas and Day 2004). If the dissolved oxygen decreases, the toxicity of ammonium in water body decreases (DWAF 2006). The accepted concentration of ammonium according to EIFAC (1964) ranges between 0.04 and 1.0 mgL^{-1} for aquatic life. According to DWAF (2006) the concentration of ammonium should not exceed 7 mgL^{-1}. The ammonium concentrations measured at both sites 1 and 2 at Phongolo River ranged between 0.08 to 0.37 mgL^{-1} and this shows that the conditions were non-toxic with regard to ammonium. No seasonal trend was observed and it should be noted that the highest values in the first three surveys was recorded at the downstream site, Site 2. This correlates with the TDS and EC results and since ammonium is often also related the degree of pollution it would appear that the level of pollution was higher downstream.

As stated before, nutrients, which in this case are the phosphates and nitrates, are regarded as factors that can influence biotic communities and it is there important that the nutrient status of a water body should be determined.

© University of Venda

Phosphate, which occurs in natural water as dissolved orthophosphate, polyphosphate or as the original phosphorous, is an essential nutrient for all aquatic flora and is a limiting factor for algal growth. Phosphate concentration determines the primary production in rivers (Chapman 2006). The natural source of phosphate is the weathering of rocks and the decomposition of organic matter. An increase of phosphate concentration from anthropogenic activities leads to algal bloom known as eutrophication (Dallas and Day 2004). According to DWAF (1996) a phosphate concentration below 5 mgL^{-1} indicates low productivity of algae. The phosphate concentration in this study ranged between 0.05 and 0.28 mgL^{-1} and where the concentrations exceeded 0.125 mgL^{-1} the situation is regarded to be in the "unacceptable" range for aquatic biota (Dallas and Day 2004).

In a natural water body the nitrogen occurs in the nitrite ion form (NO_3^-) and can be reduced biochemically to nitrite (NO_2^-) by the process of denitrification (Chapman 2006). Indigenous rocks, land drainage and plants and animals are sources of nitrate to water bodies. Nitrate is one of the essential nutrients for aquatic flora and the seasonal fluctuations can be caused by plant growth and the decay of organic matter. A nitrate concentration which exceeds 5 mgL^{-1} can be an indication of pollution caused by aspects such as fertilizer run-off or human and animal waste Chapman (2006). According to DWAF (1996) the condition where the inorganic nitrogen concentration is between 0.05 and 2.5 mgL^{-1} is considered as a mesotrophic condition. High nitrate concentrations can be toxic to aquatic biota in their young stages and values ranging between 0.5 and 1.50 mgL^{-1} are in "acceptable" range while values above 1.50mgL^{-1} are regarded as "unacceptable" (Dallas and Day 2004). The nitrate concentration ranged between 0.5 and 2.7 mgL^{-1} and nitrite between 0.02 and 0.13 mgL^{-1}. With the exception of Site 2 in surveys 2 and 4 all the nitrate concentration recorded could be classified as unacceptable, the concentration ass below 0.5 mgL^{-1}.

4.4 Primary production

Roos and Pieterse (1996) indicated that floods affected the phytoplankton population as they found that the chlorophyll-*a* concentration in Vaal River was reduced by floods.

© University of Venda

The productivity in rivers varies with season and the productivity is higher during seasons with long daylight length than seasons with short daylight length (Boyer *et al.*1993; Goldstein *et al.* 2005; Hynes 1970). The natural high flow in rivers removes the primary food materials such as algae as well as floating and submerged plants (Goldstein *et al.* 2005; Odum 1956). The modification of natural flow has an effect on sediments and floating and attached algae in rivers where high flow washes out the sediments containing attached algae and the floating algae (Poff *et al.* 1997). In this study it was observed that the annual flood release in October reduced the primary production in the river. At both Sites 1 and 2 the chlorophyll-*a* concentration per surface area, which was measured to determine the primary productivity, increased from first survey to third survey and during fourth survey after the release of flood, the concentration decreased. This is an indication that the scouring caused by the high flow had removed the benthic algae. This agrees with the findings of Marzolf (1999) who observed that the primary production in the Colorado River immediately downstream from the Glen Canyon Dam was reduced by the release of water from the impoundment.

At this point it should be pointed out that a correlation between primary production, represented by the chlorophyll-*a* concentration was observed between phosphate concentration while there were no correlation observed between production and the ammonium, nitrate, and nitrite concentrations (Table 3.5). The high chlorophyll-*a* concentration values were recorded in surveys when the phosphate concentrations were high. The study done by Roos and Pieterse (1996) showed that the chlorophyll-*a* concentration in Vaal River is positively correlated with the total N:P ratio, which agrees with findings of this study. Sakamoto (1996) however indicated that chlorophyll-*a* depended only on total nitrogen, which was not observed in this study.

4.5 Organic matter

The AFDM, measured to determine benthic organic matter, showed that the October flood flushed the organic matter in the Phongolo River. At Site 1 the AFDM increased from first to third surveys and after the release it decreased. At Site 2 before the flood

© University of Venda

release, the AFDM first decreased from the first to the second survey. AFDM was highest during third survey and during the fourth survey the AFDM had decreased. This agrees with results of Tesi *et al.* (2013) who indicated that a flood released from dam had flushed the suspended organic materials, sediments and the attached organic matter in the Po River as well as the work of Williams and Wolman (1984) who observed that a flood washes the sediment together with organic matter downstream.

