ASSESSMENT OF RIVER HEALTH USING *IN SITU* WATER QUALITY PARAMETERS AND MINI-SASS BIOMONITORING TOOL IN THE MARICO AND CROCODILE RIVERS, NORTH WEST PROVINCE, SOUTH AFRICA

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Abstract

Freshwater resources in South Africa are limited and scarce, which is mainly attributed to the country's varying climate resulting in predominantly desert to semi-desert conditions. Among the freshwater resources, groundwater is by far the most abundant and readily available source of water; followed by lakes, reservoirs and the rivers that provide a vital connection and access to freshwater. The Crocodile and Marico rivers are the two main rivers in the Crocodile (West) Marico Water Management Area (WMA) which primarily lies within the North West Province. Rivers have undergone varying degrees of mild to severe alteration or deterioration due to anthropogenic impacts. Groot Marico River catchment in the North West Province has for centuries been a highly desirable tract of land for human settlement purposes; whereas the Crocodile River is one of the most adversely affected rivers in South Africa. The River Health Programme (RHP) data on both the Marico and Crocodile rivers are outdated and the exclusive use of physic-chemical water quality parameters (which provide direct evidence of water quality) only represents the prevailing water quality at the time of sampling rather than a long-term indication of the river health. The continuous monitoring and associated protection of aquatic ecosystem condition or 'health' is important in maintaining rivers ecosystem services. The current study was to determine the current condition of the Marico and Crocodile rivers based on the mini-SASS biomonitoring tool in correlation with the selected water quality parameters in an attempt to provide a holistic assessment of the rivers and to contribute to the continuous river health monitoring. This was achieved by assessing the selected water quality parameters at various sites of the Marico and Crocodile Rivers in North West Province, in conjunction with the use on benthic macroinvertebrates in the mini-SASS biomonitoring tool. The physico-chemical water quality parameters proved effective in differentiating the seasonal temporal conditions of both the Marico and Crocodile rivers. The Marico River's aquatic habitats are generally in good condition, but are slowly becoming affected by agricultural return flows and the abstraction of water from the main stream. Given that irrigated and dryland agriculture, urban and mining dominate catchment land uses, the DO and temperature levels recorded in this study indicate that the Crocodile river are under severe stress and may potentially be on the verge of collapse. This was evident in the overall mini-SASS scores indicated in this study whereby the Crocodile River can be classified as very poor condition (critically modified – purple) with scores of <4.8 and <5.3 for sandy and rocky aquatic habitats, respectively.

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1. CHAPTER 1: RESEARCH BACKGROUND

1.1 Background of study

Freshwater resources in South Africa are limited and scarce, which is mainly attributed to the country's varying climate resulting in predominantly desert to semi-desert conditions (Heath *et al.,* 2010). Among the freshwater resources, groundwater is by far the most abundant and readily available source of water; followed by lakes, reservoirs and the rivers that provide a vital connection and access to freshwater (READ, 2015). Rivers are extremely dynamic entities, constantly changing in form, through diverse landscapes and, over time, with the seasons and rainfall (Skelton, 2001). As natural resources, rivers are a vital component of the environment as they provide important ecosystem services (Tempelhoff *et al*., 2012). Many rivers are used daily by people "in order to create opportunities for transport, irrigation, leisure and keeping alive a sentimental sense of aesthetics and natural beauty, and generally as storage facilities for a finite natural resource without which we cannot survive – fresh water" (Tempelhoff *et al*., 2012). Consequently, rivers have undergone varying degrees of mild to severe alteration or deterioration due to anthropogenic impacts (Smith-Adao *et al*., 2006).In some cases rivers are used for dumping vast amounts of pollutants that can pose serious health risk to biota and humans (Tempelhoff *et al*., 2012).

In southern Africa, rivers are an important contributor of freshwater supplies and they are under threat. The biodiversity of 84% of South Africa's rivers is severely threatened (Darwall *et al*., 2009). Few rivers in the world, which are essentially a natural element in any landscape, have remained unaffected by anthropogenic activities, mostly related to economic development (Tempelhoff *et al*., 2012). A primary example of the crucial role of rivers both ecologically and in the development of human civilisation is the River Nile; which has been an integral part of civilisation in Egypt. This is eminent in the remarkable impact its water had and still has in a desert environment (Tvedt, 2004). The Vaal River is the eight largest river in southern Africa and one of the most utilised in South Africa (*cf.* Tempelhoff, 2000; 2001; 2006). The current deteriorating of the Vaal River highlights the importance of continuously monitoring South Africa's river systems, ensuring their sustainable use and ecosystem protection.

1.2 Research problem

The Groot Marico River catchment in the North West Province has for centuries been a highly desirable tract of land for human settlement purposes (Tempelhoff *et al*., 2012). Many aspects of the river and its valuable water supplies, situated in a semi-arid region of South Africa, have been subjected to anthropogenic activities in the course of long history

(Tempelhoff *et al*., 2012). According to the River Health Programme – RHP (2005) report, the general state of the Marico River is considered as natural to good, free from significant organic pollution, with a pronounced biodiversity and overall good water quality. A recent study by Wolmarans et al. (2017) was done in which there was no correlation observed between the metal concentrations in the sediment and the diversity and abundance of benthic macroinvertebrates in the Marico River. Previous studies conducted on the Marico River have demonstrated low metal concentrations which was inconclusively attributed to natural processes such as geological weathering (Kemp *et al*., 2017). In addition to being ecologically and socio-economically important, the Marico River forms part of the protected Groot Marico Biosphere. The Marico River remains one of the least impacted systems (Wolmarans *et al*., 2017) in a region where large scale mining operations result in elevated metal concentrations in water and sediments (Almécija *et al*., 2017).

The Crocodile River is one of the most adversely affected rivers in South Africa (RHP, 2005). The southern part of the upper Crocodile River sub-catchment is highly developed with large industrial, urban and semi-urban sprawls of northern-Johannesburg, Midrand and southern Pretoria. The river is highly impacted by increased water demand and pollution which are driven by increased impervious surfaces, lack of sufficient capacity of sewer systems, and substantial channel and flow modification and detrimental change in land-use (RHP, 2005). Both the Elands and the Pienaars rivers are the major tributaries of the upper Crocodile River sub-catchment, with the Elands River impacted by the rapidly growing Rustenburg area due to expansion of platinum mining activities. The Pienaars River sub-catchment is characterised by the densely populated city of Pretoria, with the eco-status of the river regarded as poor with largely altered flow patterns further compounding on the availability of water (RHP, 2005). The lower Crocodile River sub-catchment is subjected to large-scale irrigation along the mainstream which has resulted in the alteration of the natural flow of the river (RHP, 2005). This is further compounded on by presence of dams and weirs which also impede the natural migration of fauna throughout the river (RHP, 2005).

The River Health Programme (RHP) data on both the Marico and Crocodile rivers are outdated and the exclusive use of physic-chemical water quality parameters (which provide direct evidence of water quality) only represents the prevailing water quality at the time of sampling rather than a long-term indication of the river health. As such, water quality in river systems does not reflect any altered and continuously changing environmental conditions but rather the temporal variations in water quality (Jooste *et al*., 2006). Furthermore, the land uses along river catchment continuously change over time and so does the impacts on aquatic ecosystems. This therefore warrants the need for monitoring data which consists of both water quality and biological components (Basson *et al*., 1997). The assessment of biota in rivers, in correlation with the water quality data, is a widely recognized means of determining the condition or ‘health’ of rivers (Dickens & Graham, 2002).

1.3 Research rationale

The continuous monitoring and associated protection of aquatic ecosystem condition or ‘health’ is important in maintaining rivers ecosystem services. This proposed project serves to determine the current condition of the Marico and Crocodile rivers based on the mini-SASS biomonitoring tool in correlation with the selected water quality parameters in an attempt to provide a holistic assessment of the rivers and to contribute to the continuous river health monitoring.

1.4 Aim of the study

The aim of the study is to assess the selected water quality parameters at various sites of the Marico and Crocodile Rivers in North West Province, in conjunction with the use on benthic macroinvertebrates in the mini-SASS biomonitoring tool.

1.4.1 Objectives of the study

The objectives of the study are to:

a) assess *in situ* the selected physico-chemical parameters in selected sites of the Marico River and Crocodile River.
b) determine the composition of benthic macroinvertebrates at selected sites of the Marico River and Crocodile River.
c) identify patterns between water quality and the overall scores of the mini-SASS protocol.
d) determine the overall condition or ‘health’ of the Marico and Crocodile River based on the water quality and benthic macroinvertebrates and make recommendations for future monitoring and management.

1.5 Research hypotheses

Based on the objectives of the study, the present study tested the following hypotheses:

H0: There is no difference in selected *in situ* water quality parameters and associated mini-SASS biomonitoring tool results between the Groot Marico and Crocodile rivers..

Ha: Due to the different catchment impacts, there is a difference in the selected *in situ* water quality of the Groot Marico and Crocodile rivers and this is reflected in the mini-SASS biomonitoring tool results.

1.6 Study Area

The Crocodile and Marico rivers are the two main rivers in the Crocodile (West) Marico Water Management Area (WMA) which primarily lies within the North West Province (Figure 1). It is the second most populous WMA in South Africa (Darwall *et al*., 2009). The urban and industrial complexes of northern Johannesburg and Pretoria as well as platinum mining operations northeast of Rustenburg dominate economic activity in the WMA (Darwall *et al*., 2009). The catchment area receives a mean annual runoff of 855 million m^3/annum, 75% of which flows down the Crocodile River, whereas 20% flows down the Marico River, with the remaining 5% flow down the Upper Molopo river catchment (Figure 1) (RHP, 2005). These two rivers' confluence forms the Limpopo River, which flows eastwards and subsequently drains into the Indian Ocean (RHP, 2005). The water uses for the WMA consists of urban, industrial and mining; of which a third of the water is used for irrigation and the remainder is used for rural water supply and power generation. It has been noted that the water requirements in the catchment area are far more than what can be provided by the current water resources (RHP, 2005).These two river systems were selected to provide a comparison between a supposedly pristine river system with a highly impacted river system, indicating the influences that anthropogenic activities may have on the water quality and macroinvertebrate compositions of these river systems.

The climatic conditions in the catchment area vary significantly ranging from semi-arid in the east to dry in the west. Seasonal rainfalls in the form of thunderstorms occur from October to April, providing a mean annual rainfall of 400 to 800 mm and decreases from the eastern side to the west. The terrain in the catchment area is fairly uniform, ranging from 1700 m above sea level in the Witwatersrand area to 900 m above sea level at the confluence of the Crocodile and Limpopo rivers (RHP, 2005). The catchment area is rich in mineral deposits, thus is inundated with mining activities on a large scale. The upper Crocodile sub-catchment and Marico catchments consist of dolomitic rock containing water-rich dolomitic aquifers, which occur from Pretoria to Mafikeng (Figure 1). The south-eastern part of the catchment area is dominated by urban areas, with smallholdings and agricultural activities in the north-west portion of the catchment area (RHP, 2005).

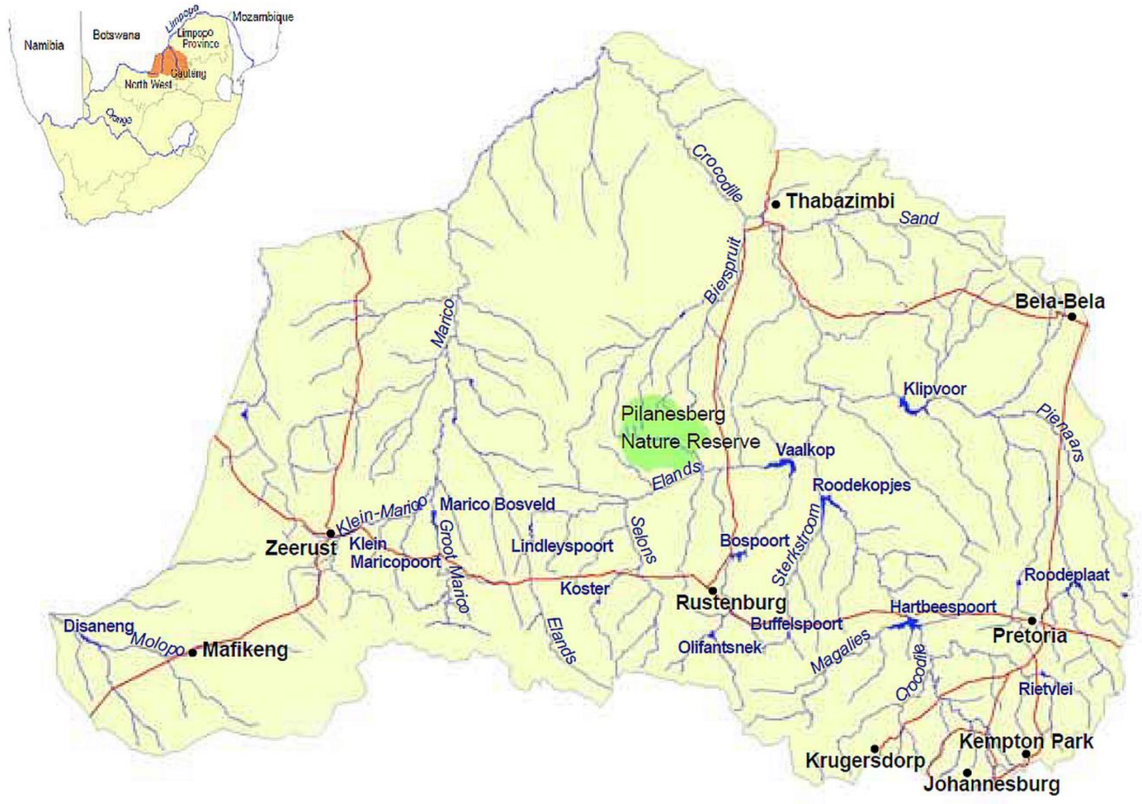

Figure 1: Major rivers, tributaries and reservoirs in the Crocodile (West) Marico Water Management Area (RHP, 2005).

1.6.1 Marico River

The Marico River, in the North-West province of South Africa, is a tributary of the Limpopo River. It is approximately 250 km long and is classified as a National Freshwater Ecosystem Priority Area (NFEPA) (Nel, 2012). The river flows in a northerly direction and joins the Klein Marico and Crocodile Rivers before flowing as headwaters into the Limpopo River on the border between South Africa and Botswana, and eventually draining into the Indian Ocean in Mozambique (Skelton, 2001). This river originates in the dolomitic aquifer plateau region of the North West province and flows through a variety of geomorphological features to its confluence with the Crocodile River (King, 1951). The perennial tributaries of the Groot Marico River emanate from dolomitic eyes, formed at contact zones between igneous rocks and the dolomites of the Transvaal Super-group (Eriksson *et al*., 2006). Perennial flow from these springs is an important ecological attribute of the upper reaches in this semi-arid catchment, forming aquatic refugia for endemic biota within this system. The upper reaches flow in deeply incised gorges that are relatively un-impacted and sheltered from human disturbances such as intensive agricultural activities (Grobler *et al*., 2007). The Marico River is one of the cleanest and healthiest rivers in South Africa, and as such it is significant in the provision of clean fresh water to the Limpopo River systems.. There are two major storage reservoirs that regulate the flow of the Marico River downstream, namely the Marico Bosveld

Dam in the upper catchment and the Molatedi Dam further downstream (Figure 1). The Marico-Bosveld Dam is located as a main stream reservoir of the Marico River, near Groot-Marico. The dam was established in 1933 with a capacity of 27,813,000 m^3 and serves mainly for irrigation purposes (DWA, 2012). The Molatedi dam is used to provide water to Gaborone, Botswana, in accordance with the TSWASA agreement (Tempelhoff *et al*., 2012). It is an earth-fill type dam located on the Marico River, near Zeerust, North West. It was established in 1986 with a capacity of 203,000,000 m^3 and serves mainly for irrigation purposes and domestic supply (DWA, 2012).

According to Department of Water Affairs (2012), the overall present ecological status (this includes fish, vegetation, and hydrology, invertebrates and water quality) for the upper reaches of the Marico River, up and downstream of Zeerust was determined as an A/B (least impacted) category. This highlights the ecological Importance and sensitivity ratings of the upper tributaries of the Marico River, such that conservation efforts are essential in maintaining their pristine ecological integrity. A total of 77 aquatic macro-invertebrate families were recorded within the Marico River Catchment area (Roux, 2010). The high number of macro-invertebrate families and the high number of these families that are sensitive an indication that habitat diversity is high and anthropogenic disturbances are limited at most of the sites (Roux, 2010).

A study by Kemp *et al*. (2017) in the Marico River indicated that the river is relatively unaffected by human activities; but metal concentrations, mainly from natural sources, occasionally exceed environmental quality guidelines. In the study, positive correlations were observed between metals in sediment and macroinvertebrates, while no correlation was observed between metal concentrations in water and macroinvertebrates (Kemp *et al*., 2017). Kimberg *et al*. 2014 evaluated the impact of the Largemouth Bass *Micropterus salmoides* (Lacepède, 1802), which is listed as one the most invasive alien species in the world (Lowe *et al.*, 2000).

The tributaries of the Groot Marico River are characterised by relatively neutral pH values (7.3–8.1) and low hardness (TDS: 159–323 mg/ℓ) (Kimberg *et al.*, 2014). Kimberg *et al*. (2014) also states that the Marico River Catchment area lies in summer rainfall region and therefore, temperature and river flows follow a seasonal pattern with winters characterised by low water flow and low temperature (9.6 °C), while summers are characterised by high temperatures (22.7 °C) and increased water flows.

1.6.2 Crocodile River

The Crocodile River is one of the major tributaries of the Limpopo River, originating at Roodepoort and flowing through the Hartbeespoort Dam and past Thabazimbi towards the

Botswana border wherein it joins the Marico River. The Crocodile River catchment consists of an area of about 29 400 km^2 with nine major storage dams in the catchment. The naturalised mean annual runoff is 1 200 million cubic metres per year, with an estimated maximum yield of 859 million cubic metres per year (DWAF, 2004). The upper section of the Crocodile River catchment, which is located south east of the Hartbeespoort Dam, is situated in the Gauteng Province. This upper Crocodile sub-catchment area occurs upstream of the confluence with the Elands River and has two large dams, namely the Hartbeespoort and Roodekopjes dams RHP, 2005). The central and western portion of the Crocodile River falls within the North West Province, whereas the lower north-east portion of the Crocodile River is found in the Limpopo Province. The river flows in a north/north-westerly direction until the confluence with the Marico River, after which it is called the Limpopo River. The lower portion of Crocodile River consists of two large tributaries, namely the Sand River and the Bierspruit River which join the Crocodile River west of the town of Thabazimbi. This portion of the river is dominated by Irrigation as the largest water demand in this sub-area.

The Crocodile River is highly impacted by anthropogenic activities which includes domestic, agricultural and industrial activities. These anthropogenic activities in the broader catchment influence the quantity and quality of the water, which has a direct impact on the ecological integrity of the river. In addition to the increased water demand in the catchment area, there are numerous sources of pollution that are contributing to the reduced levels of water quality. These sources include, but not limited to, agricultural return flows, industrial discharges, sewage spills and discharges (RHP, 2005).

2. CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

In South Africa, the monitoring of water quality was primarily focused on measuring the physical and chemical parameters of a water body (Roux *et al*., 1993). The sole measurements of physical and chemical parameter do not reflect the overall health of an ecosystem (Roux *et al*., 1993). The use of biomonitoring supplemented these assessments. Biological monitoring is based on the premise that the overall health of an ecological system is often indicated by the health state of the organisms that inhabit that particular ecosystem (Adams *et al*., 1993); and that contaminants that may be present in water are detrimental to both the physiology and, ultimately, the survival of organisms that inhabit the water body (Handy, 2003).

Biomonitoring techniques provide for the use of living organisms to assess the health of the environment (both aquatic and terrestrial) (Davies & Day, 1998). The use of micro- or macro organisms is based on their sensitivity and long-term exposure to environmental conditions, thus providing an indication of both temporal and long-term changes (Resh *et al.*, 1996; Jacobsen *et al*., 2008). Indicator species whose presence or absence reflects the conditions in aquatic ecosystems, form an integral part of any aquatic biomonitoring technique (Rosenburg & Resh, 1993; Dallas, 2000). Aquatic biota such as fish, amphibians, reptiles, aquatic macro-invertebrates, zooplankton, algae and bacteria are used in various aquatic biomonitoring techniques which encompass indicator species, biotic indices, biodiversity indices and rapid bio-assessments (Reece & Richardson, 1999).

2.2 Freshwater Invertebrates as Indicators

Aquatic macroinvertebrates inhabit ponds, lakes, wetlands, streams and rivers. Although they may vary in sizes, aquatic macroinvertebrates are predominantly small such that they can be retained on a net with a mesh size of 0.25 mm (WRC, 2001). Each macroinvertebrate group is generally restricted to a portion of the river in which the physical and chemical conditions are favourable (Gerber & Gabriel, 2002). Therefore, the upper, middle and lower reaches of the river may have varying compositions of macroinvertebrates.Anthropogenic activities such as sewage discharge, timber harvesting, and acid mine drainage affect the hydrology and chemical characteristics of the river (Oberholster, *et al.*, 2008). These changes in the characteristics of the stream subsequently affect the availability and quality of habitat, thus directly nfluence the density of aquatic macroinvertebrates and their assemblages (Oberholster, *et al.*, 2008). This is because macroinvertebrates have specific requirements in terms of temperature, dissolved oxygen, substrate types, etc. (Oberholster, *et al.*, 2008). Macroinvertebrates also form important component of food chain as they are a source of nutrition for birds and fish, and are also involved in the breakdown of organic matter and nutrients (WRC, 2001). The variations in in river characteristics mean that there is a difference in macroinvertebrate communities in each river, many of which exist as larval and nymph stages on which the descriptions of each group is based on (Gerber & Gabriel, 2002). Therefore, the aquatic macroinvertebrate community composition in river can be used to give an accurate assessment of river health (WRC, 2001). These can be ideally used for biomonitoring as various taxonomic groups have varying sensitivities to pollution; they allow for detection of the spatial impacts of pollution due to their sedentary nature; ubiquitous in aquatic systems; they are relatively easy to collect and identify; and they allow for continuous water quality monitoring due to their prolonged exposure to any adverse conditions in the watersource. Aquatic macroinvertebrates that are commonly used as indicators of water quality in river systems include mollusks, crustaceans, insects, arachnids and annelids (see Appendix 2) (Resh *et al.*, 1995).

2.2.1 Order Trichoptera (Caddisfishes)

Caddisfly larvae spend a large portion of their life cycle in water (Holzenthal *et* al., 2007). They have a very low tolerance to pollution, and thus are an excellent indicator for water quality and river health (Dickens & Graham, 2002).

2.2.2 Order Ephemeroptera (Mayflies)

Mayfly nymphs which are burrowers and bottom sprawlers are primarily found in calm waters of ponds or backwaters of streams, whereas others cling on to rocks and submerged substrates found in fast riffles (Wang & McCafferty, 1996). The flat-headed and brushlegged mayflies have a very low tolerance to pollution, thus their presence indicates very good water quality (Dickens & Graham, 2002).

2.2.3 Order Hemiptera (True flies)

Hemiptera is regarded as the most diverse but with few groups that are adapted to aquatic habitats (Anderson, 1979). Some groups are able to remain under water while remaining in contact with the water surface, whereas others are found on the water surface (Anderson, 1979). True flies are classified as highly tolerant to pollution (Dickens & Graham, 2002).

2.2.4 Order Odonata (Dragonflies/Damselflies)

Odonata consists of two sub-orders, namely Zygoptera (damselflies) and Anisoptera (true dragonflies) (Remsburg & Turner, 2009). Both the adult and nymph stages of these sub-orders are easily distinguishable based on their morphology. Both the damselflies and dragonflies are moderately tolerant to pollution, which also makes them a good indicator for good river health.

2.2.5 Order Coleoptera (Beetles)

Majoriy of the insects in Coleoptera are terrestrial, with a few families whose larval stages are aquatic. They are found in every inhabitable freshwater habitat which range from temporary pools to river streams (Rainio & Niemelä, 2003). Beetles are generally moderately tolerant to pollution (Dickens & Graham, 2002).

2.2.6 Order Diptera (Flies, Mosquitoes, Midges)

Diptera aquatic larval and pupal stages can be found in almost every aquatic habitat (Medvedev *et al*., 2007). Most Diptera pupae are inactive and float around or tightly fastened to rocks or other solid substrate, while Mosquito and Midge pupae are able to move around the water body (Medvedev *et al*., 2007). Most Diptera have low pollution tolerance values, are generally strong indicators of poor water quality (Dickens & Graham, 2002).

2.2.7 Order Plecoptera (Stoneflies)

Stoneflies are commonly found in unpolluted rivers, and their nymphs are exclusively aquatic. The nymphs are found beneath stones in streams with high levels of dissolved oxygen (Roque *et al*., 2008). Stoneflies have having a very low tolerance to pollution, such thus their presence is a strong indication of pristine water quality, with very little or no pollution (Dickens & Graham, 2001).

2.2.8 Order Hydracarina (Water mites)

Water mites are found in abundance in freshwater habitats clinging to submerged vegetation or in pools (Sabatino *et al*., 2000). They are moderately tolerant to pollution (Dickens & Graham, 2002).

2.2.9 Class Turbellaria (Flatworms)

Freshwater Turbellaria have a high sensitivity to light, thus they are more abundant in shaded areas or areas where they can hide and offer a good food supply (Baguñà & Riutort, 2004). Flatworms are highly tolerant to pollution category (Dickens & Graham, 2001).

2.2.10 Class Decapoda (Crabs, Shrimps)

Benthic crustaceans in rivers and streams are characterized by their marked endemism and sometimes low species numbers. Correa-Araneda et al. (2010) indicated a correlation between the abundance of specific species of the genera *Aegla* and *Parastacus* with low pH is associated with low oxygen and a high concentration of organic matter. Crabs are highly tolerant to pollution, whereas shrimps are moderately tolerant to pollution (Dickens & Graham, 2002).

2.2.11 Class Hirudinae (Leeches)

Hirudinae (leeches) vary in size, ranging from being minute to giant species that reach up to 45cm when extended; and generally hide under stones or among plants or in detritus (Brinkhurst, 1982). Leeches are highly tolerant to pollution and are strong indicators of poor water quality (Dickens & Graham, 2002).

2.2.12 Class Gastropoda (Snails, Limpets)

Majority of freshwater Gastropoda have spiral shells while just a few limpet genera have flatter, conical shells (Strong *et al*., 2008). Snails are highly tolerant to pollution (Dickens & Graham, 2001). They also occur in unpolluted waters, as such may be regarded as a poor indicator of pollution.

2.3 South African Scoring System (SASS)

Aquatic macroinvertebrates are commonly used as indicators of water quality and metal exposure (Van Ael *et al*., 2015). In South Africa, South African Scoring System (SASS) is widely recognised as a rapid and inexpensive method for evaluating or determining the condition or 'health' of aquatic ecosystem in rivers (Dickens & Graham, 2002); and was developed by Chutter (1994). This method is based on the use of benthic macroinvertebrates as indicator organisms for bio-assessments due to their visibility to the naked eye, ease of identification, rapid life cycle (based on seasonal changes) and their sedentary habits (Dickens & Graham, 2002). Although numerous bio-assessment techniques exists that vary in complexity and region of implementation, South Africa's exemplary history in this field has culminated in the refinement of invertebrate technique and its application in a National River Health Programme (RHP) (Dickens & Graham, 2002) and more recently in the River Ecostatus Monitoring Programme (WRC, 2016).

After various revisions and modifications over the years, the SASS system is now on version 5 (Dickens & Graham, 2002). The essence of the method lies in allocating a quality score to specific and readily identifiable aquatic invertebrate taxa. The score is an indication of the taxon's sensitivity to pollution.

Samples of aquatic invertebrates are collected from the river using standardised methods, immediately examined on the riverbank, and then the sample is 'scored', based on the prescribed scores allocated to each taxon. After a fixed identification period the scores of the taxa found are summed to derive a Sample Score. The total number of SASS taxa identified is counted and an Average Score per Taxon (ASPT) may be calculated by dividing the Sample Score by the total number of taxa. Each of these three measures, or indices, provides useful information as to the biological condition of the river. Generally, the higher the Sample Scores, Number of Taxa and ASPT, the better the biological condition or health of that river (Dickens & Graham, 2002).

SASS 5 currently form part of the River Ecostatus Monitoring Programme (previously RHP), which make use of various indices and models to determine the Ecostatus of rivers. The Ecostatus of a river are determined by the use of the Geomorphological Driver Assessment Index (GAI), Physico-Chemical Driver Assessment Index (PAI), Fish Response Assessment Index (FRAI), Macro-invertebrate Response Assessment Index (MIRAI), Riparian Vegetation Response Assessment Index (VEGRAI) and Index of Habitat Integrity (IHI) (WRC, 2008).

2.3.1 miniSASS biomonitoring tool

The mini-SASS technique was developed by Graham et al. (2004) based on the premise that reliable indicators of the SASS method are often difficult and expensive to derive; such that certain expertise skills and experience are required for SASS monitoring method which may not necessarily be affordable in terms of costs related to human resource. As such, the mini-SASS technique was developed as a low technology, scientifically reliable and robust method for monitoring the water quality and river health in rivers and streams. The reason for its development was for use in citizen science, where the public can make use of a simple scientific based tool to determine the condition of rivers and streams (WRC, 2019). The technique uses aquatic macroinvertebrates similarly to SASS because they are: ubiquitous in aquatic systems; relatively sedentary (which allows for spatial impacts of pollution to be detected); different taxonomic groups have varying sensitivity to pollution; relatively easy to identify; and can be used as continuous water quality monitors (Graham *et al*., 2004). Mini-SASS is primarily based on a tolerance scale, derived from the SASS5 scoring system which ranges from highly tolerant (sensitivity range of 1 – 5), moderately tolerant (sensitivity range of 6 – 10), and very low tolerance (sensitivity range of 11 – 15) (Dickens & Graham, 2002). As an example the presence of Stoneflies is a good indicator of good water quality, as these macroinvertebrates are high depended on clean, oxygen saturated waters (Wenn, 2008). Therefore they have a high sensitivity score and a low tolerance for pollution.

Although the SASS is a relatively simple technique for a trained practitioner, for the layman it is generally beyond reach because of the need to be able to identify up to 90 different aquatic invertebrate families that form the backbone of the technique (Graham *et al*., 2004). For non-invertebrate taxonomists this requires a moderately high degree of training and therefore restricts the technique to a small number of ‘specialists’ able to identify the taxa

(Graham *et al*., 2004). Thus, with the obvious shortcomings such the low quality data and the relatively sophisticated identification skills needed by the SASS system, there was a need for an intermediate level of biomonitoring that provides reliable water quality / river health data that could be applied by non-specialists (Graham *et al*., 2004). The mini-SASS varies from the SASS in that it minimises the number of aquatic invertebrate groupings and increases the ease of identification; but still robust enough to produce results comparable to those of the full SASS technique and still geographically widely applicable (Graham *et al*., 2004).

2.4 Water Quality

Water quality is used to describe the aesthetic, biological, chemical and physical properties of water which are used to determine whether water is viable for various uses (Dallas & Day, 2004). The evaluation of water quality of freshwater resources is often utilised in the protection of the health and integrity of aquatic ecosystems (Dallas & Day, 2004). Many of these properties, that define water quality, are dependent on constituents that are either suspended or dissolved in water. These properties also include physical properties like water temperature, colour and oxygen concentration.

2.4.1 South African Water Quality Guidelines (SAWQG)

The water quality of a stream or dam is described with respect to its suitability for its intended purpose. It is not enough to classify water as good or bad solely based on scientific measurements without knowledge of its intended use. As such, it should be determined if the water meets the criteria required for industrial, mining, farming, or domestic purposes; and if it is suitable to maintain a healthy ecosystem. South Africa's Department of Water Affairs and Forestry (DWAF), now called Department of Water and Sanitation (DWS), has developed a series of South African Water Quality Guidelines (SAWQG) (DWAF, 1996a, b, c, d, e) as the primary source of information for fitness of use assessments of water. Water quality parameters are compared to a generic range of South African Water Quality Guidelines (SAWQG). These water quality guidelines encompasses based on international literature, but also consist of more detailed technical and scientific information for each water quality constituent (DWAF 1996e). The information provided by SAWQG for each water quality constituent is described in the form of numerical data and/or detailed account of its effects on the suitability of the water for a specific use.

2.4.2 Water Quality Constituents

The physical, aesthetic, chemical and biological properties of water are controlled or influenced by constituents that are either dissolved or suspended in water (DWAF 1996e). The constituents or parameters that are used to describe the water quality and the framework in which they are used are separated into physico-chemical parameters, nutrients, metalloids and metals, and major ions.

2.4.2.1 Physico-chemical parameters

The physic-chemical parameters are also referred to as system variables and include water temperature (˚C), dissolved oxygen (DO), pH, electrical conductivity (EC), salinity, total alkalinity and turbidity. Essential aquatic ecosystems processes are regulated by these parameters, which fluctuate seasonally and in some systems over a period of 24 hours. Detrimental variations in the duration, amplitude and frequency of these cycles may cause severe disruptions to the ecology of the system (DWAF 1996e). The water quality criteria for these constituents, such as pH, dissolved oxygen and temperature, are given as numerical ranges in the SAWQG.

a) Water temperature

Water temperature can be defined as the condition of a body that determines the transfer of heat to, or from, other bodies (Ward, 1985). The solubility of oxygen (O_2) carbon dioxide (CO_2), nitrogen (N) and hydrogen (H) gases decreases with increasing temperature, thus affecting the rates of chemical reactions which impact the metabolic rates of aquatic organisms (Dallas & Day, 1993). In South Africa, the temperatures of inland waters generally range from 5–30˚C, with the thermal properties of running waters reliant on various features of the region and catchment area (Walmsley & Butty, 1980). The water temperature is measured on site by means of either a thermometer or a thermistor, and is expressed as degrees Celsius (˚C) (DWAF, 1996e).

b) Dissolved oxygen

Gaseous oxygen (O_2) is generated through photosynthesis by phytoplankton and aquatic plants, and also dissolves from the atmosphere in water although it is moderately soluble in water (Wetzel, 1975). Dissolved oxygen (DO) measurements are depicted as either a percentage of the saturation concentration or as milligrams per litre (mg/ℓ) at the time of sampling. The DO concentration is critical for the normal functioning and survival of the aquatic biota, and thus provides a useful measure of the health of an aquatic ecosystem (Wetzel & Likens, 1991). In unpolluted or relatively pristine surface waters, DO concentrations are usually saturated. The saturation level however depend on the temperature; for example, the saturation concentrations that are typical at sea level (where TDS values are below 3000 mg/ℓ) are 12.77 mg/ℓ at 5˚C, 10.08 mg/ℓ at 15˚C, and 9.09 mg/ℓ at 20˚C (DWAF, 1996e). An oxygen-sensitive electrode is used to measure the dissolved oxygen concentration in water *in situ*, the dissolved oxygen is measured based on the lowest instantaneous concentration that is recorded alongside other related water quality parameters at the time of sampling (DWAF, 1996e).

c) pH (Acidity and Alkalinity)

The pH is depicted as a value which is a measurement of the activity of hydrogen ions in a water sample (Dallas & Day, 1993). Pure water (water containing no solutes) has a pH of 7.0 at 24˚C; that is, the number of OH^- and H^+ ions are equal. Therefore the water is considered to be electrochemically neutral (Golterman *et al.*, 1978). The pH values for surface fresh water typically range between 4 and 11, with most fresh waters in South Africa being relatively well buffered at pH ranges between 6 and 8 (more or less neutral) (Dallas & Day, 1993). The overall pH value is calculated based on the mean hydrogen ion ([H+]) concentration, and may be measured by storing water in sampling bottles to be subsequently determined using laboratory pH meter (DWAF, 1966e) or an in situ field water quality instrument.

2.4.2.2 Non-toxic inorganic constituents

Some inorganic constituents are considered non-toxic because they may result in toxic effects at extreme concentrations, but generally occur in low concentrations as system characteristics (Wetzel & Likens, 1991). The natural concentrations of these constituents depend on localised hydrological, physical and geochemical processes (DWAF, 1996e). According to DWAF (1996e), the criteria are given as numerical ranges but can be depicted as proportional changes from local background and prevailing conditions for constituents such as total dissolved solids (TDS).

a) Total dissolved solids/salts (TDS)

The total dissolved solids concentration, is a measure of the quantity of all compounds dissolved in water, whereas the total dissolved salts concentration is a measure of the quantity of all dissolved compounds in water that carry an electrical charge (Wetzel, 1975). The total dissolved salts concentration is usually utilised as an estimate of the concentration of total dissolved solids in the water, since most dissolved substances in water carry an electrical charge (DWAF, 1996e).

b) Electrical conductivity

Electrical conductivity (EC) is used to measure how much electrical current can be conducted by the waster as a result of the presence of ions in water (DWAF, 1996e). These ions include potassium, calcium, sulphate, bicarbonate, chloride, nitrate, sodium, magnesium and carbonate; all of which carry an electrical charge (Alabaster & Lloyd, 1980). Majority of the organic compounds do not dissociate into ions (ionise) when dissolved in water, and thus do not affect the EC (Alabaster & Lloyd, 1980). Portable conductivity meters are used to measure the electrical conductivity, which is expressed in terms of milli Siemens per meter (mS m^{-1}) and is a useful surrogate measure of TDS (DWAF, 1996d).

2.4.3 Target Water Quality Ranges (TWQR)

The effects of specific water quality constituents on some species or components of an aquatic ecosystem are easily described, but the interrelationships between various components of these ecosystems pose numerous difficulties (DWAF, 1996e). However, developing an approach in which water quality criteria are employed ensures the protection of a larger portion of species within each trophic level; thus insuring the overall health integrity of the system (DWAF, 1996d, e). As such, the water quality objectives should cautiously be set at a level which prevents adverse effects on aquatic ecosystems. The water quality criteria include the Target Water Quality Range (TWQR), the Chronic Effect Values (CEV) and the Acute Effect Values (AEV), which can be used to evaluate specific water quality constituents. The TWQR is the range of concentrations or concentrations within which no measurable adverse effects are expected on the health of aquatic ecosystems and should therefore ensure their protection (DWAF 1996e). The CEV is defined as that concentration or concentration of a constituent at which there is expected to be a significant probability of measurable chronic effects to up to 5% of the species in the aquatic community. The AEV is defined as that concentration or concentration of a constituent above which there is expected to be a significant probability of acute toxic effects to up to 5% of the species in the aquatic community.

2.4.3.1 Target guideline ranges for system variables

a) Water temperature

The TWQR for water temperature is recommended to be stated in terms of the site- and case-specific "natural" temperature regime (DWAF, 1996e). The local conditions in cases should be determined (including seasonal and diel variability) before any water quality objective for an aquatic ecosystem is set as indicated in Table 1.

Table 1: Water temperature TWQRs for aquatic ecosystems (DWAF, 1966e).

Water Resource	Target Water Quality Range **(TWQR)**

All aquatic ecosystem	Water temperature should not be allowed to vary from the background average daily water temperature considered to be normal for that specific site and time of day, by > 2˚C, **or** by > 10%, **whichever estimate is the more conservative**

b) Dissolved oxygen

According to DWAF (1996e), the criteria that are used for dissolved oxygen concentrations (as percentage saturation) are given in terms of the Minimum Allowable Values (MAV) in Table 2. The concentrations provided offer limits which can be implemented in the protection of aquatic biota from the adverse effects of depleted oxygen.

Table 2: Dissolved oxygen TWQRs and Criteria for aquatic ecosystems (DWAF, 1996e).

TWQR and Criteria	**Concentration (% Saturation)**	**Condition**
Minimum Allowable Values	4mg/l or > 40% saturation	Below these levels anoxic conditions set in.

d) pH (Acidity and Alkalinity)

The reduction in pH often results in acid-tolerant organisms replacing less tolerant organisms, thus causing a change in the aquatic community and ultimately the dynamics of the aquatic ecosystem (DWAF, 1996e). Acid wastes containing bicarbonate alkalinity result in the formation of free carbon dioxide, when discharged into water. In alkaline water the free CO_2 may be liberated and become toxic to fish even if the pH does not drop to a level normally considered toxic DWAF, 1996e) (see Table 3).

Table 3: Criteria for pH in aquatic ecosystems (DWAF, 1966e).

Water Resource	Target Water Quality Range **(TWQR)**
All aquatic ecosystem	pH values should not be allowed to vary from the range of the background pH values for a specific site and time of day, by > 0.5 of a pH unit, or by > 5 %, and should be assessed by whichever estimate is the more conservative.

e) Total dissolved solids/salts (TDS)

The TWQR for TDS is evaluated based on case- and site-specific TDS contents. Thus, in all cases, the prevailing local conditions should be determined. These conditions include the

TDS contents, variability and seasonal changes before determining or setting the water quality criteria (Table 4).

Table 4: TWQR criteria for TDS (DWAF, 1996e).

Water Resource	**Target Water Quality Range**
All inland waters	● TDS contents should not be changed by > 15% from the normal cycles of the water body under unimpacted conditions at any time of the year; and ● The amplitude and frequency of natural cycles in TDS contents should not be changed.

3. CHAPTER 3: METHODOLOGY

3.1 Sampling Sites

Four sites in the Marico River (site 1 to 4) and four sites in the Crocodile River (site 5 to 8) catchments were selected for sampling. The selected of the sites was influenced by logistical accessibility to the rivers, availability of water and suitability for mini SASS sampling. The coordinates of each sampling site were determined with a Garmin Nuvi 500 GPS. Four sampling surveys per sampling site where conducted starting from 23/02/2017 to 24/05/2018.

3.1.1 Marico River Sampling Sites 1–4

Sampling sites 1 (S 25° 38' 29.712" E 26° 25' 54.624") and 4 (25°38'33.4"S 26°24'47.5"E) are located upstream from the town of Groot Marico, whereas site 2 (25°35'17.7"S 26°24'40.5"E) is located within Groot Marico town (Figure 2). Sites 1 and 4 are characterised by Muddy and sandy substratum, filamentous algae, abundant marginal and aquatic vegetation, stones in current, stones out of current, riffle, run and pool. Site 2 consists of little to no vegetation, bedrock, stones in current, riffle, run and pools. Sampling site 3 (25°27'31.3"S 26°23'26.1"E) is located after the river passes through the Marico Bushveld Nature Reserve in which the river forms a reservoir (Marico Bushveld Dam). Sites 3 consists of marginal and aquatic vegetation, filamentous algae and bedrock.

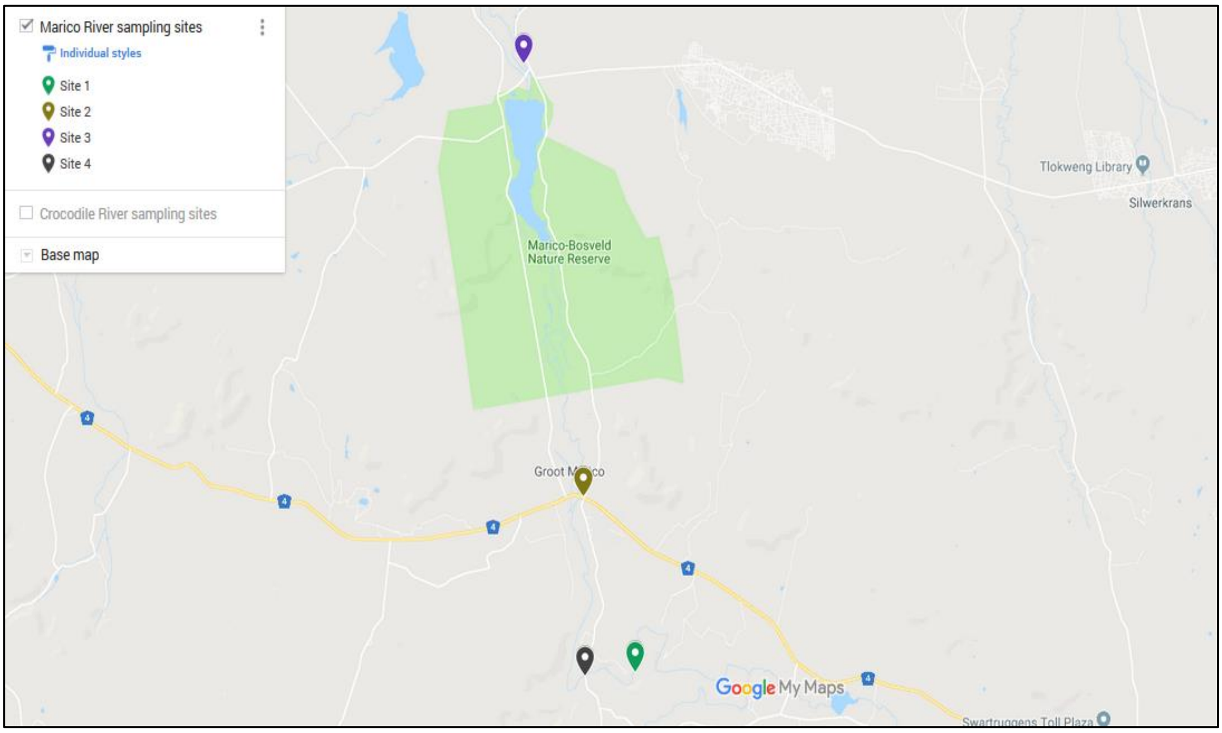

Figure 2: Marico River sampling sites S1, S2, S3 and S4 (Google Maps, 2018).

3.1.2 Crocodile River Sampling Sites 5–8

Sampling sites 5 to 8 are located in the lower Crocodile River catchment area. Site 5 (24°38'37.0"S 27°22'15.7"E) is a relative reference site which is upstream of most mining activities in the area and site 6 (24°38'26.6"S 27°22'06.2"E) is located downstream of the confluence between the Rooikuilspruit and Crocodile River (Figure 3). Both sites 5 and 6 are characterised by flowing streams and pools with mud and clay substratum, stones in some portions of the river. Site 7 (24°38'42.4"S 27°20'45.2"E) is located upstream of the confluence between the Bierspruit River and the Crocodile River, whereas site 8 (24°38'41.0"S 27°19'30.1"E) is located downstream of Bierspruit confluence with Crocodile River consist of running streams and pools with sand substratum and filamentous algae.

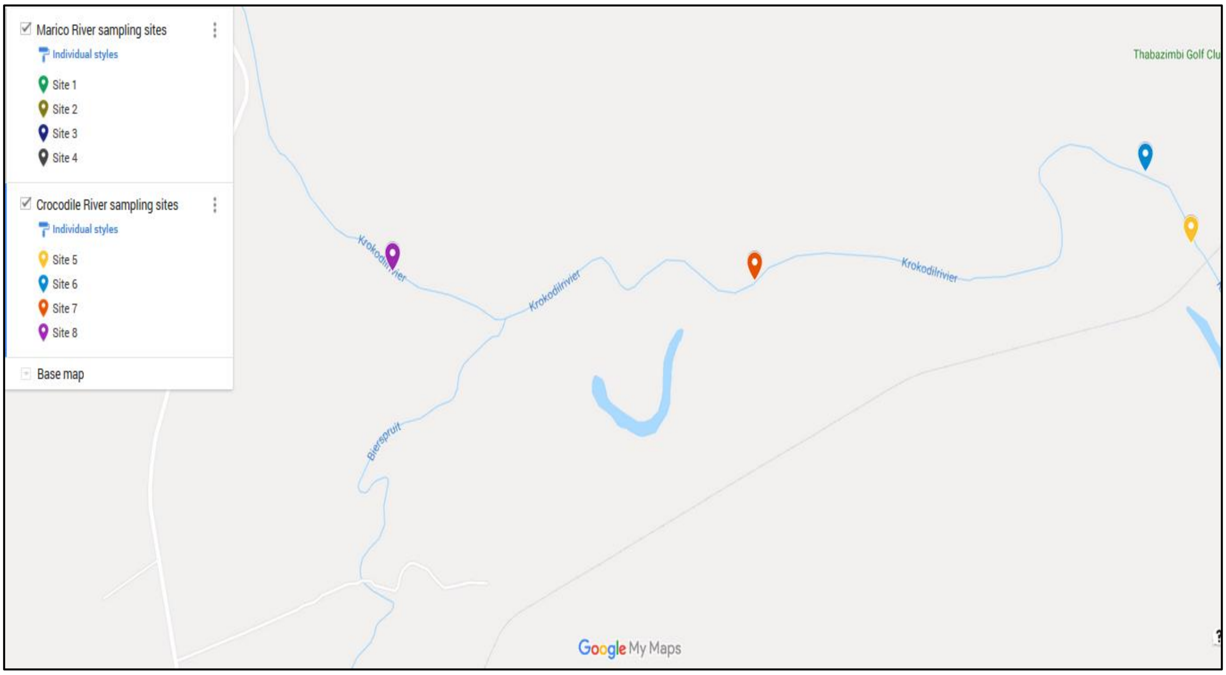

Figure 3: Crocodile River sampling sites S5, S6, S7 and S8 (Google Maps, 2018).

Two other DWA sampling sites A3GMAR-Rieke (25°27'40.3"S 26°23'30.8"E) and A3KMAR-Veeph (25°25'32.0"S 26°21'57.3"E) in the Marico River System were also visited in March 2017 but were deemed not suitable for SASS sampling as they consisted of isolated pools of water.

3.2 Sampling methods

3.2.1 Water quality sampling

Dissolved oxygen (DO), pH, water temperature, salinity and conductivity was determined *in situ* by means of a handheld YSI multi-parameter instrument (YSI 556 Model Multi Probe meter). Each of the parameters was measured based on subsurface readings between 8:00

and 12:00am. The water quality parameters were recorded on a data sheet along with sampling site aesthetics.

3.2.2 Collection of macroinvertebrates

A mini-SASS net was used to collect samples. The macro invertebrates was collected by sampling the vegetation (marginal and aquatic instream), gravel and sand, and stone biotopes with a 30 cm × 30 cm × 30 cm (mesh size 500 µm) sweep net for approximately 5 min each (Wolmarans *et al*. 2017). Stones in and out of current were sampled by brushing each stone off with a soft brush whilst collecting the macroinvertebrates in a net held downstream from the stone. The contents of the net was decanted into a plastic tray and families present in sufficient biomass (2 g per family, single or pooled organisms) and a variety of functional feeding groups was identified in accordance with the mini-SASS protocol (Graham *et al*., 2003). Care was taken to ensure that the macroinvertebrates are not discarded together with the debris and vegetation. In cases whereby the samples could not be readily identified in field, they were preserved in 70% ethanol.

3.2.3 Identification of macroinvertebrates

A dichotomous key, together with the identification guide, was utilised to assign each group a sensitivity score (see Appendix 1). A magnifying glass was used to help identify and distinguish between different macroinvertebrate groups (Appendix 2). A pair of tweezers and pipette was used so pick up small organisms for closer inspection.

3.2.4 Interpretation of the mini-SASS scores

A mini-SASS score sheet was used to record each of the macroinvertebrate group sensitivity scores (Table 5). Each macroinvertebrate group has a different sensitivity score which is based on their tolerance to pollution levels in the water. Groups with a higher score indicate a lower tolerance to pollution, meaning that the water is relatively unpolluted. Groups with a low sensitivity score are therefore found in more polluted waters, as they are more resistant to the effects of water pollution. The mini-SASS score sheet was incorporated into a master data sheet which allows for recording of water quality parameters, river aesthetics and mini-SASS scores (see Appendix 3). The mini-SASS produces only one score, which is similar and comparable to the ASPT (average score per taxon) produced by the more complex version of SASS (Graham *et al*., 2003).

Table 5: mini-SASS Scoring System (Graham *et al*., 2004).

Groups	**Sensitivity Score**
Flat worms	3
Worms	2
Leeches	2
Crabs or shrimps	6
Stoneflies	17
Minnow mayflies	5
Other mayflies	11
Damselflies	4
Dragonflies	6
Bugs or beetles	5
Caddisflies (cased or uncased)	9
True flies	2
Snails	4
TOTAL SCORE	
NUMBER OF GROUPS	
AVERAGE SCORE (miniSASS Score)	
Average Score = Total Score ÷ Number of groups	

The average sensitivity score for each site was calculated by adding all the sensitivity scores for the macroinvertebrate groups that were found, and then dividing that by the number of groups found. Each average score is then compared with the predetermined ecological categories which are dependant of the habitat type at the sampling site (Table 6).

Table 6: Ecological categories based on mini SASS scores (Dallas, 2007)

Ecological category (Condition)	**River Category Score**	
	Sandy Type	**Rocky Type**
NATURAL CONDITION (Unchanged/untouched – Blue)	>6.9	>7.2
GOOD CONDITION (Few modifications – Green)	5.9 to 6.8	6.2 to 7.2
FAIR CONDITION (Some modifications – Orange)	5.4 to 5.8	5.7 to 6.1
POOR CONDITION (Lots of modifications – Red)	4.8 to 5.3	5.3 to 5.6
VERY POOR CONDITION (Critically modified – Purple)	<4.8	<5.3

3.3 Data analyses methods

3.3.1 Water quality analyses

The chemo-physical parameters used in this study were temperature, dissolved oxygen (DO), pH, electrical conductivity (EC), salinity, and total dissolved solids (TDS). The results for these parameters are depicted graphically showing variations in season and sampling sites within each river systems and between the two river systems. Water quality results were interpreted using the South African Water Quality Guidelines (SAWQG), specifically those pertaining to the Aquatic Ecosystem. Due to the scope of this project, the case specific temperature, TDS, oxygen concentration and pH regime, guiding the WQG could not be determined. These constituents are reported relative to each river system investigated, with guideline values reflected in Table 7. For the purpose of this research project, all the TWQR for the water quality constituents are based on DWAF (1996e) for aquatic ecosystems.

Table 7: Guideline values for water quality constituents (DWAF, 1996e).

CONSTITUENT	**GUIDELINE VALUE**	**REASON**
Temperature	Not available	
TDS	Not available	
Oxygen	4mg/l or > 40% saturation	Below these levels anoxic conditions set in.
pH	6 – 8	Generally accepted standard for South African water (Dallas and Day, 1993)

The water quality constituents were subjected to statistical analyses to determine whether there was a significant difference in the water quality between the Marico and Crocodile rivers, and whether there is a significant difference between the four sampling sites within each river. In each parameter evaluated, a P-value of less than 0.05 (5% confidence interval used) depicts a significant difference in the parameter between seasons, sampling sites and river systems. The descriptive statistical analyses where conducted using Microsoft Excel, after which the significant differences between the mean values where compared using the Mann-Whitney U test run on SPSS version 21.0 (IBM Corp, 2012). This non-parametric test is relevant to two-sample comparisons due to the expected small number of values expected from the data set (MacFarland & Yates, 2016). The data was subjected to one-way analysis of variance (ANOVA) to determine whether there are any statistically significant differences between the means / averages of the two or more independent groups (i.e. seasons). This was done for the datafor each river (between sites), and also the clumped data between the

Marico and Crocodile rivers for comparison. The relatively simplistic nature of the water quality parameters dataset with its small number of values meant that the dataset could not be normalized either by increasing sample size or through transformations of the original data (Mackey, 2008).

3.3.2 Mini-SASS analyses

The average sensitivity scores at each site for the sampling periods where added and a mean value was calculated for each site in accordance with Graham *et al*. (2003). The significant differences between the mean values where compared using the Mann-Whitney *U* test run on SPSS version 21.0 (IBM Corp, 2012). This non-parametric test is relevant to two-sample comparisons due to the expected small number of values expected from the data set (MacFarland & Yates, 2016). The overall mini-SASS scores was compared with the target ranges as indicated by Graham *et al*. (2003).

Average sensitivity scores for each of the four sites for the Crocodile and Marico River systems were added together and the total divided by 4 to give an average sensitivity score for each river system. This was done for each of the four surveys conducted. These averages were then ranked and compared to each other to test for significant differences between them to better delineate the variations between the two river systems. These mean values were then compared to each other using the Mann-Whitney *U* test. This non-parametric test is relevant for two-sample comparisons (MacFarland & Yates, 2016).

3.4 Project Limitations

The sampling sites in this project were selected based on logistics and accessibility of the sites. Thus, the sampling sites could not be place strategically after every point of anthropogenic activities. This limited the number of sampling sites which could be included as part of the study.