4.6 Benthic macro-invertebrates

Variation in substrate particles such as sand, gravel, cobbles and boulders support a high abundance and diversity of benthic macro-invertebrates (Endrick 2008). An increased availability of sediment for borrowing benthic macro-organisms also increases the abundance and diversity of such benthic macro-organisms (Mantel *et al.* 2010). This would imply that reduced flows, where an increase in sedimentation occurs, would lead to an increase in benthic macro-invertebrate diversity and abundance. On the contrary high flows, and particularly erosive floods, would lead to a decrease in abundance and diversity. This would then constitute a regime shift with regard to benthic macro-invertebrates. At Site 1 the valley is narrow resulting in a high level of erosion. At Site 2 the valley was wider which resulted in a slight deposition of eroded materials and less erosion. The seasonal comparison of benthic macro-invertebrate family abundance using Non-metric Multidimensional Scaling showed that there was no variation between the pre- and post-flood benthic macro-invertebrates abundance but there was significant difference between the sites. The Pongolopoort dam regulates the water flow downstream and it is shown to have an impact on benthic macro-invertebrate abundance and diversity. The stronger flow at Site 1 flushed the substrate resulting in a lower benthic macro-invertebrates diversity than at Site 2 where the flow was not as strong. Erosive floods in rivers flush the movable particles in the river downstream. Benthic macro-invertebrates have a strong correlation with the size of the substrate's particles (Endrick 2008; Ogbeibu and Oribhabor 2002) and are sensitive to changes in the stream bed caused by the erosion and deposition of sediments (Endrick 2008).

© University of Venda

The highest family diversity was recorded during the second survey and the lowest during fourth survey after the release of flood. This agrees with the findings of Ogbeibu and Oribhabor (2002) who showed that a change of habitat resulted from releases from an impoundment had affected diversity indices in the Ikpoba River, Southern Nigeria.

The increase in abundance of benthic macro-invertebrates first increased from the first survey to the third survey and then decreased during the fourth survey after the release of the annual flood in October. At both site 1 and 2 the abundance was highest during the third survey. The biomass of benthic macro-invertebrates also first increased from the first to third survey and then decreased during the fourth survey after the release of annual flood disturbance. At both Site 1 and 2 the biomass was highest during the third survey. The negative effect of flood on benthic macro-invertebrate abundance and biomass is supported by the findings of Mantel *et al.* (2010) who investigated the effect of changes in discharge on the benthic macro-invertebrates focusing on flow reduction and increase and formed flow derives the available physical habitat the life cycles of aquatic organisms. Building dams in rivers have an effect to the composition and abundance aquatic organisms downstream (Mantel *et al.* 2010).

Environmental factors showed a strong relationship with the benthic macro-invertebrates observed in the Phongolo River. Factors such as electric conductivity, oxygen, pH, ammonium and nitrite concentrations had an effect on the benthic macro-invertebrates. This is supported by the research done by Odume and Muller (2011) and Kilonzo *et al.* (2014) who found that dissolved oxygen, TDS and pH had an effect on the aquatic invertebrate diversity and abundance.

The reduction in biomass is supported by the fact that after the October flood release higher proportions of smaller sized organisms were observed at both sites 1 and 2 and that the majority of the macro-invertebrates present at these two sites preferred fast flowing conditions. This indicates that a regime shift was caused by the October 2013 flood release. If it is considered that a flood was also released in October 2012 and that

© University of Venda

the macro-invertebrate diversity and abundance reached a peak in August it is suggested that the novel regime did not last until the next flood in October 2013.

4.7 Conclusion

It can therefore be concluded that the flood release in October 2013 did not affect water quality but reduced the primary production, organic matter as well as benthic macro-invertebrate abundance, diversity and biomass. Therefore a novel macro-invertebrate regime, or regime shift downstream was created by the flood release from Pongolapoort Dam.

© University of Venda

University of Venda
Creating Future Leaders

4.8 Reference list

Allan JD. 1995. Stream Ecology: Structure and functioning of running waters. London: Chapman and Hall.

ANZECC (Australian and New Zealand Environment and Conservation Council). 1992. *Australian water quality guidelines for fresh and marine waters*. National Water Quality Management Strategy Paper No 4. Canberra: Australian and New Zealand Environment and Conservation Council.

Boyer JN, Christian BR, Stanley DW. 1993. Patterns of phytoplankton primary productivity in the Neuse River estuary, North Carolina, USA. *Marine Ecology Progress Series* 97: 287-297.

Bunn SE, Arthington AH. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental Management* 30: 492-507.

Chapman D. 1996. *Water Quality Assessments – A guide to Use of Biota, Sediments and Water in Environmental monitoring* (2nd edn). Cambridge: University Press.

Chutter FM. 1994. The rapid biological assessment of streams and river water quality by means of macro-invertebrate communities in South Africa. In: Uys M.C. (ed.) *Classification of rivers and environmental health indicators*.