4. CHAPTER 4: RESULTS

4.1 Chemo-physical parameters results

All field sheets and results used in this study are reflected in Appendix 4 to 19 and all statistical analysis are summarised in Appendix 20 to 31. Table 8 and

Table 9 indicate a comparison of water quality parameters between sampling sites (sites 1 to 8). The average site-specific temperature ranged from 14.53 to 18.00 °C in Marico River, with no significant difference ($p>0.05$) between Site 1, 2, 3 and 4. The average site-specific temperature in the Crocodile River ranged from 22.14 to 24.92 °C, with no significant difference ($p>0.05$) between Site 5, 6, 7 and 8. Although site 3 has higher dissolved oxygen (%) than the other sites in the Marico River, there was no significant difference in dissolved oxygen between the four sampling sites (sites 1 to 4). However, sites 5 to 8 in the Crocodile River had low dissolved oxygen (%) saturation ranging from an average of 24.69 to 53.58 % saturation (Table 9). The average pH values in the Marico River ranged from 8.12 to 9.58; whereas those recorded from the Crocodile River ranged from 2.03 to 5.12. There was a significant variation in the pH values between the sites in the Marico River ($P<0.05$). The electrical conductivity (µS/cm) and total dissolved solids (g/ℓ) average values showed similar patterns in that the Crocodile River Sites 5 to 8 showed more elevated values than the Marico River Sites 1 to 4.

Table 8: The average chemo-physical parameters recorded at the four sampling sites from Marico River during the study period (n=4).

PARAMETERS	S1	S2	S3	S4	P$^{\#}$
Water temperature (°C)	18.00 ± 5.70	17.51 ± 4.60	14.53 ± 5.19	17.67 ± 4.29	0.95
Dissolved oxygen (mg/ℓ)	6.57 ± 2.42	5.28 ± 2.20	7.45 ± 0.87	6.19 ± 1.42	0.28
Dissolved oxygen (%)	56.13 ± 15.00	48.55 ± 12.41	65.93 ± 4.74	55.63 ± 4.59	0.04
pH	8.26 – 9.44 ± 0.49	8.35 – 9.58 ± 0.55	8.12 – 8.91 ± 0.35	8.39 – 8.78 ± 0.19	0.05
EC (µS/cm)*	202.25 ± 0.06	237.75 ± 0.03	180.00 ± 0.01	225.25 ± 0.03	0.98
TDS (g/ℓ)	0.145 ± 0.03	0.189 ± 0.00	0.164 ± 0.01	0.153 ± 0.02	1.00

*EC = Electrical Conductivity, $^{\#}$P = statistical significance, S = sampling site.

Table 9: The average chemo-physical parameters recorded at the four sampling sites from Crocodile River during the study period (n=4).

PARAMETERS	S5	S6	S7	S8	P$^{\#}$

Water temperature (°C)	**22.14 ± 3.36**	**23.99 ± 2.93**	**23.98 ± 3.13**	**24.92 ± 1.81**	**0.81**
Dissolved oxygen (mg/ℓ)	**5.63 ± 2.10**	**2.01 ± 0.15**	**2.09 ± 0.15**	**2.22 ± 0.51**	**0.80**
Dissolved oxygen (%)	**53.58 ± 6.82**	**24.69 ± 1.89**	**30.88 ± 2.91**	**25.94 ± 4.75**	**0.05**
pH	**5.12 – 8.73 ± 1.77**	**2.03 – 10.01 ± 4.46**	**2.89 – 9.80 ± 4.41**	**2.78 – 9.88 ± 4.36**	**0.004**
EC (µS/cm)*	**296.85 ± 0.03**	**602.75 ± 0.01**	**567.50 ± 0.04**	**550.50 ± 0.04**	**0.71**
TDS (mg/ℓ)	**0.266 ± 0.02**	**0.408 ± 0.04**	**0.374 ± 0.02**	**0.422 ± 0.05**	**0.98**

*EC = Electrical Conductivity, $^{\#}$P = statistical significance, n = number of surveys conducted, S = sampling site

4.1.1 Water temperature

During winter, the temperatures recorded ranged from 9.59°C to 22.56°C, with the lowest value recorded from site 3 in Marico River and the highest from site 8 in Crocodile River. A similar pattern is indicated in Figure 6 whereby the seasonal temperature readings in the Crocodile River where higher than those of the sampling sites in the Marico River. The high summer temperature readings were recorded from site 8 at 26.95°C and the lower 18.45°C recorded from site 2 (Appendix 20). The seasonal temperature readings where significantly higher (P = 0.006) (Table 10) in the Crocodile River than those recorded in the Marico River.

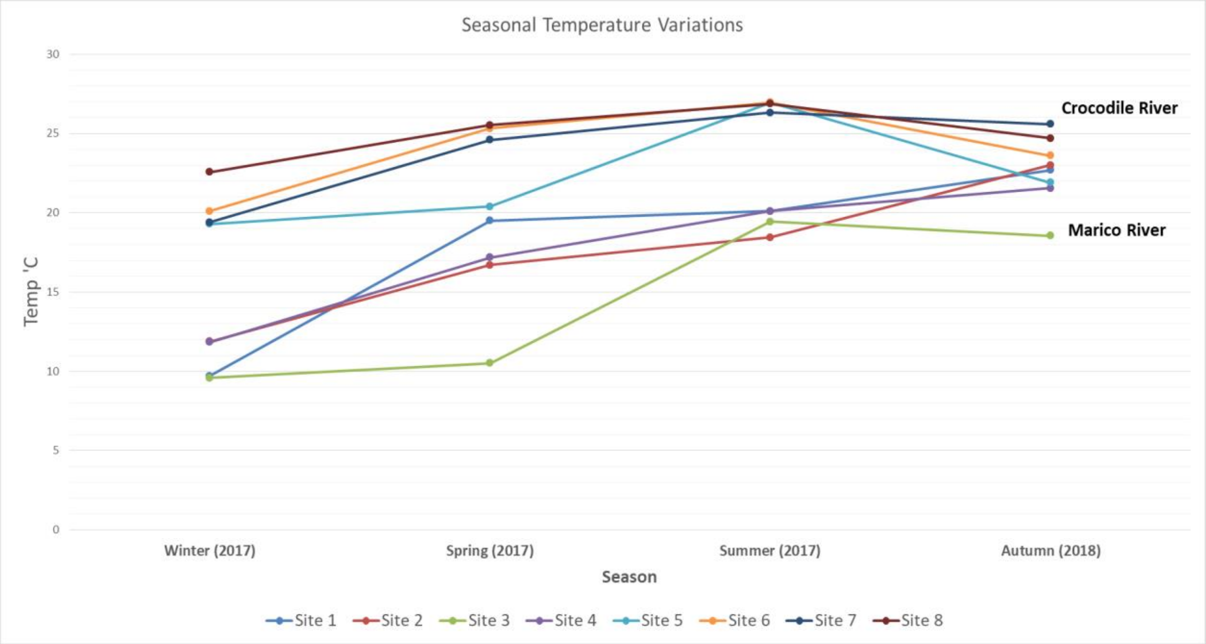

Figure 4: Seasonal temperature (°C) readings recorded during the four surveys conducted. Key: S1, S2, S3, S4 = sampling sites within the Marico River System, S5, S6, S7, S8 = sampling sites within the Crocodile River System (2017–2018).

There was no significant variation (P>0.05) (Table 8) in the overall water temperatures between the selected sites within the Marico River (P = 0.95) and within Crocodile River (P = 0.81). However, the Crocodile River displayed higher average temperatures per site as compared to the Marico River. Overall, higher average water temperatures were recorded in the Crocodile River (sites 5 to 8), whereas lower temperatures where recorded in Marico River (sites 1 to 4).

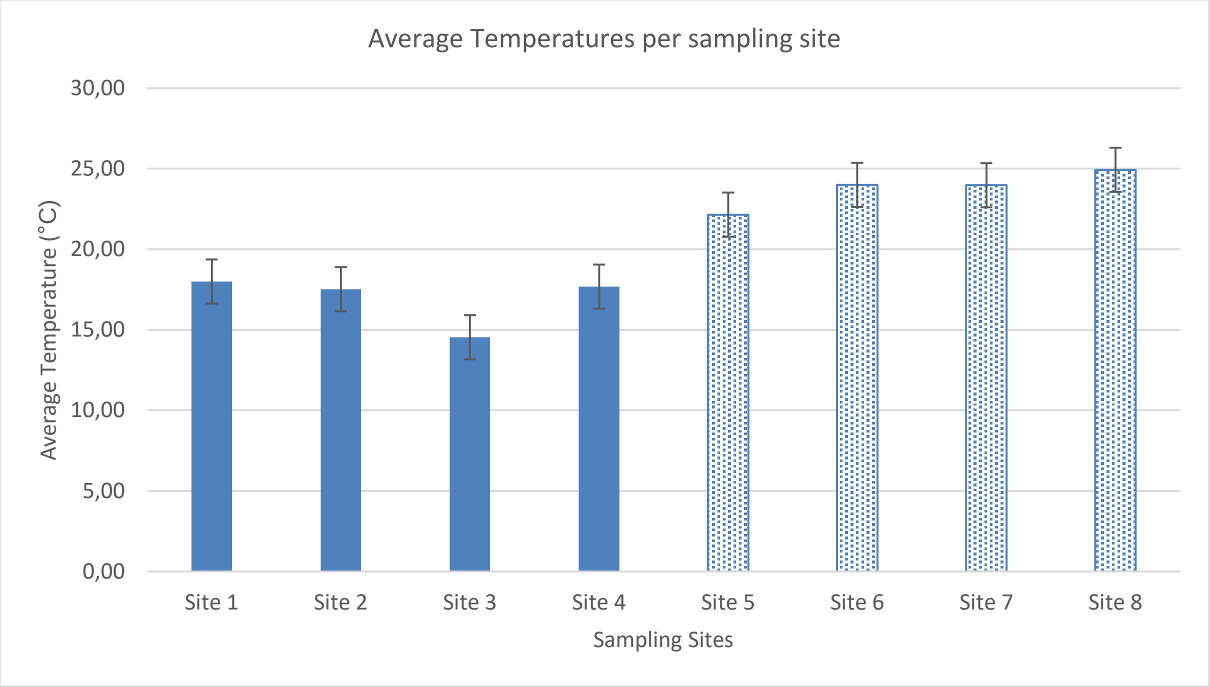

Figure 5: Average temperature (°C) readings recorded during the four surveys conducted. Key: S1, S2, S3, S4 = sampling sites within the Marico River System, S5, S6, S7, S8 = sampling sites within the Crocodile River System.

There was a significant difference (p = 0.006) in temperature values between the Marico and Crocodile rivers (Table 10). Thus the two river systems where subjected to different seasonal temperature variations between winter 2017 to autumn 2018.

Table 10: ANOVA analysis of seasonal temperature readings between the Marico and Crocodile rivers

Temperature (°C)

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	292.410	3	97.470	5.204	.006
Within Groups	524.388	28	18.728		
Total	816.798	31			

df - degrees of freedom

The temperature datasets for Marico River and Crocodile River were ranked from highest to lowest. The sum of ranks for Marico River was 11.00 and the mean rank was 6.50. The sum of ranks for Crocodile River was 25.00 and the mean rank was 6.25 (Table 11). These mean ranks were then compared to each other to determine the significant difference in temperature between Marico and Crocodile River. There is a significant difference (p = 0.043) between the pooled average temperature values between the Marico and Crocodile rivers (Table 11) regardless of the insignificant variations (p>0.05) in sampling sites of each river system. This meant that although there was a significant difference in temperature between the two river systems, there was no significant difference between sites 1 to 5 and 6 to 8.

Table 11: Mann-Whitney U analysis site-specific of temperature readings

Ranks

	River	N	Mean Rank	Sum of Ranks
Temperature	Marico River	4	2.75	11.00
	Crocodile River	4	6.25	25.00
	Total	8		

Test Statistics[a]	
Mann-Whitney U	1.000
Wilcoxon W	11.000
Z	-2.021
Asymp. Sig. (2-tailed)	.043
Exact Sig. [2*(1-tailed Sig.)]	.057[b]

a. Grouping Variable: River

b. Not corrected for ties.

4.1.2 Dissolved oxygen (DO)

Dissolved oxygen saturation levels in the Marico River were recorded above the levels that indicate anoxic conditions (Figure 6). There was no significant difference (P = 0.05) in the dissolved oxygen (DO) concentrations (%) between the four sampling sites in the Crocodile River (

Table 9), whereas there was a significant difference (P = 0.04) in the sampling sites of the Marico River (Table 8). Four sampling sites in the Crocodile River where below anoxic conditions (4mg/l or > 40% saturation) throughout the four surveys conducted; with the exception of site 5 whose values where recorded above the minimum TQWR (Figure 7). Although there where minor fluctuations in the % saturation in season, there was no significant difference (P = 0.873) in the recorded seasonal dissolved oxygen values (Table 12) between the Crocodile and Groot Marico rivers. There was no significant difference (P = 0.05) in the average dissolved oxygen between the four sampling sites in the Crocodile River, whereas there was a minor difference (P = 0.04) in the dissolved oxygen between the sites in the Marico River (Table 8). It is worth noting that site 5 had the highest average dissolved oxygen (53.58% saturation) of all the sites in the Crocodile River (Figure 7).

Table 12: ANOVA analysis of seasonal dissolved oxygen readings in the Groot Marico and Crocodile Rivers

Dissolved. Oxygen

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	205.698	3	68.566	.233	.873
Within Groups	8249.144	28	294.612		
Total	8454.843	31			

df - degrees of freedom

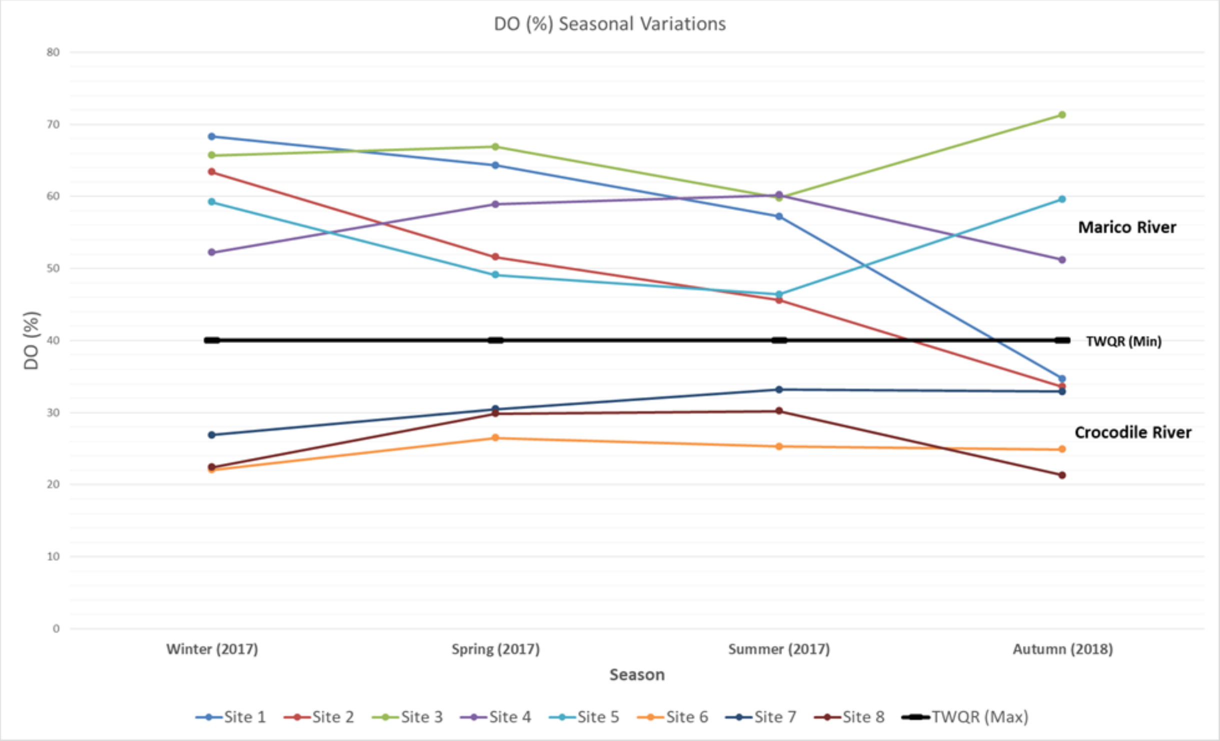

Figure 6: Seasonal variations in dissolved oxygen (%) readings recorded during the four surveys conducted. Key: S1, S2, S3, S4 = sampling sites within the Marico River System, S5, S6, S7, S8 = sampling sites within the Crocodile River System.

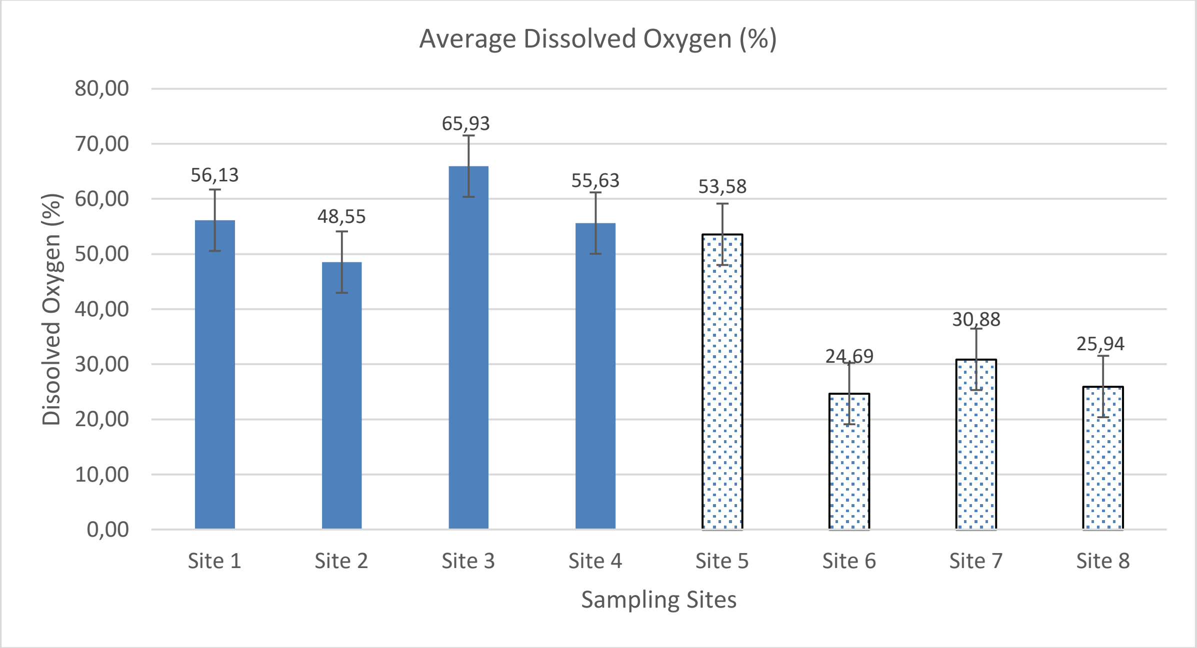

Figure 7: Average dissolved oxygen (%) readings recorded during the four surveys conducted. Key: S1, S2, S3, S4 = sampling sites within the Marico River System, S5, S6, S7, S8 = sampling sites within the Crocodile River System.

The average dissolved oxygen datasets (%) for Marico River and Crocodile River were ranked from highest to lowest. The sum of ranks for Marico River was 26.00 and the mean rank was 6.50. The sum of ranks for Crocodile River was 10.00 and the mean rank was 2.50. These mean ranks were then compared to each other (Table 13). The P = 0.021 which is less than 0.05 (5% confidence interval used), which indicates that there is a significant difference between the average dissolved oxygen (%) readings of the Marico and Crocodile Rivers (Table 13).

Table 13: Mann-Whitney U analysis site-specific of dissolved oxygen readings

Ranks

	River	N	Mean Rank	Sum of Ranks
DO	Marico River	4	6.50	26.00
	Crocodile River	4	2.50	10.00
	Total	8		

Test Statistics[a]	
Mann-Whitney U	.000
Wilcoxon W	10.000
Z	-2.309
Asymp. Sig. (2-tailed)	.021
Exact Sig. [2*(1-tailed Sig.)]	.029[b]

a. Grouping Variable: River

b. Not corrected for ties.

4.1.3 pH

Throughout the study alkaline conditions (pH 8.12 – 9.58) persisted in the Marico River (Table 8), with pH values recorded in site 1 (8.89) being higher than those detected at sites 2, 3, and 4, respectively. In contrast, the Crocodile River displayed both acidic and alkaline conditions with a wide range (pH 1.78 – 10.01) (

Table 9,Figure 9:) with the highest pH values per site (site 5, 6, 7, and 8) recorded during summer. Acidic conditions were noted in site 6, 7 and 8 of the Crocodile River during autumn and spring, with a significant difference of P = 0.004 in terms of the seasonal fluctuations in the pH per site (

Table 9) and also a significant difference (P = 0.016) in the seasonal pH readings (Table 14).

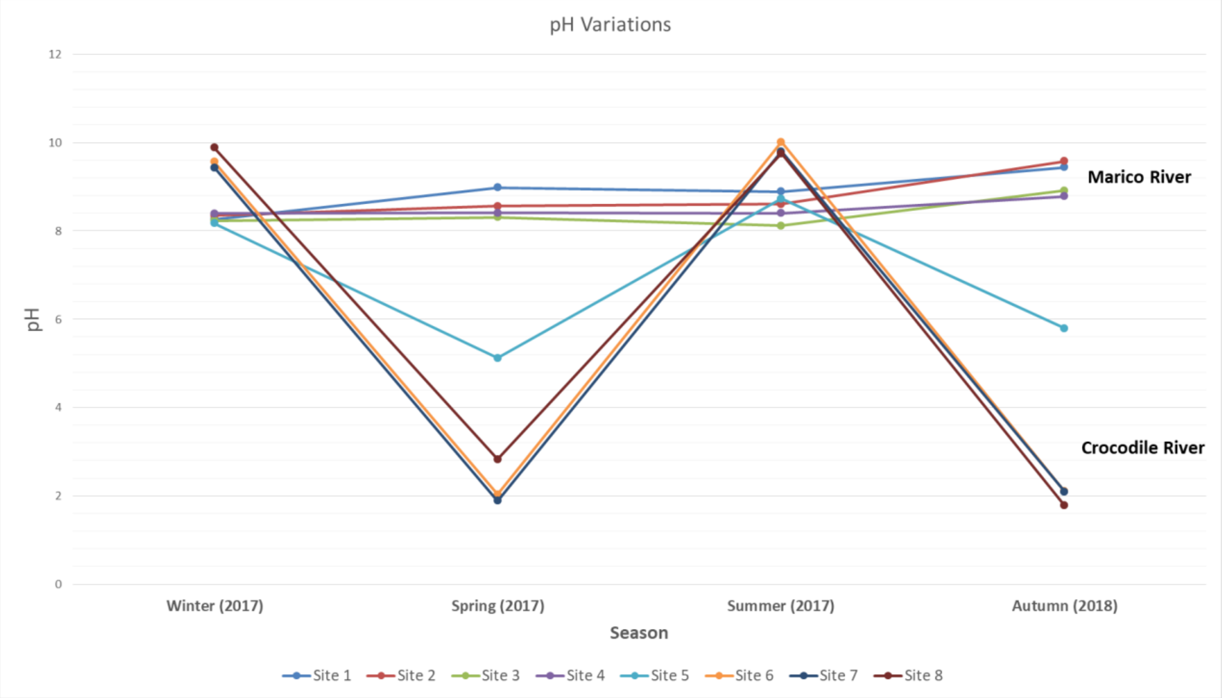

Figure 8: Seasonal variations in pH readings recorded during the four surveys conducted. Key: S1, S2, S3, S4 = sampling sites within the Marico River System, S5, S6, S7, S8 = sampling sites within the Crocodile River System.

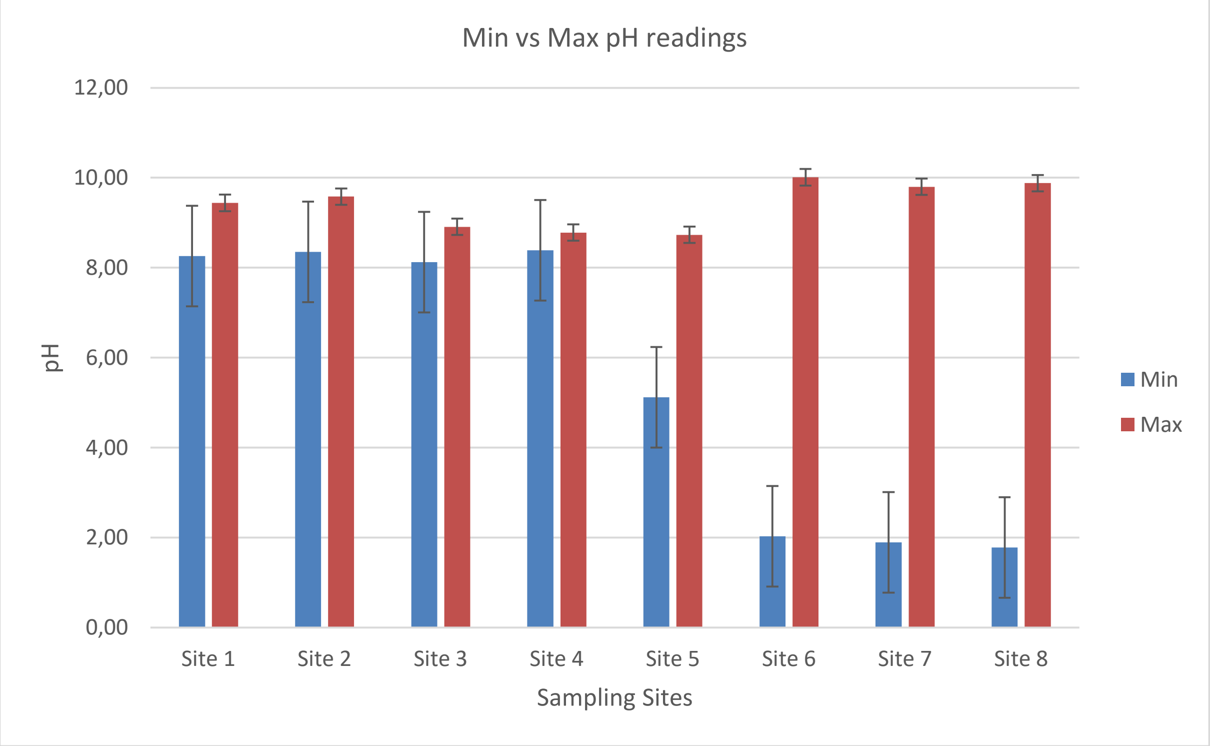

Figure 9: Minimum vs Maximum variations in pH readings recorded during the four surveys conducted. Key: S1, S2, S3, S4 = sampling sites within the Marico River System, S5, S6, S7, S8 = sampling sites within the Crocodile River System.

Table 14: ANOVA analysis of seasonal pH readings

pH

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	72.542	3	24.181	4.081	.016
Within Groups	165.892	28	5.925		
Total	238.434	31			

df - degrees of freedom

The average pH datasets for Marico River and Crocodile River, depicted in Figure 10, were ranked from highest to lowest. The sum of ranks for Marico River was 18.00 and the mean rank was 4.50. The sum of ranks for Crocodile River was 18.00 and the mean rank was 4.505. These mean ranks were then compared to each other (Table 15). The average pH readings between the two river systems did not differ much, hence there was a no significant difference (P = 1.00) between the overall pH values between the Marico River and Crocodile River (Table 15).

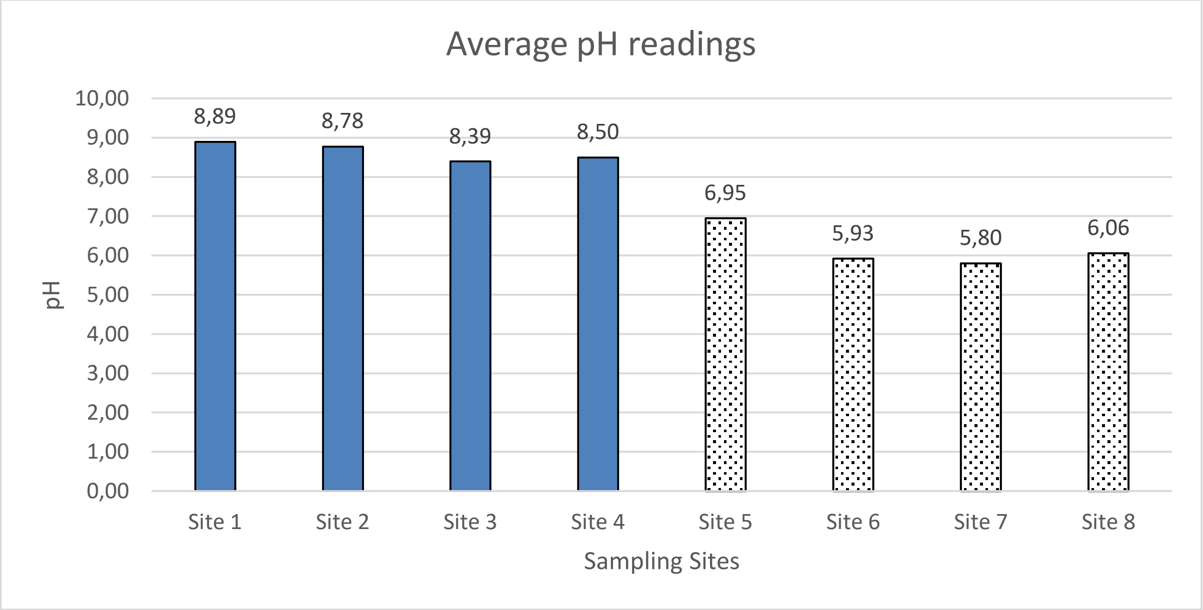

Figure 9: Average pH readings recorded during the four surveys conducted. Key: S1, S2, S3, S4 = sampling sites within the Marico River System, S5, S6, S7, S8 = sampling sites within the Crocodile River System.

Table 15: Mann-Whitney U analysis site-specific of pH readings

Ranks

	River	N	Mean Rank	Sum of Ranks
pH	Marico River	4	4.50	18.00
	Crocodile River	4	4.50	18.00
	Total	8		

Test Statistics[a]	
Mann-Whitney U	8.000
Wilcoxon W	18.000
Z	.000
Asymp. Sig. (2-tailed)	1.000
Exact Sig. [2*(1-tailed Sig.)]	1.000[b]

a. Grouping Variable: River

b. Not corrected for ties.

4.1.4 Total Dissolved Solids (TDS)

The mean TDS in the Crocodile River ranged from 0.229 to 0.485 mg/ℓ (Appendix 16) and from 0.126 to 0.191 mg/ℓ in the Marico River (Appendix 10). Higher average TDS values were recorded in the Crocodile River (sites 5, 6, 7, and 8) throughout all the seasonal surveys (Figure 11).

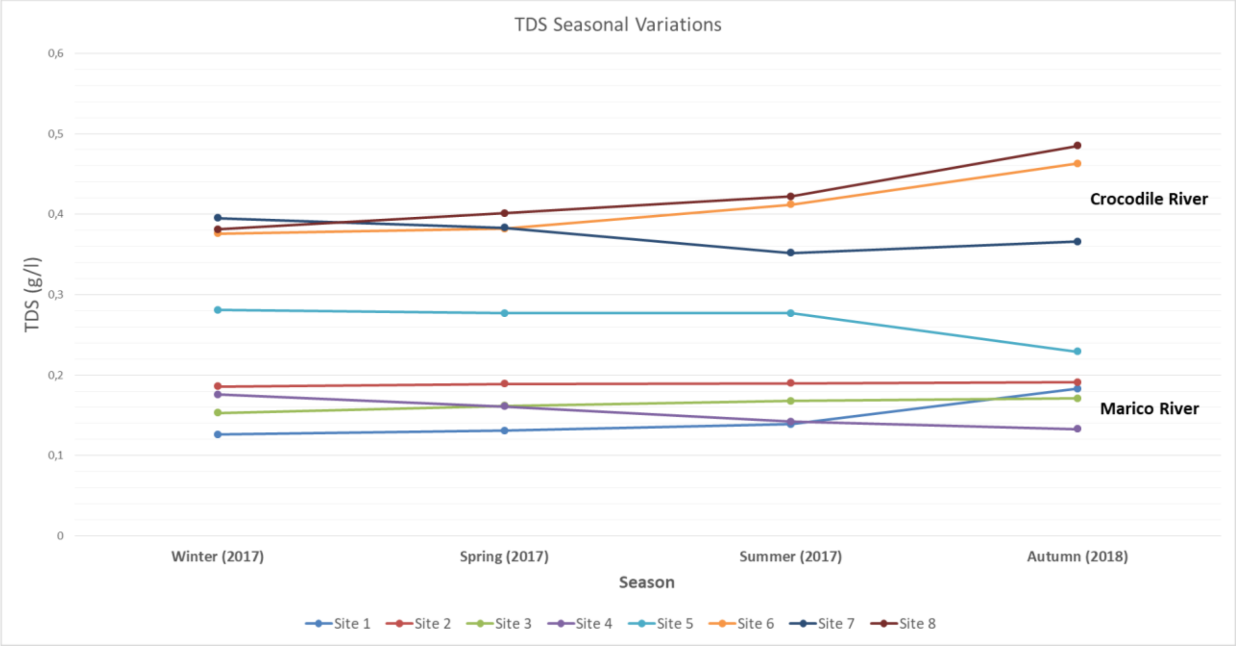

Figure 10: Seasonal variations in Total Dissolved Solids (TDS) readings recorded during the four surveys conducted. Key: S1, S2, S3, S4 = sampling sites within the Marico River System, S5, S6, S7, S8 = sampling sites within the Crocodile River System.

There was no significant difference in the TDS values of the site 1 to 4 (P = 1.00) of the Marico River (Table 8); and site 5 to 8 (P = 0.98) of the Crocodile River (Table 16). There was also no significant difference in the average TDS values with each river system (P = 0.990). However, the overall TDS values in the Crocodile River were higher in all the sampling sites (5 to 8) of the river than those in the Marico River (Figure 12).

Table 16: ANOVA analysis of seasonal TDS readings

TDS

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.002	3	.001	.039	.990
Within Groups	.416	28	.015		
Total	.418	31			

df - degrees of freedom

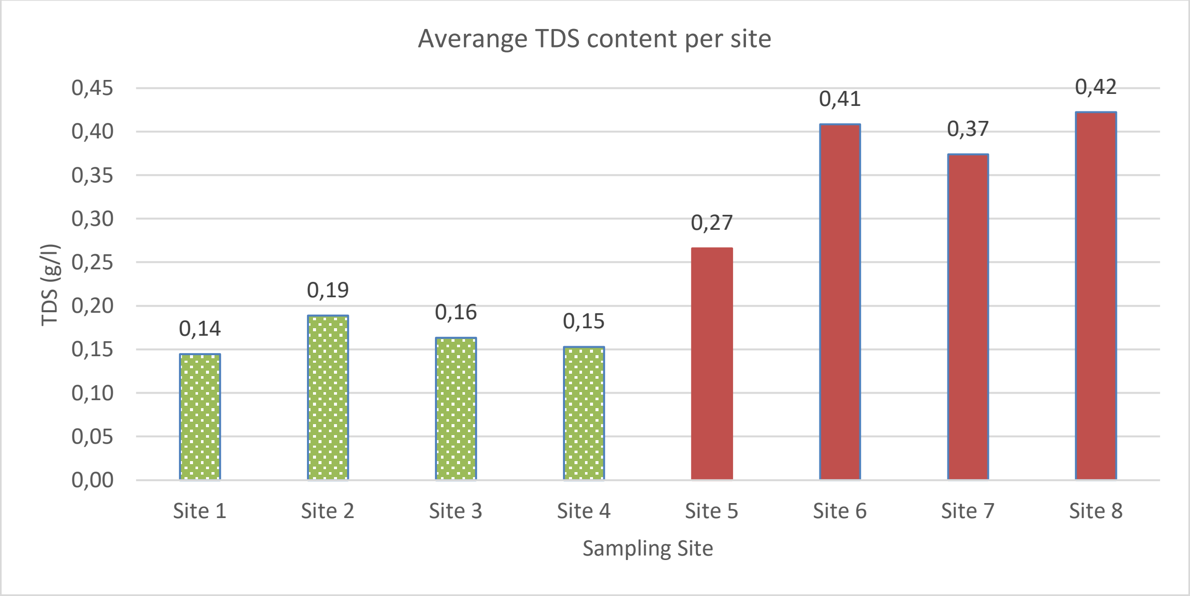

Figure 11: Average total dissolved solids (TDS) readings recorded during the four surveys conducted. Key: S1, S2, S3, S4 = sampling sites within the Marico River System, S5, S6, S7, S8 = sampling sites within the Crocodile River System.

The Total Dissolved Solids (TDS) datasets for Marico River and Crocodile River were ranked from highest to lowest. The sum of ranks for Marico River was 10.00 and the mean rank was 2.50. The sum of ranks for Crocodile River was 26.00 and the mean rank was 6.50. These mean ranks were then compared to each other. The P = 0.020 which is less than 0.05 (5% confidence interval used), this indicates that there is a significant difference between the TDS readings of the Marico and Crocodile Rivers (Table 17).

Table 17: Mann-Whitney U analysis site-specific of TDS readings

Ranks

	River	N	Mean Rank	Sum of Ranks
TDS	Marico River	4	2.50	10.00
	Crocodile River	4	6.50	26.00
	Total	8		

Test Statistics[a]	
Mann-Whitney U	.000
Wilcoxon W	10.000
Z	-2.323
Asymp. Sig. (2-tailed)	.020
Exact Sig. [2*(1-tailed Sig.)]	.029[b]

a. Grouping Variable: River

b. Not corrected for ties.

4.1.5 Electrical Conductivity (EC)

It was noted from the data that any change in the total dissolved solids (TDS) subsequently affects the electrical conductivity of the water (although not by the same factor). The electrical conductivity (EC) reported for Marico River ranged from 0.138 to 0.283 µS/cm (Appendix 10) and 0.265 to 0.629 µS/cm in the Crocodile River (Appendix 6). The seasonal EC values for sites 6, 7 and 8 in the Crocodile River were higher than those reported for site 5 (Figure 12). Overall, the Crocodile River had higher EC readings than the Marico River throughout all the seasons.