Chutter FM. 1998. Research on the rapid biological assessment of water quality impacts in streams and rivers. WRC Report. No.422/98. South Africa: Water Research Commission.

Dallas HF. 1997. A preliminary evaluation of aspects of SASS for the rapid bioassessment of water quality in rivers, with particular reference to the incorporation of SASS in a national biomonitoring programme. *South African Journal of Aquatic Science* 23: 79-94.

Dallas HF, Day JA. 2004. *The effect of water quality variables on aquatic ecosystems*: A review. Water research Commission Technical Report 224/O4. Pretoria: Water Research Commission.

Dickens CWS, Graham PM. 2002.The South African Scoring System (SASS) version 5 rapid bio-assessment method for rivers. *African Journal of Aquatic Science* 27:1-10.

DWAF (Department of Water Affairs and Forestry). 1996. South African Water Quality Guidelines. Volume 7: Aquatic Ecosystem.

© University of Venda

University of Venda
Creating Future Leaders

Endrick LB. 2008. *Evaluation of the Impacts Highwat Construction on Sediment and Benthic Macroinvertebrates in Appalachian Streams. Davis College of Agriculture, Forestry and Consumer Sciences.* Virginia: West Virginia University.

EIFAC (European Inland Fisheries Advisory Commission). 1964. *Onwards Working Party on Water Quality Criteria for European Freshwater Fish.* EIFAC Technical Paper No. 1. Rome: European Inland Fisheries Advisory Commission Technical Paper Series.

Goldstein RM, Schalk CW, Kempf J. 2005. *Primary productivity in Meduxnekeag River.* SI Report No. 2009-5029. Canada: Scientific Investigation

Haghighi AT, Marttila H, Kløve B. 2014. Development of a new index to assess rivers regime impacts after dam construction. *Global Planetary Change* 122: 186-196.

Hynes HBN. 1970. *The Ecology of Running Waters.* Canada: University of Toronto Press.

Kilonzo F, Masese FO, Van Griensven A, Bauwens W, Obando J, Lens PNL. 2014. Spatial-temporal variability in water quality and macro-invertebrate assemblages in the Upper Mara River basin, Kenya. *Physics and Chemistry of Earth* 67: 93-104.

Mantel SK, Muller NWJ, Hughes BA. 2010. Ecological impacts of small dams on South African rivers Part 2: Biotic response – abundance and composition of macroinvertebrate communities. *Institute for Water Research* 36: 55-76.

Marzolf GR. 1999. Effect of Flooding on Plant Production Downstream from Glen Canyon Dam.USGS Report No. 060-99. United State: Geographical Survey.

Odum HT. 1956. Primary production in flowing waters. *Limnology and Oceanography* 2: 102-117.

Odume NO, Muller WJ. 2011. Diversity and structure of Chironomidae communities in relation to water quality difference in the Swartkops River. *Physics and Chemistry of the Earth* 36: 929-938.

Ogbeibu AE, Oribhabor F. 2002. Ecological impact of river impoundment using benthic-invertebrates as indicators. *Institute* for *Water Research* 36: 2427–2436.

Poff NL, Allad JD, Bain MB, Karr JR, Prestegaard KL, Richter BD, Sparks RE, Stromberg JC. The natural flow regime: A paradigm for river conservation and restoration. *BioScience* 47: 769-784.

© University of Venda

University of Venda
Creating Future Leaders

Robison-Brayan I. 2004. Technical memorandum: pH requirements of Freshwater Aquatic Life. *Elke Groove, CA 956524* 916: 714-1802.

Roos JC, Pieterse AJH. 1996. Seasonal variation of phytoplankton biomass in the middle Vaal River, South Africa. *Water SA* 22: 33-41.

Sakamoto M. 1966. Primary production by phytoplankton community in some Japanes lakes and its dependence on lake depth. *Arch hydrology* 62: 1-28.

Tesi T, Miserocchi S, Acri F, Langone L, Boldrin A, Hatten JA, Albertazzi S. 2013. Flood-driven transport sediment, particulate organic matter, and nutrients from Po River watershed to the Mediterranean Sea. *Journal of hydrology* 498: 144-152.

Thirion C, *Mocke A, Woest P. 1995. Biological Monitoring of Streams and Rivers: A User manual, Institute for Water Quality Studies*. WWQS Report No. N000/00/REQ1195. Pretoria: Department of Water Affairs and Forestry

USEPA (United States Environmental Protection Agency). 1986. *Quality Criteria for Water*. Washington D.C. Report No. 440/5-86-001. Washington D.C.: Office of Water Regulations and Standards

Webb RH, Schmidt JC, Collier M. 1999. *Dams And Rivers: A primer on the downstream effects of dams*.. USGS circular No.1126. United State: Geological Survey.

Williams GP, Wolman MG. 1984. Downstream effects of dams on alluvial rivers. *Science* 273: 1558-1561.

WHO (World Health Organization). 1984. *Guidelines for Drinking-Water Quality. Volume 2. Health Criteria and Other Supporting Information*. WHO report No. EOS/98. Geneva: World Health Organization.

Odume NO, Muller WJ. 2011. Diversity and structure of Chironomidae communities in relation to water quality difference in the Swartkops River. *Physics and Chemistry of the Earth* 36: 929-938.