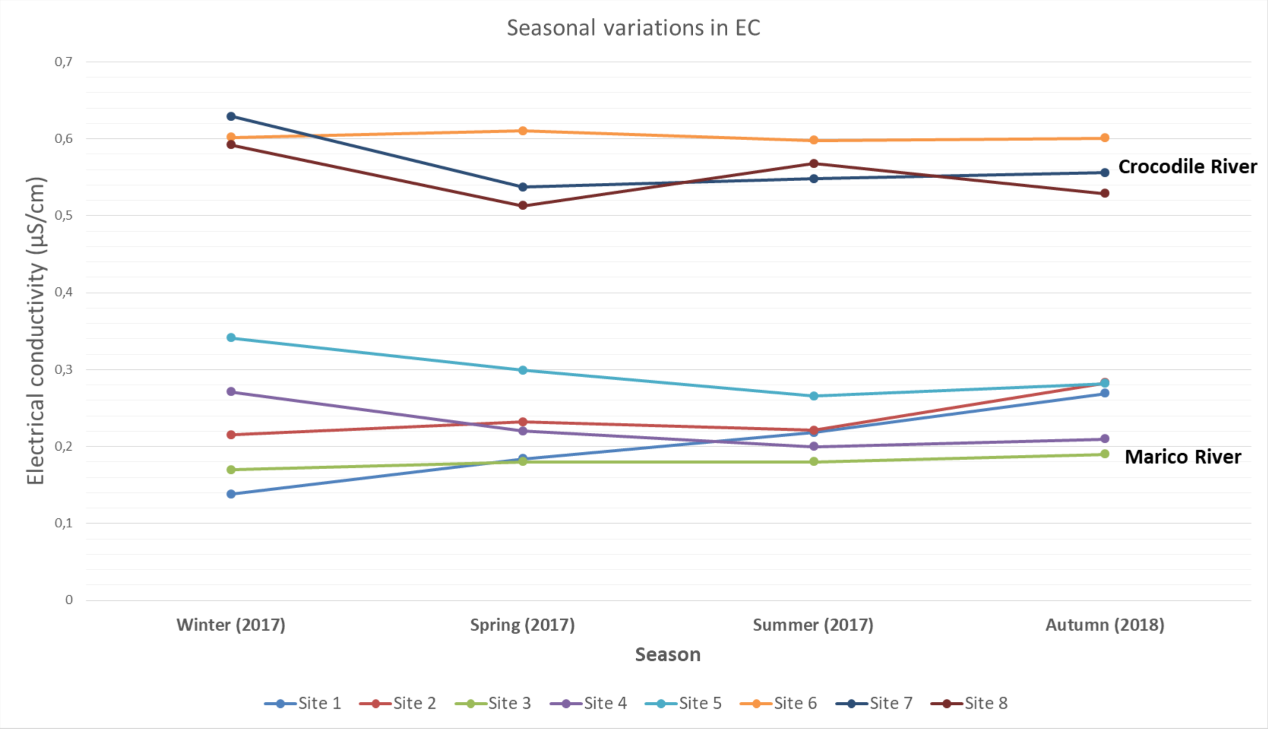

Figure 12: Seasonal variation electrical conductivity (EC) readings recorded during the four surveys conducted. Key: S1, S2, S3, S4 = sampling sites within the Marico River System, S5, S6, S7, S8 = sampling sites within the Crocodile River System.

There was no significant difference in the EC values within each river system (P>0.05) (Table 18). This is such that there is no significant difference between the average EC values between sites 1 to 4, and between sites 5 to 8. However, the pooled average EC values for the Crocodile River (site 5 to 8) were higher than the Marico River (sites 1 to 4) (Figure 14); much like those of the TDS. This was further substantiated by the Mann-Whitney U analysis, which indicated a significant difference between the average EC values between the two river systems (Table 19).

Table 18: ANOVA analysis of seasonal EC readings

TDS

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.002	3	.001	.049	.890
Within Groups	.416	26	.015		
Total	.418	31			

df - degrees of freedom

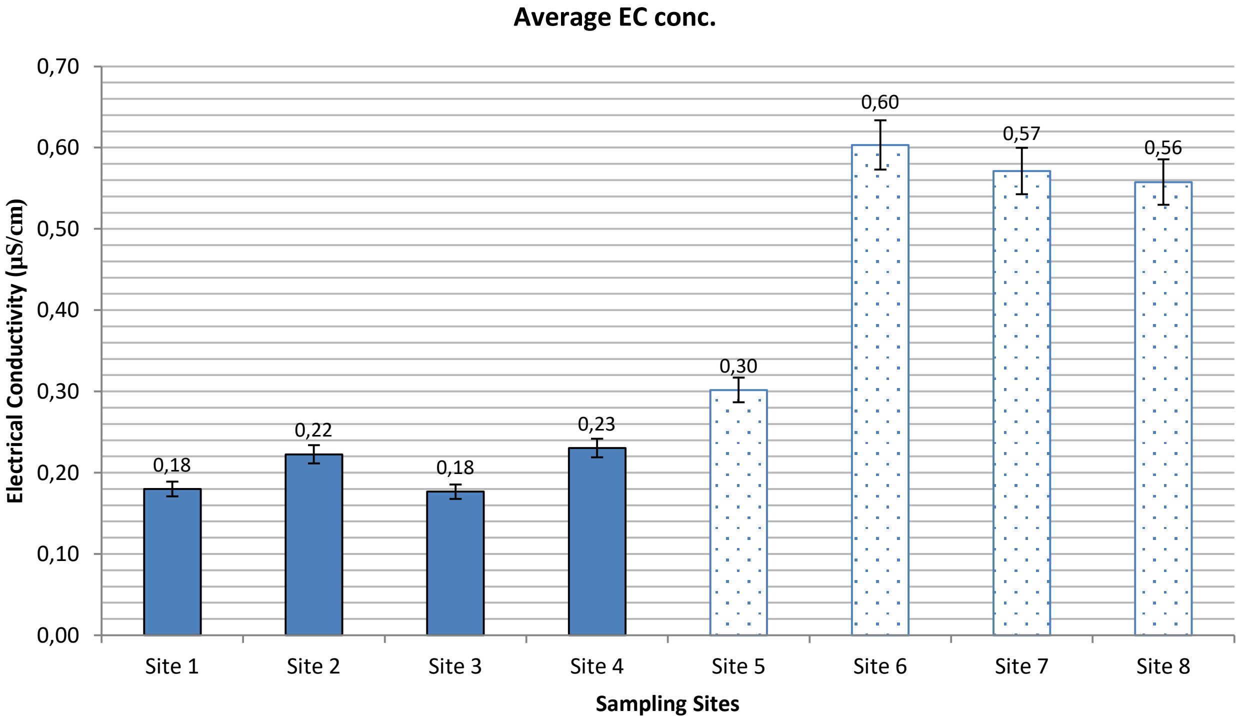

Figure 13: Average Electrical Conductivity (EC) readings recorded during the four surveys conducted. Key: S1, S2, S3, S4 = sampling sites within the Marico River System, S5, S6, S7, S8 = sampling sites within the Crocodile River System.

Table 19: Mann-Whitney U analysis site-specific of EC readings

Ranks

	River	N	Mean Rank	Sum of Ranks
EC	Marico River	4	2.50	10.00
	Crocodile River	4	6.50	26.00
	Total	8		

Test Statistics[a]	
Mann-Whitney U	.000
Wilcoxon W	10.000
Z	-2.323
Asymp. Sig. (2-tailed)	.030
Exact Sig. [2*(1-tailed Sig.)]	.039[b]

a. Grouping Variable: River

b. Not corrected for ties.

4.2 Mini-SASS results

Macroinvertebrate groups in this study were scored using the miniSASS score sheet. The presence or absence of these macroinvertebrates is depicted in Figures 15 to 23 in which each seasonal occurrence is colour-coded.

4.2.1 Marico River

a) Site 1

The ten macroinvertebrate groups that were found on all four surveys of sampling, and their corresponding sensitivity scores were Snails (4), True flies (2), Caddisflies (cased & uncased) (9); Bugs or beetles (5); Dragonflies (6), Damselflies (4), Other Mayflies (11); Minnow mayflies, Stoneflies (17); Crabs or shrimps (6), and worms (2). No leeches and flatworms were recorded; the True flies, Caddisflies, and Minnow mayflies were not recorded in autumn; whereas the snails were only recorded in the autumn survey (Figure 14). Worms where not recorded in winter, whereas Crabs / Shrimps where not recorded in summer.

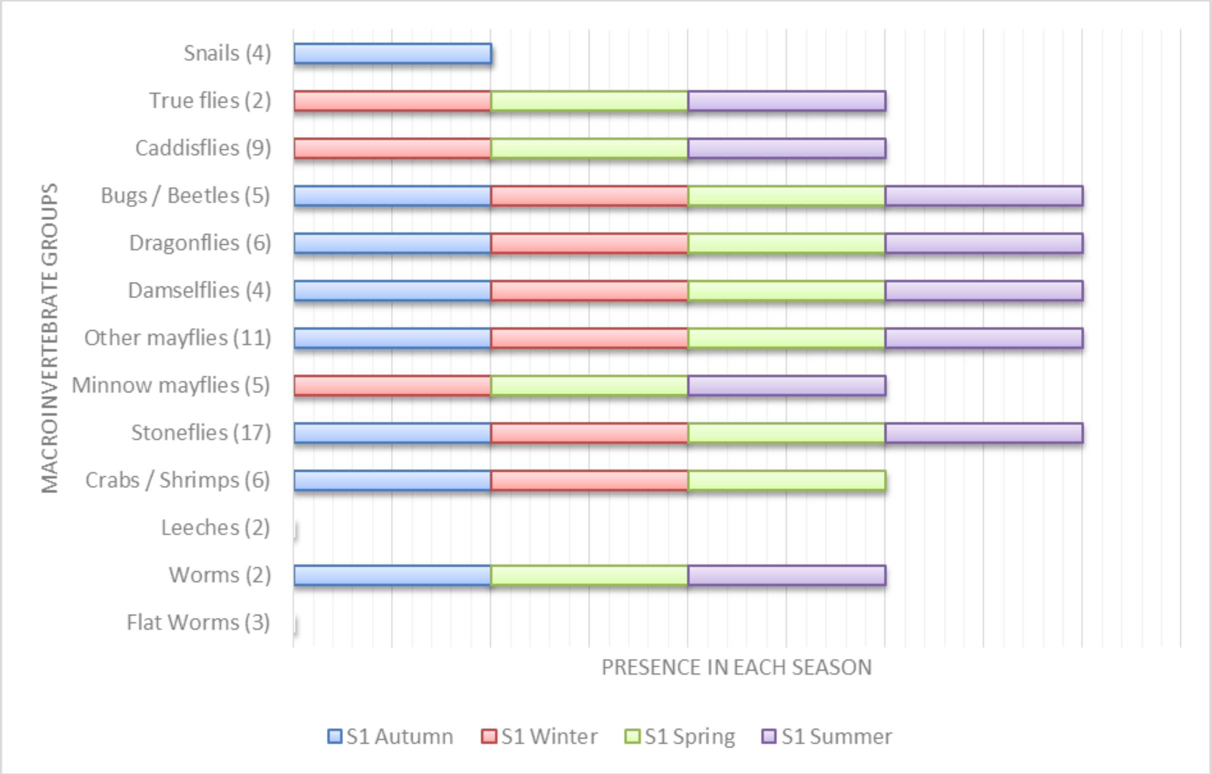

Figure 14: Graph of sensitivity scores for macroinvertebrate groups found at Site 1 for all four seasons.

b) Site 2

Twelve of the 13 macroinvertebrate groups were found in Site 2, with the exception of flatworms (3). No bugs / beetles (5) and minnow mayflies (5) were recorded in spring; whereas stoneflies (17) were not recorded during the spring survey, and leeches were only recorded during autumn and winter. No Dragonflies were recorded during the spring survey (Figure 15).

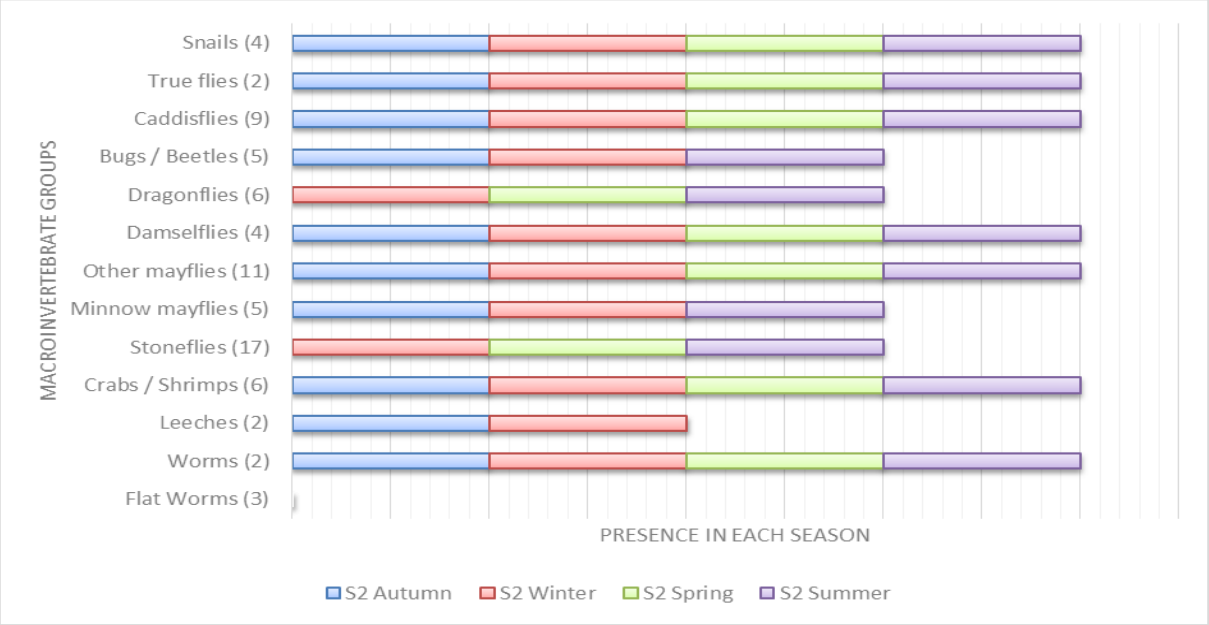

Figure 15: Graph of Sensitivity Scores for Macroinvertebrate Groups found at Site 2 for all four seasons.

c) Site 3

Only nine macroinvertebrate groups were recorded in Site 3, namely: snails (4), True flies (2), Caddisflies (9), bugs / beetles (5), Dragonflies (4), Damselflies (4), other mayflies (11), leeches (2), and worms (2). The True flies and worms were not found in autumn, whereas the damselflies were not found during the spring survey. The rest of the recorded groups occurred throughout the four seasonal surveys conducted (Figure 16).

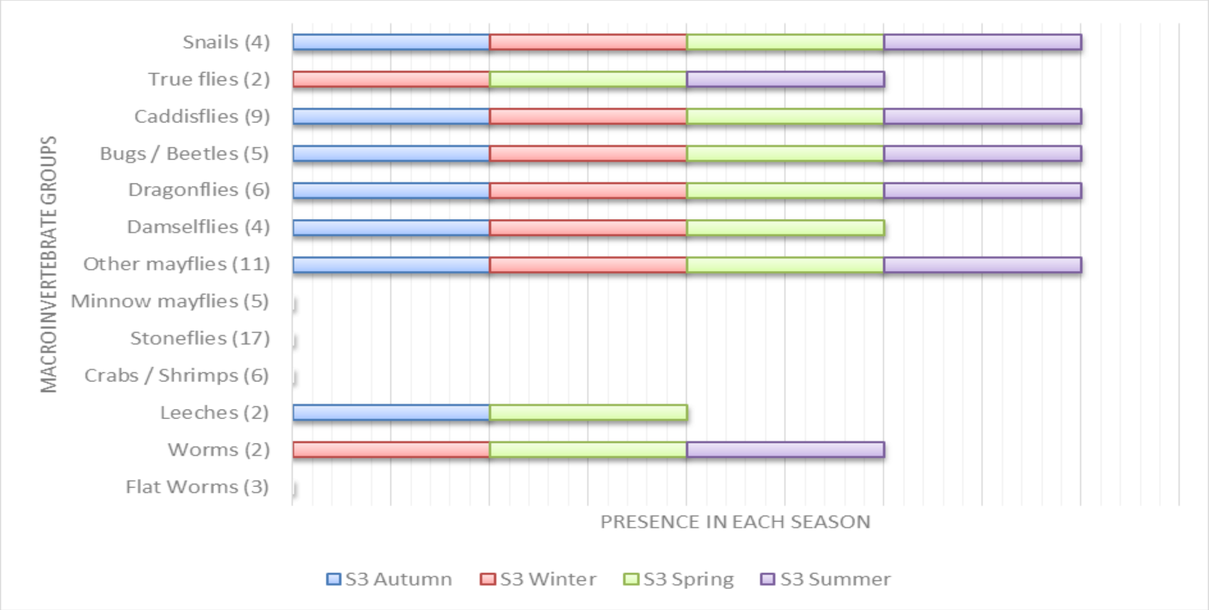

Figure 16: Graph of Sensitivity Scores for Macroinvertebrate Groups found at Site 3 for all four seasons.

d) Site 4

Twelve macroinvertebrate groups were found in Site 4, with the exception of flatworms (3) (Figure 18). The damselflies (2) were found during the winter and spring surveys; the bugs / beetles (5) were not found in the autumn survey; and the worms (2) were found in the winter and summer surveys. The rest of the macroinvertebrate groups were found in all the seasonal surveys. It was also that majority of the macroinvertebrate groups occurred all year round (Figure 17).