© University of Venda

Appendix

Appendix 1: Field form

Field form: Influence of floods

PROJECT ..... DATE ..... TIME .....

RIVER ..... Site no and name .....

a)Geographical Position

Altitude (m)	South	East

b) Active channel dimensions

f) Macro-channel dimensions

Width (m)	Depth max (m)		Width (m)	Flow level					
				none	low	moderate	strong	fresh	flood

c) In situ physic-chemical parameters

pH	Conduct µS	Water temp. °C	Oxygen $mg/^{-1}$	Oxygen %	TDS (ppm)

d) Chemical characteristics of the water (lab results)

TSS	Turbidity	NO_3	NO_2	PO_4	Ca	Alkalinity	Hardness

e) Macro-invertebrate biotopes present (Indicate with a cross)

SIC		SOC		Over/veg		Mud & sand		Indicate
								Biotope present
								Surber done
								Velocity
								Dom. substrate

f) Checklist of samples taken (indicate YES/NO)

Water	Cobbles	Pendant inserted	Surber sample	Photo

General remarks

© University of Venda

SITE MAP: a) delineate and number biotopes *on map* and b) in table record readings of velocity, depth and substrate.

	Selected points		
Hab no	Velocit m/s	Dep th m	Substrate BR/B/C/G/S/S l

Appendix 2: Measured environmental factors during the four surveys at both site 1 and 2.

Site #	pH	con	temp	oxygen	oxygen%	TDS	Depth	Velocity	NH4	P	Nitrate	Nitrite
1S1a	7.38	254	23.7	10.88	128.6	126	50	0.9	0.11	0.14	1.6	0.04
1S1b	7.38	254	23.7	10.88	128.6	126	22	0.01	0.11	0.14	1.6	0.04
1S2a	7.6	281	25.3	9.31	115.4	141	33	1.2	0.18	0.05	2.7	0.05
1S2b	7.6	281	25.3	9.31	115.4	141	17	0.6	0.18	0.05	2.7	0.05
2S1a	8.13	259	17.4	11.13	115.1	129	36	0.6	0.08	0.09	2.3	0.02
2S1b	8.13	259	17.4	11.13	115.1	129	25	0.3	0.08	0.09	2.3	0.02
2S1c	8.13	259	17.4	11.13	115.1	129	24	0.7	0.08	0.09	2.3	0.02
2S1d	8.13	259	17.4	11.13	115.1	129	20	0.4	0.08	0.09	2.3	0.02
2S2a	8.12	375	20.1	13.3	118.6	187	25	0.52	0.11	0.28	0.9	0.03
2S2b	8.12	375	20.1	13.3	118.6	187	28	0.7	0.11	0.28	0.9	0.03
2S2c	8.12	375	20.1	13.3	118.6	187	24	0.5	0.11	0.28	0.9	0.03
2S2d	8.12	375	20.1	13.3	118.6	187	23	31	0.11	0.28	0.9	0.03
3S1a	8.14	257	18.5	9.2	110.3	127	28	0.4	0.17	0.1	3	0.13
3S1b	8.14	257	18.5	9.2	110.3	127	25	0.4	0.17	0.1	3	0.13
3S1c	8.14	257	18.5	9.2	110.3	127	27	0.44	0.17	0.1	3	0.13
3S1d	8.14	257	18.5	9.2	110.3	127	31	0.21	0.17	0.1	3	0.13
3S2a	8.38	331	20.7	12.4	121.9	166	27	0.6	3.27	0.14	1.2	0.04
3S2b	8.38	331	20.7	12.4	121.9	166	26	0.44	3.27	0.14	1.2	0.04
3S2c	8.38	331	20.7	12.4	121.9	166	30	0.8	3.27	0.14	1.2	0.04
3S2d	8.38	331	20.7	12.4	121.9	166	20	0.34	3.27	0.14	1.2	0.04
4S1a	8.08	261	22.1	8.62	112	130	16	0.82	0.2	0.21	1.2	0.02
4S1b	8.08	261	22.1	8.62	112	130	18	0.84	0.2	0.21	1.2	0.02
4S1c	8.08	261	22.1	8.62	112	130	20	0.3	0.2	0.21	1.2	0.02
4S1d	8.08	261	22.1	8.62	112	130	30	0.45	0.2	0.21	1.2	0.02
4S2a	8.03	363	24.8	8.6	110.1	182	19	0.78	0.18	0.1	0.5	0.05
4S2b	8.03	363	24.8	8.6	110.1	182	23	0.6	0.18	0.1	0.5	0.05
4S2c	8.03	363	24.8	8.6	110.1	182	15	0.35	0.18	0.1	0.5	0.05
4S2d	8.03	363	24.8	8.6	110.1	182	12	0.23	0.18	0.1	0.5	0.05

© University of Venda

Appendix 3: Measured Chlorophyll-*a* and AFDM per surface in the four surveys in the Phongolo River during the period of April to November 2013