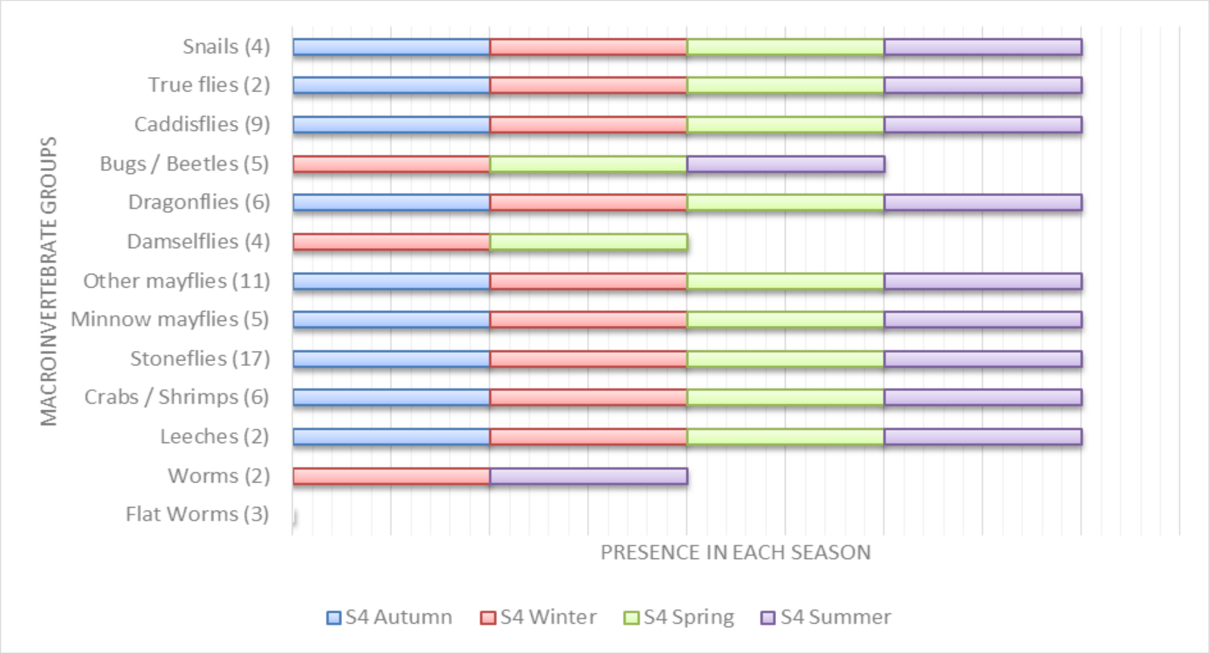

Figure 17: Graph of Sensitivity Scores for Macroinvertebrate Groups found at Site 4 for all four seasons.

4.2.2 Crocodile River

a) Site 5

Nine macro invertebrate groups where reported from Site 5 (Figure 19), predominantly during the spring and summer surveys. The Dragonflies (6) where only recorded during autumn. The leeches only occurred during autumn, winter and summer (Figure 18). Groups that were not recorded in site 5 throughout the study are snails (4) Caddisflies (9), Stone Flies, and Flatworms (2).

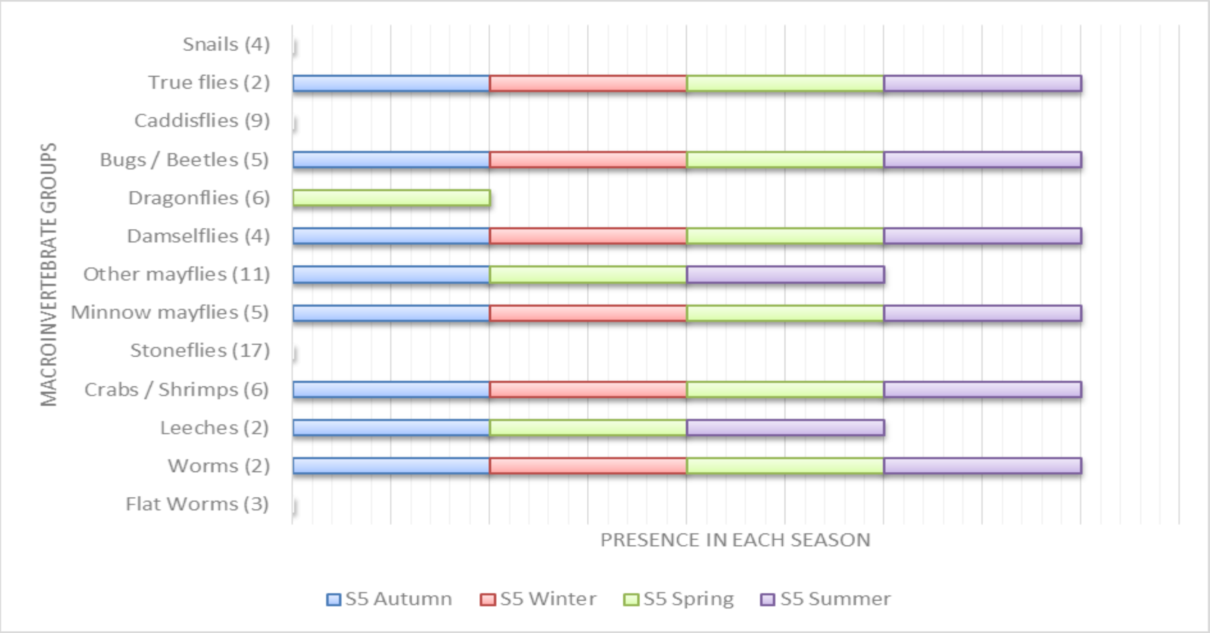

Figure 18: Graph of Sensitivity Scores for Macroinvertebrate Groups found at Site 5 for all four seasons.

b) Site 6

Seven macroinvertebrate groups where reported from site 6, all of which showed variation in terms of their occurrence. All six groups reported for site 6 have low sensitivity scores (Figure 19). Five of the seven reported groups occurred in all the seasons, namely: True Flies (2), Damselflies (4), Minnow mayflies (5), Leeches (2), and Worms (2).

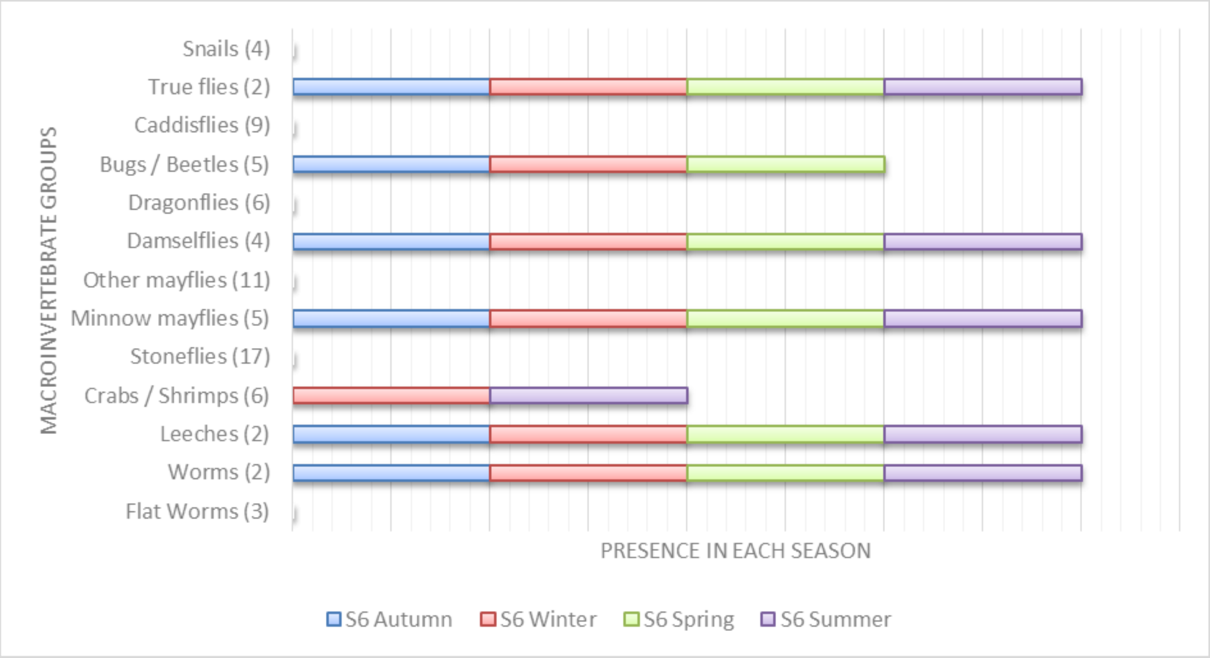

Figure 19: Graph of Sensitivity Scores for Macroinvertebrate Groups found at Site 6 for all four seasons.

c) Site 7

Six macroinvertebrate groups where reported for site 7, with bugs / beetles only reported only in winter. The leeches where reported during winter, spring and summer, whereas the True Flies, Damselflies, Minnow mayflies and Worms occurred throughout all the seasons (Figure 20).

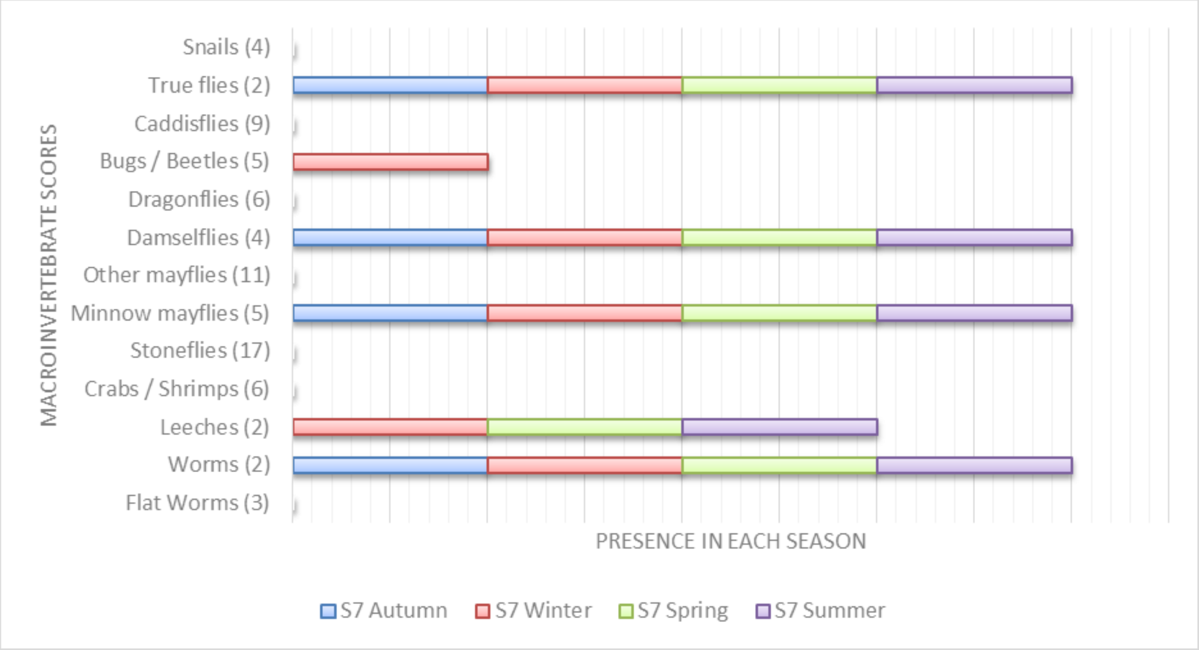

Figure 20: Graph of Sensitivity Scores for Macroinvertebrate Groups found at Site 7 for all four seasons.

d) Site 8

The only macroinvertebrate group found on all four surveys of sampling and its corresponding sensitivity score was that of worms (2) and Damselflies (4) (Figure 15). The other two macroinvertebrate groups, leeches (2) and snails (4) where only recorded during the autumn and winter surveys, whereas the crabs / shrimps (6) where only recorded in winter (Figure 21).

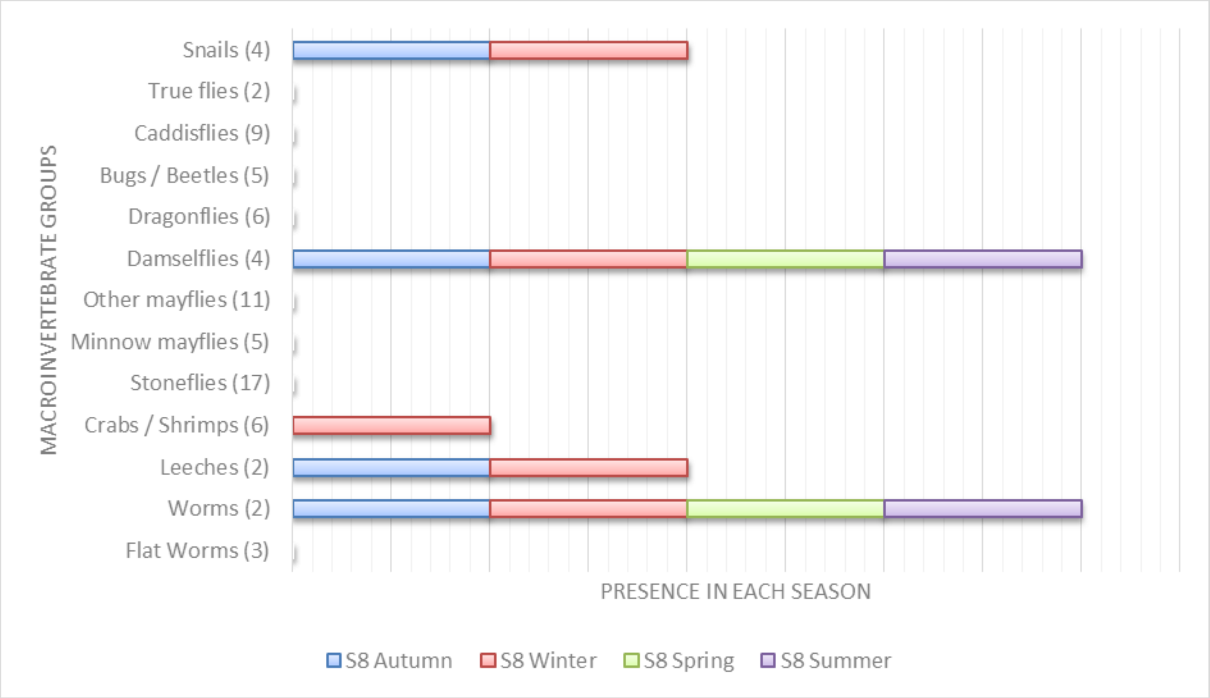

Figure 21: Graph of Sensitivity Scores for Macroinvertebrate Groups found at Site 8 for all four seasons.

4.3 Overall mini SASS scores

The overall macroinvertebrate sensitivity scores (pooled for all four surveys) ranged from 5.0 – 7.2 ± 4.49 in the Marico River; whereas the scores ranged from 0.5 – 3.3 ± 2.14 in the Crocodile River. Thus, the Crocodile River indicated very low and narrow mini-SASS score compared to the Marico River (Figure 23). The highest score (7.2) was reported during winter (2017) in the Marico River and the lowest score (0.5) recorded from the Crocodile River during spring and summer (2017). The sensitivity scores in the Marico River varied marginally, and thus indicated consistently good conditions throughout all seasons (Figure 22) when compared to the ecological categories outlined in Table 6. The sensitivity scores in the Crocodile River also varied marginally, but indicated consistently adverse conditions throughout all seasons.

The average sensitivity score was calculated by dividing the total score by the number of macroinvertebrate groups found in each sampling site. There was statistically no significant difference ($P>0.05$) between the seasonal scores, with the exception of Site 2 which displayed a significant variation ($P<0.05$) in the seasonal scores. There was no significant difference between the scores of the sites in the Marico River (Site 1, 2, 3, and 4); whereas in the Crocodile River, Site 5 produced significantly higher scores than Site 6, 7, and 8. The mini SASS scores for each river (Marico and Crocodile rivers) were pooled for comparison between the two rivers. The Marico River displayed significantly higher mini SASS scores ($P>0.05$) than those of the Crocodile River. These scores ranged from slightly impacted (4–6) to good quality stream (>6) in the Marico River, but ranged from impacted stream (2–4) to highly impacted stream (0–2) in the Crocodile River.

The average mini SASS scores for Marico River and Crocodile River were ranked from highest to lowest. The sum of ranks for Marico River was 26.00 and the mean rank was 6.50. The sum of ranks for Crocodile River was 10.00 and the mean rank was 2.50. These mean ranks were then compared to each other. The P = 0.021 which is less than 0.05 (5% confidence interval used), indicates that there is a significant difference between the average mini-SASS scores of the Marico and Crocodile Rivers (Table 20).

Table 20: Mann-Whitney U analysis site-specific of mini-SASS scores

Ranks

	River	N	Mean Rank	Sum of Ranks
miniSASS	Marico River	4	6.50	26.00
	Crocodile River	4	2.50	10.00
	Total	8		

Test Statistics[a]	
Mann-Whitney U	.000
Wilcoxon W	10.000
Z	-2.309
Asymp. Sig. (2-tailed)	.021
Exact Sig. [2*(1-tailed Sig.)]	.029[b]

a. Grouping Variable: River

b. Not corrected for ties.

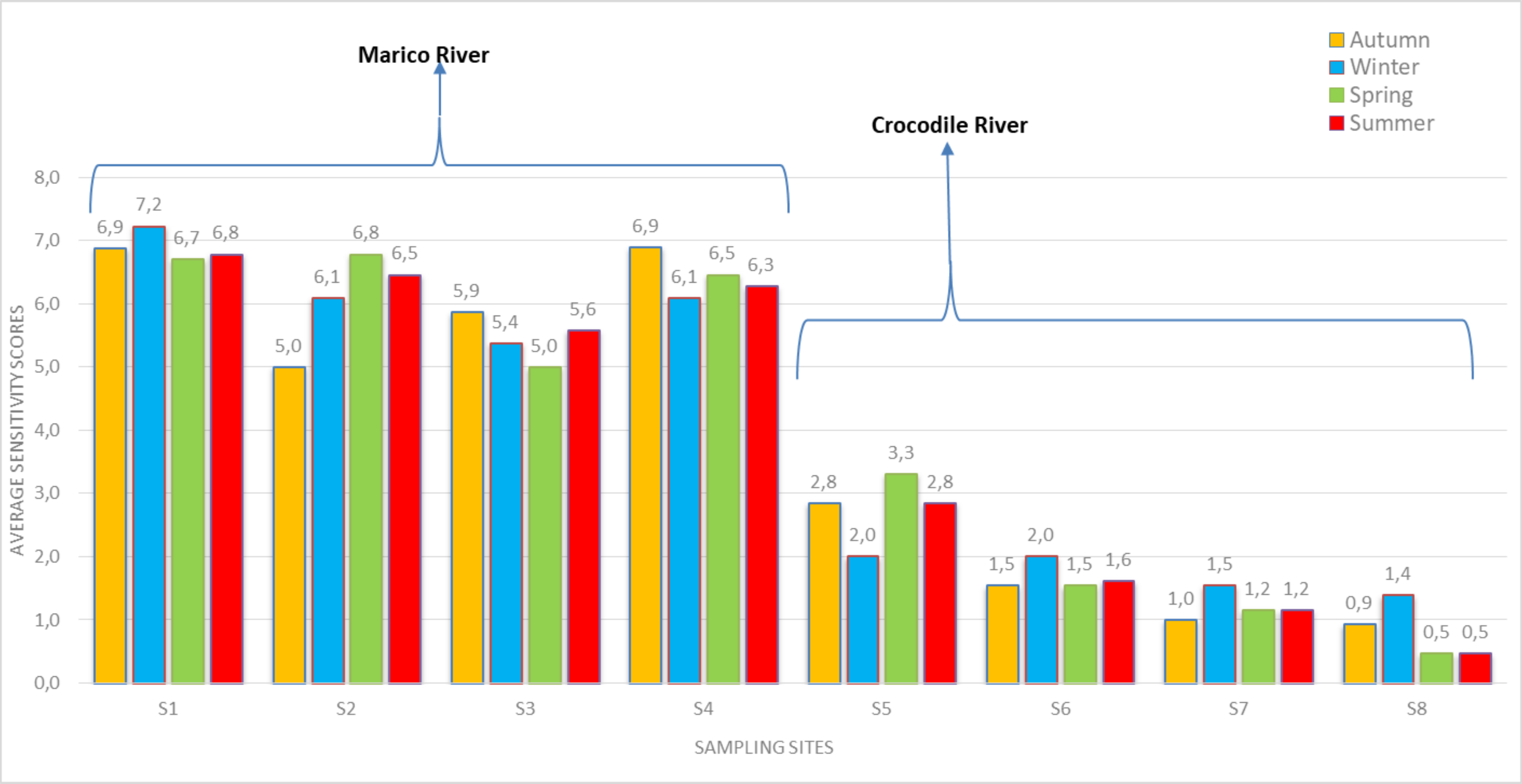

Figure 22: Site specific seasonal mini SASS scores in both the Marico and Crocodile rivers.