Site #	Chlorophyll-*a*	Surface area (cm)	Chlorohyll-a per cm2	AFM per surface area
1S1a	11.4640	7782.2000	0.0015	0.0249
1S1b	11.4640	7782.2000	0.0015	0.0090
1S2a	11.4640	8081.5500	0.0014	0.0090
1S2b	11.4640	8081.5500	0.0014	0.0117
2S1a	14.3300	2815.3000	0.0051	0.0117
2S1b	17.1960	3600.0000	0.0048	0.0089
2S1c	25.7940	2925.1500	0.0088	0.0025
2S1d	20.0620	457.8730	0.0015	0.0042
2S2a	8.5980	4373.0000	0.0020	0.0176
2S2b	8.5980	6283.4000	0.0014	0.0064
2S2c	63.0520	4386.2000	0.0144	0.0049
2S2d	5.7320	4818.2000	0.0012	0.0039
3S1a	318.1260	500.9300	0.6351	0.0055
3S1b	366.8480	344.7800	1.0640	0.0041
3S1c	372.5800	585.3300	0.6365	0.0058
3S1d	106.0420	411.2050	0.2579	0.0154
3S2a	51.5880	457.8550	0.1127	0.0032
3S2b	57.3200	905.0950	0.0633	0.0089
3S2c	1005.9660	519.2950	1.9372	0.0079
3S2d	117.5060	555.1000	0.2117	0.0040
4S1a	48.7220	3335.7000	0.0146	0.0062
4S1b	11.4640	3667.2000	0.0031	0.0072
4S1c	5.7320	4491.8000	0.0013	0.0072
4S1d	8.5980	4386.2000	0.0020	0.0221
4S2a	5.7320	2969.8500	0.0019	0.0221
4S2b	14.3300	552.8964	0.0010	0.0084
4S2c	8.5980	4322.0500	0.0020	0.0074
4S2d	11.4640	3999.5000	0.0029	0.0074

© University of Venda

Appendix 4: The benthic macro-invertebrate diversity observed at the two sites in the four surveys in the Phongolo River during the period of April to November 2013 (P = present and A = absent).

Family	Site 1	Site 2
Atyidae	P	P
Baetidae	P	P
Chironomidae	P	P
Chlorocyphidae	A	P
Coenagriidae	A	P
Elmidae	P	P
Gomphidae	A	P
Gyrinidae	P	A
Heptageniidae	P	P
Hydrophilidae	P	P
Hydropsychidae	P	P
Leptoceridae	P	A
Leptophlebiidae	P	P
Libellulidae	P	P
Naucoridae	A	P
Oligochaeta	P	P
Oligoneuridae	A	P
Philopotamidae	A	P
Physidae	P	P
Psychomyiidae	P	P
Pyralidae	P	P
Simulidae	P	P
Tabanidae	P	P
Thiaridae	P	P
Tricorythidae	A	P
Total number of families	18	23

© University of Venda

Appendix 5: The seasonal benthic macro-invertebrate diversity observed in the Phongolo River during the period of April to November 2013 (P = present and A = absent).

Family	First survey- April 2013	Second Survey- July 2013	Third survey- Sept 2013	Fourth survey- Nov 2013
Atyidae	P	P	P	P
Baetidae	P	P	P	P
Chironomidae	A	P	A	P
Chlorocyphidae	A	P	A	A
Coenagriidae	A	P	A	A
Elmidae	A	P	P	P
Gomphidae	A	A	P	A
Gyrinidae	A	P	A	A
Heptageniidae	P	P	P	A
Hydrophilidae	A	P	A	A
Hydropsychidae	P	P	P	P
Leptoceridae	A	P	A	A
Leptophlebiidae	P	P	P	P
Libellulidae	P	P	P	P
Naucoridae	P	A	A	A
Oligochaeta	A	P	P	A
Oligoneuridae	P	A	A	A
Philopotamidae	A	A	P	A
Physidae	P	P	P	P
Psychomyiidae	P	P	P	A
Pyralidae	P	A	A	P
Simulidae	A	A	P	P
Tabanidae	A	P	P	A
Telogonodidae	P	A	A	A
Thiaridae	P	P	P	P
Tricorythidae	P	A	A	A
Total number of families	13	18	15	11

© University of Venda

Appendix 6: A comparison of the benthic macro-invertebrate diversity observed at site 1 and 2 in the Phongolo River during the period of April to November 2013 (A = absent and P = present).

	First survey-April 2013		Second survey-July 2013		Third survey -Sept 2013		Fourth survey-Nov 2013	
Family	**Site 1**	**Site 2**	**Site 1**	**Site 2**	**Site 1**	**Site 2**	**Site 1**	**Site 2**
Atyidae	P	A	P	P	P	P	P	P
Baetidae	P	P	P	P	P	P	P	P
Chironomidae	A	A	P	P	A	A	A	P
Chlorosyphidae	A	A	A	P	A	A	A	A
Coenagriidae	A	A	A	P	A	A	A	A
Elmidae	A	A	P	A	P	P	P	A
Gomphidae	A	A	A	A	A	P	A	A
Gyrinidae	A	A	P	A	A	A	A	A
Heptageniidae	P	P	P	P	P	P	A	A
Hydrophilidae	A	A	P	P	A	A	A	A
Hydropsychidae	P	A	P	P	P	P	P	P
Leptoceridae	A	A	P	A	A	A	A	A
Leptophlebiidae	P	P	P	P	P	P	P	P
Libellulidae	P	P	P	P	A	P	P	P
Naucoridae	A	P	A	A	A	A	A	A
Oligochaeta	A	A	P	P	P	P	A	A
Oligoneuridae	A	P	A	A	A	A	A	A
Philopotamidae	A	A	A	A	A	P	A	A
Physidae	P	P	A	P	P	A	A	P
Psychomyiidae	A	P	P	A	P	P	A	A
Pyralidae	A	P	A	A	A	A	P	A
Simulidae	A	A	A	A	P	P	P	A
Tabanidae	A	A	A	P	P	P	A	A
Thiaridae	P	P	P	P	P	P	P	P
Tricorythidae	A	P	A	A	A	A	A	A
Total number of families	8	11	14	14	12	14	9	8

© University of Venda

University of Venda
Creating Future Leaders

Appendix 7: The abundance of benthic macro-invertebrate families observed at site 1 and 2 during the four surveys in the Phongolo River during the period of April to November 2013 (N = no specimen found).

Family	Site 1	Site 2
Atyidae	3	8
Baetidae	136	179
Chironomidae	5	12
Chlorocyphidae	N	1
Coenagriidae	N	1
Elmidae	4	1
Gomphidae	N	1
Gyrinidae	2	N
Heptageniidae	21	12
Hydrophilidae	2	2
Hydropsychidae	74	89
Leptoceridae	1	N
Leptophlebiidae	13	50
Libellulidae	8	57
Naucoridae	N	1
Oligochaeta	6	2
Oligoneuridae	N	1
Philopotamidae	N	27
Physidae	3	6
Psychomyiidae	3	20
Pyralidae	1	1
Simulidae	466	69
Tabanidae	1	2
Telogonodidae	1	4
Thiaridae	526	57
Abundance	1276	603

© University of Venda

University of Venda
Creating Future Leaders

Appendix 8: The total abundance of the benthic macro-invertebrate families observed during the surveys in the Phongolo River during the period of April to November 2013 (N = no specimen found).

Family	First survey- April 2013	Second Survey- July 2013	Third survey- Sept 2013	Fourth survey- Nov 2013
Atyidae	1	6	2	2
Baetidae	91	129	57	38
Chironomidae	N	12	N	5
Chlorocyphidae	N	1	N	N
Coenagriidae	N	1	N	N
Elmidae	N	1	3	1
Gomphidae	N	N	1	N
Gyrinidae	N	2	N	N
Heptageniidae	3	27	3	N
Hydrophilidae	N	4	N	N
Hydropsychidae	3	79	57	24
Leptoceridae	N	1	N	N
Leptophlebiidae	17	27	17	2
Libellulidae	4	19	38	4
Naucoridae	1	N	N	N
Oligochaeta	N	3	5	N
Oligoneuridae	1	N	N	N
Philopotamidae	N	N	27	N
Physidae	3	3	1	2
Psychomyiidae	2	1	20	N
Pyralidae	1	N	N	1
Simulidae	N	N	320	215
Tabanidae	N	1	2	N
Telogonodidae	5	N	N	N
Thiaridae	82	157	273	71
Tricorythidae	1	N	N	N
Abundance	215	474	826	365

UNIVERSITY OF VENDA
LIBRARY

© University of Venda

Appendix 9: The abundance of benthic macro-invertebrates families observed at Site 1 and Site 2 during the four surveys in the Phongolo River during the period of April to November 2013 (N = no specimen found).

	First survey-April 2013		Second survey-July 2013		Third survey -Sept 2013		Fourth survey-Nov 2013	
Family	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2
Atyidae	1	N	1	5	1	1	N	2
Baetidae	32	59	36	93	40	17	28	10
Chironomidae	N	N	5	7	N	N	N	5
Chlorosyphidae	N	N	N	1	N	N	N	N
Coenagriidae	N	N	N	1	N	N	N	N
Elmidae	N	N	1	N	2	1	1	N
Gomphidae	N	N	N	N	N	1	N	N
Gyrinidae	N	N	2	N	N	N	N	N
Heptageniidae	2	1	17	10	2	1	N	N
Hydrophilidae	N	N	2	2	N	N	N	N
Hydropsychidae	3	N	49	30	14	43	8	16
Leptoceridae	N	N	1	N	N	N	N	N
Leptophlebiidae	9	8	2	25	1	16	1	1
Libellulidae	2	2	5	14	N	38	1	3
Naucoridae	N	1	N	N	N	N	N	N
Oligochaeta	N	N	2	1	4	1	N	N
Oligoneuridae	N	1	N	N	N	N	N	N
Philopotamidae	N	N	N	N	N	27	N	N
Physidae	2	1	N	3	1	N	N	2
Psychomyiidae	N	2	1	N	2	18	N	N
Pyralidae	N	1	N	N	N	N	1	N
Simulidae	N	N	N	N	251	69	215	N
Tabanidae	N	N	N	1	1	1	N	N
Thiaridae	64	18	145	12	256	17	61	10
Tricorythidae	N	1	N	N	N	N	N	N
Total abundance	116	99	269	205	575	251	316	49

© University of Venda

Appendix 10: The total biomass of the benthic macro-invertebrate families observed at sites 1 and 2 in the Phongolo River during the period of April to November 2013 (N = specimen not found).

	Biomass (g)	
Family	**Site 1**	**Site 2**
Atyidae	0.043	0.108
Baetidae	0.199	0.065
Chironomidae	0.001	0.006
Chlorocyphidae	N	0.002
Coenagriidae	N	0.001
Elmidae	0.005	0.002
Gomphidae	N	0.012
Gyrinidae	0.005	N
Heptageniidae	0.047	0.012
Hydrophilidae	0.011	N
Hydropsychidae	0.124	0.077
Leptoceridae	0.000	N
Leptophlebiidae	0.011	0.369
Libellulidae	0.474	2.454
Naucoridae	N	0.008
Oligochaeta	0.0103	0.010
Oligoneuridae	N	0.001
Philopotamidae	N	0.036
Psychomyiidae	0.011	0.013
Physidae	0.008	0.005
Pyralidae	0.006	0.001
Simulidae	0.080	0.024
Tabanidae	0.039	0.021
Thiaridae	6.036	0.620
Tricorythidae	N	0.000
Total Biomass	7.4088	3.852

© University of Venda

Appendix 11: The total biomass of the benthic macro-invertebrates families observed during the four surveys in the Phongolo River during the period of April to November 2013 (N = no specimen found).

	Biomass (g)			
Family	**First survey- April 2013**	**Second survey- July 2013**	**Third survey- Sept 2013**	**Fourth survey- Nov 2013**
Atyidae	0.003	0.042	0.054	0.053
Baetidae	0.016	0.049	0.032	0.167
Chironomidae	N	0.003	N	0.004
Chlorocyphidae	N	0.002	N	N
Coenagriidae	N	0.001	N	N
Elmidae	N	0.001	0.005	0.001
Gomphidae	N	N	0.012	N
Gyrinidae	N	0.005	N	N
Heptageniidae	0.004	0.035	0.021	N
Hydrophilidae	N	0.011	N	N
Hydropsychidae	0.006	0.109	0.065	0.021
Leptoceridae	N	0.001	N	N
Leptophlebiidae	0.004	0.008	0.005	0.364
Libellulidae	0.046	0.530	1.753	0.599
Naucoridae	0.008	N	N	N
Oligochaeta	N	0.005	0.015	N
Oligoneuridae	0.001	N	N	N
Philopotamidae	N	N	0.036	N
Psychomyiidae	0.009	0.008	0.002	0.004
Physidae	0.001	0.001	0.012	N
Pyralidae	0.001	N	0.001	0.006
Simulidae	N	N	0.064	0.040
Tabanidae	N	0.002	0.059	N
Thiaridae	0.675	2.232	2.671	1.079
Tricorythidae	0.001	N	N	N
Total Biomass (g)	0.775	3.043	4.809	2.337

© University of Venda

University of Venda
Creating Future Leaders

Appendix 12: The total biomass in grams of benthic macro-invertebrates families observed at site 1 and Site 2 during the four surveys in the Phongolo River during the period of April to November 2013 (N = no specimen found).

	Biomass (g)							
	First survey-April 2013		Second survey-July 2013		Third survey -Sept 2013		Fourth survey-Nov 2013	
Family	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2
Atyidae	0.003	N	0.008	0.034	0.033	0.021	N	0.053
Baetidae	0.003	0.013	0.022	0.027	0.016	0.017	0.159	0.008
Chironomidae	N	N	0	0.002	N	N	N	0.0036
Chlorosyphidae	N	N	N	0.002	N	N	N	N
Coenagriidae	N	N	N	0.001	N	N	N	N
Elmidae	N	N	0.001	N	0.004	0.002	0.001	N
Gomphidae	N	N	N	N	N	0.012	N	NN
Gyrinidae	N	N	0.005	N	N	N	N	N
Heptageniidae	0.003	0	0.027	0.008	0.017	0.003	N	N
Hydrophilidae	N	N	0.011	N	N	N	N	N
Hydropsychidae	0.006	N	0.09	0.018	0.024	0.041	0.004	0.017
Leptoceridae	N	N	N	N	N	N	N	N
Leptophlebiidae	0.002	0.002	0.006	0.002	0.002	0.003	0.002	0.362
Libellulidae	0.005	0.041	0.122	0.408	N	1.753	0.347	0.252
Naucoridae	N	0.008	N	N	N	N	N	N
Oligochaeta	N	N	0.003	0.002	0.007	0.008	N	N
Oligoneuridae	N	0.001	N	N	N	N	N	N
Philopotamidae	N	N	N	N	N	0.036	N	N
Psychomyiidae	0.008	0.001	N	0.008	0.002	N	N	0.004
Physidae	N	N	0.001	N	0.007	0.005	N	N
Pyralidae	N	0.001	N	N	N	0.001	0.006	N
Simulidae	N	N	N	N	0.04	0.024	0.04	N
Tabanidae	N	N	N	0.002	0.039	0.02	N	N
Thiaridae	0.589	0.085	2.209	0.023	3.432	0.238	0.805	0.274
Tricorythidae	N	N	N	N	N	N	N	N
Total Biomass (g)	0.62	0.153	2.505	0.537	3.623	2.185	1.363	0.973

© University of Venda

University of Venda
Creating Future Leaders

Appendix 13: Benthic macro-invertebrates abundance at sub-sites.

Family	1S1a	1S1b	1S2a	1S2b	2S1a	2S1b	2S1c	2S1d	2S2a	2S2b	2S2c	2S2d	3S1a	3S1b	3S1c	3S1d	3S2a	3S2b	3S2c	3S2d	4S1a	4S1b	4S1c	4S1d	4S2a	4S2b	4S2c	4S2d
Athericidae								1	1																			
Atydae																			1									
Baetidae			1							1	1		1	3				1				1					1	
Chironomidae	4	27	5	3	56	7	8	14	7	7	35	20	31	22	6	12		5		8	4	2	12	3	11	2	5	2
Chlorocyphidae									5		6	1															5	
Coenagrionidae													1															
Elmidae													1															
Gomphidae								1						1	1					1			1					
Gyrinidae	1																		1									
Heptageniidae							1		1																			
Hydrophiilidae			2		1	1	7	6	3		8	2		1		1					1							
Hydropsychidae									2		2																	
Leptoceridae	1	2			4		16	18	11	3	10	16	1	7	1	5	1	17	8	4	14		7		1	7	6	3
Leptophlebiidae								1																				
Libellulidae	9		5	3		2						17	8			1					16		1				1	
Naucoride	2			2	2	1			2	2	8	3	1					8	14	11	5	1				2		
Oligocheata				1																								
Oligoneuridae							1		1			1				1	3		1									
Philopotamidae	1				1																							
Physidae																			20	7								
Psychomyiidae			2		1								3				1											2
pyralidae					2	1										2		4	6	8								
Simulidae					1																			1				
Tabanidae														215	16	20		26	17	22	4	40	140	25	10			
Thiaridae										1				1						1								
Tricorythidae	30	22	42	5	13	84	19	35	7			8	4	43	52	158	3		2	8	7	2	24	19	16	7		1
Thiaridae				1																								

© University of Venda

University of Venda
Creating Future Leaders

Appendix 14: Benthic macro-invertebrates biomass at sub-sites.

	Biomass																												
Family	1S1a	1S1b	1S2a	1S2b	2S1a	2S1b	2S1c	2S1d	2S2a	2S2b	2S2c	2S2d	3S1a	3S1b	3S1c	3S1d	3S2a	3S2b	3S2c	3S2d	4S1a	4S1b	4S1c	4S1d	4S2a	4S2b	4S2c	4S2d
Athericidae								0.158	0.138																			
Atydae																			0.003									
Baetidae			0.003						0.008	0.005		0.016	0.013				0.033				0.021						0.014	
Chironomidae	6E-04	0.003	2E-04	0.006	0.007	0.003	0.002	0.009	0.008	0.009	0.008	0.006	0.004	0.008	0.003	0.004		0.003		0.011	0.003	0.008	0.005	0.141	0.006	0.003	0.002	0.002
Chlorocyphidae									5E-04		8E-04	0.001															0.004	
Coenagrionidae													0.002															
Elmidae													7E-04															
Gomphidae								8E-04						0.002	0.002					0.002			8E-04					
Gyrinidae	0.001																		0.012									
Heptageniidae							0.002		0.004																			
Hydrophilidae			0.003		5E-04	0.003	0.002	0.014	0.009		0.004	9E-04	0.003	0.004	0.008	0.005					0.003							
Hydropsychidae									0.011																			
Leptoceridae		4E-04	0.006			0.007	0.003	0.026	0.055	0.01	0.005	0.002	8E-04	0.011	0.003	0.01	0.001	0.017	0.011	0.002	0.012		9E-04		0.003	0.007	0.006	0.004
Leptophlebiidae								2E-04																				
Libellulidae		0.002		3E-04	0.002		0.006					0.002	4E-04			0.002					0.003		0.002					0.362
Naucoride		0.005			0.041	0.008	0.09		0.023	0.159	0.148	0.088	0.013					0.308	0.844	0.442	0.158	0.347				0.221		
Oligocheata				0.008																								
Oligoneuriidae							0.002		0.001			0.002				0.001	0.006		0.008									
Philopotamidae	3E-04				7E-04																							
Physidae																			0.025	0.011								
Psychomyiidae			0.008		0.001									0.008			0.002											0.004
pyralidae					2E-04	9E-04										0.007		0.002	0.002	0.001								
Simuliidae					7E-04															5E-04						0.006		
Tabanidae														0.032	0.003	0.004		0.007	0.005	0.005	0.008	0.027	0.001	0.008	0.004			
Thiaridae										0.002				0.039						0.02								
Tricorythidae			2E-04	4E-04																7E-04								
Thiaridae	1.114	0.465	0.125	0.043	0.042	0.144	1.156	0.346	0.563			0.014	0.009	0.231	0.618	1.321	0.263		0.038	0.122	0.079	0.547	0.02	0.141	0.098	0.212		0.01

© University of Venda

Appendix 15: SASS Version 5 scoring sheet.

Table 1: The SASS Version 5 scoring 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				
Oligoneuriidae	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...vellidae*	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				
Buliminae*	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 1m²; 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)

© University of Venda