5. CHAPTER 5: DISCUSSIONS

5.1 Water quality

Aquatic ecosystems go through changes along with normal climatic fluctuation. These variations occur seasonally and in some systems over a period of 24 hours. The climatic fluctuations influence the physico-chemical parameters, which then influence the essential ecosystem processes (DWAF 1996e).

The significant difference ($P = 0.043$) between the average temperature readings of the Marico and Crocodile Rivers can the attributed to numerous factors such as the variations in water current at different sites of the rivers, higher ambient temperature as a result of lack of riparian cover, or the high content of total dissolved solids/salts (TDS) observed in the Crocodile River. Site 3 in the Marico River is subjected to high water current and thus the warmer surface water is continuously mixed, heated and cooled by prevailing atmospheric conditions when compared to the other four sites; hence the observed seasonal temperature fluctuations.. Minor temperature fluctuations in the Crocodile River were observed which may have an effect on the toxicity of ions such as cyanide ions ($CN^–$) (Davies & Day, 1998). The water temperature showed significant variations between the respective seasonal surveys. However, the most notable outcome from the surveys is the significant difference between the Marico River (Site 1, 2. 3 and 4) and the Crocodile River (Site 5, 6, 7 and 8). The temperature variations between the two rivers could be attributed to the difference in the overall elevation on the river sites, with the sampling sites in the Marico River generally higher than those on the Crocodile River. This difference in temperature may therefore be due to the chemical composition and/or physical attributes of the water column in each river. The elevated site-specific temperatures in the Crocodile River, as compared to those of the sites in the Marico River, physically meant that less oxygen can dissolve in the warmer water than in the cooler water. This also influences the rate at which chemical reactions in the water occur. The rates of biochemical reactions (such as those involved in photosynthesis) usually double for every 10°C rise in temperature (Davies & Day, 1998). This rise in temperature subsequently also affects the physiological reactions of aquatic macroinvertebrates. Temperature, linked to oxygen content is a signification limiting factor to macroinvertebrate compositions of river systems.

The variations in temperatures are corroborated by the difference in the percentages (%) and concentrations (mg/ℓ) of dissolved oxygen (DO). The seasonal % saturation for sites 6, 7 and 8 in the Crocodile River where well below the recommended lethal saturation values (Figure 4). The values denoted in Table 4 indicate that the TWQR for DO is 80–120% of saturation, were any values >60% saturation are considered sub-lethal and any values >40% saturation are lethal. Sites 1 and 2 in The Marico River where below the lethal % saturation during autumn, although these two sites showed % saturation above the lethal TWQR for the subsequent sampling surveys conducted in winter, spring and summer. This may be attributed to temporal variations in the flow rate during these surveys which may have had an effect on the % saturation of DO at the time of sampling. The other sites, including site 5 in the Crocodile River, where well above the % oxygen saturation considered lethal. However, the difference in the % saturation of DO was subjected to statistical analysis to determine if the variations observed in Figure 4 were statistically significant, with a confidence interval of 95% ($P<0.05$). It was determined that there was no significant difference between the average DO values between the seasons ($P = 0.873$) although there was a significant difference between the two rivers ($P = 0.021$).

Most freshwaters, in South Africa, are relatively well buffered and more or less neutral, with pH ranges between six and eight (DWAF 1996e). The pH of natural waters is determined by geological influences and biotic activities (Dallas & Day, 1999). The pH values in the Marico River (S1, S2, S3 and S4) were relatively constant with not significant difference in average pH values between sampling sites ($P = 0.05$). The highest recorded pH values where 9.58 and the lowest was 8.26; all of which were within the TWQR. There was a significant difference ($P = 0.004$) in the pH values between the sampling sites (S5, S6, S7 and S8) in the Crocodile River. This is such that the average pH values were 6.95, 5.93, 5.80, and 6.06 for sampling site S5, S4, S6 and S7, respectively. This was indicative of more acidic conditions occurring upstream of Site 6 compared for the relatively neutral conditions upstream of Site 5. In terms of seasonal variation, the pH values ranged between 1.78 and 10.1; with the highest values recorded in winter (9.88) and summer (10.01) and the lowest values recorded for autumn (1.78) and spring (1.89) which may be indicative of more pollutants being washed from the catchment area and higher flows associated with the rainfall season. These extreme fluctuations in pH create an unstable environment for the macroinvertebrates that inhabit those specific sampling sites. This variation may indicate anthropogenic activities upstream which ultimately subject both aquatic plants and animals to a stressed environment. It should be note that site 5 in the Crocodile catchment is located in a stream that has no recorded anthropogenic activities upstream, whereas sites 6, 7, and 8 in the Crocodile River are downstream from mining and agricultural activities (Figure 8:). This may result in the observed low pH levels as a result of human-induced acidification. These impacts being compounded by draining from agricultural lands and mines into the Crocodile River during the rainy season. This disturbs the buffering effect of neutral waters and results in the fluctuating acidity and alkalinity depicted in sites 6, 7, and 8; with site 5 experiencing fewer fluctuations due to it not being subjected to the same level of detrimental impacts.

There are significant differences (P = 0.020) in the levels of total dissolved solids (TDS) between the two rivers, with the Crocodile River having extremely high content of TDS (2.27–4.85 g/ℓ) compared to the Marico River (0.14–0.15 g/ℓ). The relatively high TDS content of the Crocodile River can be attributed to anthropogenic activities upstream; thus subsequently washing debris from the upper catchment (RHP, 2005). This results in the water becoming murky and retaining excessive heat as indicated (Dallas & Day, 1999). The TDS is indicative of the amount of material dissolved in the water, and may also be measured as conductivity (EC) or as salinity. However, TDS represents the total quantity of dissolved material, organic and inorganic, ionised and un-ionised in a sample of water. It is often naturally determined by the geomorphology of the region, and is related to the conductivity as shown by Figure 11: and Figure 12. Very little is known about the effects of increased TDS on freshwater organisms (Davies & Day, 1998). However, anthropogenic activities do have a direct effect on the concentration of TDS by way of soil erosion, chemical loading from pollution and organic loading from waste discharge upstream, with most of the particulate matter dissolving in the river water and flowing downstream (Davies & Day, 1998).

In contrast, sites 1, 2, 3, and 4 in the Marico River had low levels of TDS in comparison with the Crocodile River. This was also evident in the water clarity and the low EC readings at the sampling sites on the Marico River. This is such that there was no statistical significance in the TDS values between / within the sampling sites between the Marico and Crocodile rivers; and among the seasons in each river system.

5.2 Aquatic macroinvertebrates (mini-SASS)

Regional variations in climatic conditions and water quality parameters are not limited to the abiotic environment. Aquatic macroinvertebrates are also adopted to living in water containing a particular suite of chemical and physical characteristics. Thus altered water quality has a significant effect on the presence and distribution of aquatic biodiversity (Dallas & Day, 1999).

The macroinvertebrate groups that were found in the Marico River, and their corresponding sensitivity scores were Snails (4), True flies (2), Caddisflies (cased & uncased) (9); Bugs or beetles (5); Dragonflies (6), Damselflies (4), Other Mayflies (11); Minnow mayflies (5), Stoneflies (17); Crabs or shrimps (6), worms (2), and leeches (2). The only macroinvertebrate group that was not recorded from the Marico River is the Flatworms (3). Presence of macroinvertebrates such as caddisflies, dragonflies, mayflies, and stoneflies is an indicator of good water quality and habitat integrity. This is because these groups have a low tolerance to pollution (Dickens & Graham, 2001). Of the four sampling sites in the Marico River, site 3 had less abundance of macroinvertebrate groups that the other three sites. Site 3 is located downstream from the Marico Bushveld Dam which may cause alterations in the natural hydrology of the stretch of river at site 3. This, in turn, affects the quality and quantity of habitat available for macroinvertebrates such as mayflies which require submerged substrates (Wang & McCafferty, 1996; Dickens & Graham, 2002).

True flies were found on all four surveys. These true flies are considered resistant to environmental stress (Wenn, 2008), with a sensitivity score of (2). Their presence does not necessarily indicate very good water quality.

The macroinvertebrate groups that were found in the Crocodile River, and their corresponding sensitivity scores were Snails (4), True flies (2), Bugs or beetles (5); Dragonflies (6), Damselflies (4), Other Mayflies (11); Minnow mayflies (5), Crabs or shrimps (6), worms (2), and leeches (2). No Snails (4), Stoneflies (17), and Flatworms (3) where found in any of the sampling sites (5 to 8). Both snails and flatworms are relatively resistant to pollution and adverse aquatic conditions. However, the absence of stoneflies in all four surveys conducted should be of concern since they are common in unpolluted rivers. Stoneflies are classified as having extremely low tolerance to pollution (Dickens & Graham, 2002). Therefore, their absence is a strong indication of poor water quality, and very low habitat integrity in a river system. The difference in macroinvertebrate composition between the Marico and Crocodile rivers is further corroborated by the variation in the average mini-SASS scores of not just the individual sampling sites but also between the two river systems. The average scores for the Marico River ranged from 5.0 to 7.2, which indicative of good water quality; whereas the average scores for the Crocodile River ranges from 0.5 to 3.3, which is indicative of poor water quality.

There were no clear seasonal trends evident in the mini-SASS scores within both the Marico and Crocodile rivers. However, the mini-SASS scores were higher at site 1 and 4 of the Marico River when compared to the other sampling sites 2 and 3. This may be attributed to the locations of both site 1 and 4, being situated upstream from the Marico Town whose anthropogenic activities such as sewage discharge may pose detrimental effects on both site 2 and 3 (see Figure 2). The same can be said for the sampling sites in the Crocodile River, whereby both site 8 and 7 are located downstream from the mining activities occurring in the Thabazimbi Iron Ore Mine. The average mini-SASS scores for site 7 and 8 ranged from 1.0 to 1.5 and from 0.5 to 1.4, respectively. According to a report by Anglo-American (2015), the low flow conditions in the Crocodile River are usually prevalent during the drier months, and could be linked to a change in water quality resulting from a smaller dilution factor for the effluents between site 6 and site 7. The average mini-SASS scores for site 5 and 6 ranged from 2.0 to 3.3 and from 1.5 to 2.0, respectively. These relatively low scores may be attributed to the release of less water from impoundments upstream of site 5 during the drier months. This affects the availability of suitable submerged habitats for aquatic macroinvertebrates.

In general, the habitat integrity of the lower Crocodile River is poor due to extensive irrigation and multiple abstractions having a severe impact on river functioning (Kemp et *al.*, 2016). This is because the rate of flow in the mainstream is regulated through a series of weirs and dams resulting in unseasonal releases (to maintain irrigation) which leads to undercutting of river banks and increased sedimentation (Kemp et *al.*, 2016). Subsequently, the abundance, diversity and distribution of macroinvertebrate communities is poor due to reduced water quality and diminished flows leading to dry sections and isolated pools (Kemp et *al.*, 2016).

5.3 General

The physico-chemical water quality parameters proved effective in differentiating the seasonal temporal conditions of both the Marico and Crocodile rivers. The Marico River's aquatic habitats are generally in good condition, but are slowly becoming affected by agricultural return flows and the abstraction of water from the main stream. This is further compounded on by numerous farm dams, weirs and some development upstream of the Marico-Bosveld Dam. The river can be classified as 'FAIR" in terms of macroinvertebrate integrity primarily due to localised poor water quality and impacting changes in aquatic habitat. The Crocodile River is classified as of "POOR" ecological status. Both the overall mini-SASS scores and the physico-chemical water quality parameters indicated similar patterns within each sampling site for both river systems. These patterns indicate how the presence of anthropogenic activities may harm the ecological state of a river if left without any form monitoring and associated management intervention.

Given that irrigated and dryland agriculture, urban and mining dominate catchment land uses, the DO and temperature levels recorded in this study indicate that the Crocodile river are under severe stress and may potentially be on the verge of collapse. This creates inhospitable conditions under which most macroinvertebrate groups, except the most hardy, have difficulty to survive. This was evident in the overall mini-SASS scores indicated in this study whereby the Crocodile River can be classified as very poor condition (critically modified – purple) with scores of <4.8 and <5.3 for sandy and rocky aquatic habitats, respectively. This subsequently extends to the higher food chain organisms such as fish. The physico-chemical characteristics of both the Crocodile and Marico rivers should continuously be monitored to prevent eutrophication in the river. These need to be addressed by the water regulatory bodies, more especially the Department of Water and Sanitation (DWS) and the continuous publication of relevant research by the Water Research Commission (WRC) to inform DWS policies for water resource management.

6. CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

Almost 71% of the major river systems in South Africa are considered to be either endangered or critically endangered. This is due to the increasing exploitation of not just the river systems, but also the terrestrial biomass in the catchments of these river systems (Nel *et al*., 2004). The exponentially growing industrialisation and urbanisation upstream of the Crocodile Rice has placed it under threat from the detrimental effects of pollution due to the extensive agricultural activities, the sporadic release of water from impoundments such as the Hartbeespoort Dam, and large mining developments north of the Magaliesberg (Wittmann, 1975; Taylor *et al*., 2007; De Klerk *et al*., 2012; DWA, 2012). These stressors, to which aquatic ecosystems and biotopes are subjected, have a significant effect on the diversity, abundance and distribution of biota. In contrast, the general state of the Marico River has been considered to be ‘natural’ to ‘good’, free of significant organic pollution, with a pronounced biodiversity and overall good water quality (RHP, 2005).Thus there is a need for continuous monitoring of not just this river system but also other river systems in South Africa through the River Ecostatus Monitoring Programme (REMP), previously known as the River Health Programme. This also required comparing the highly impacted Crocodile River with a relatively pristine river system such as the Marico River.

6.1 Conclusion

Reliable indicators of water quality and river health are often difficult and expensive to derive (Graham, 2012). The mini-SASS tool was developed as a low technology, scientifically reliable and robust technique to monitor water quality in rivers and streams. This was based on the tried and tested SASS (South African Scoring System) technique; and involved reducing the taxonomic complexity of SASS to a few aquatic invertebrate groupings which would act as surrogates for the complete suite of SASS taxa. However, there are limitations identified with the mini-SASS biomonitoring tool such as its accuracy in identifying specific types and extent of water pollution. The tool itself is, however, intended an early warning tool that is available for use by the general public. As such, this study set out to test its accuracy by comparing the SASS results with the *in situ* water quality parameters.

The study tested the following Hypotheses:

H0: There is no difference in selected in situ water quality parameters between the Groot Marico and Crocodile Rivers and associated mini-SASS results.

Ha: Due to different catchment impacts, there is a difference in the selected in situ water quality of the Groot Marico and Crocodile Rivers and this is reflected in the mini-SASS data.

The alternative hypothesis is supported as the in situ water quality data and mini-SASS data did indicate a difference between the Groot Marico and Crocodile Rivers.

Results obtained from both short-term (in current study) and long-term (obtained from literature) monitoring data indicated that water quality in the Crocodile River is increasingly becoming poor and approaching a tipping point. This has resulted in authorities fearing that the river may be the point at which no amount of anthropogenic interventions may restore the river to its natural state. The mini SASS scores distinctly indicated the variation between the Crocodile River and the Marico River in terms on the average scores allocated per river, and per sampling site. Thus, it is apparent that the Marico River is generally in a good state, from an ecosystem health perspective, whereas the effects of environmental degradation and pollution in the Crocodile River are starting to manifest themselves in the form of the lack of diversity in aquatic macroinvertebrates, as reflected in lower mini-SASS scores and associated sensitive taxa. These macroinvertebrates are good indicators of the long-term conditions of an aquatic ecosystem compared to the water quality which is indicative of the temporal but prevailing conditions at the time of sampling.

Overall, the current water quality parameters evaluated in the Marico River in this study meet the Target Water Quality Ranges (TWQR) set by The Department of Water and Sanitation (DWS) for aquatic ecosystem health. Although the Marico River is relatively in good condition, the results in this study indicate that there are certain areas of the river system which are slightly impacted. This is because water quality of two of its major tributaries, namely, the Klein Marico River and the Sterkstroom, is defined as ‘FAIR’ to ‘POOR’ (Dallas, 2007). Thus, care and focus must be given to the anthropogenic activities in the larger Marico catchment in the future. The Crocodile River is highly impacted as indicated by both the water quality results and the diversity and abundance of aquatic macroinvertebrates indicated in this study.

6.2 Recommendations

Although the mini SASS approach is a good, simple and inexpensive form of evaluating water quality, it does not explain certain aspects which may influence the presence or absence of certain macroinvertebrate groups. Thus *in situ* reading of certain water quality parameters is also recommended to be done in parallel to the mini SASS protocol to give an accurate long-term and short-term holisitic overview of the conditions of a river system. This study indicated that Crocodile River has lower mini-SASS scores in comparison to Marico River and this is also reflected in the observed water quality parameters. The mini-SASS biomonitoring tool does fill the gap wherein there is a practical need for water quality monitors that are accessible to non-specialists. This, however, may require establishing it as a key tool for monitoring aquatic ecosystems through citizen science.

Given that irrigated and dryland agriculture dominate catchment land uses, the mining activities that may supposedly continue unregulated, the dilapidated state of waste water treatment facilities in the Crocodile River catchment; it is recommended that legislative actions be taken to ensure compliance with environmental legislations by these industrial and domestic sources of effluents and pollutants. This is because the effects of these anthropogenic activities accumulates as the water flows downstream, with increased levels of eutrophication experienced in the major reservoirs along this river system. As such, it is vital to continuously monitor river systems through integrated water resource management plans and their implementation. More funding should be allocated to ensure the capacitation of government departments in terms of infrastructure and human resources to ensure compliance of facilities such as waste water treatment plants; and enforcement where needed for non-complaint mines and factories.

6.3 Scientific contributions

The findings of this study are particularly relevant to the on-going River Ecological status Monitoring Programme (previously River Health Programme) within the North West Department of Rural, Environment, and Agricultural Development to better understand and investigate the current state of the river systems in the North West Province; and also establish where resources could be better allocated to combat water pollution in an inherently arid province. This application and use of mini-SASS will also stimulate use of this tool by schools, NGO’s and conservation organisations to monitor rivers, as part of the civil science initiatives being driven by WRC.

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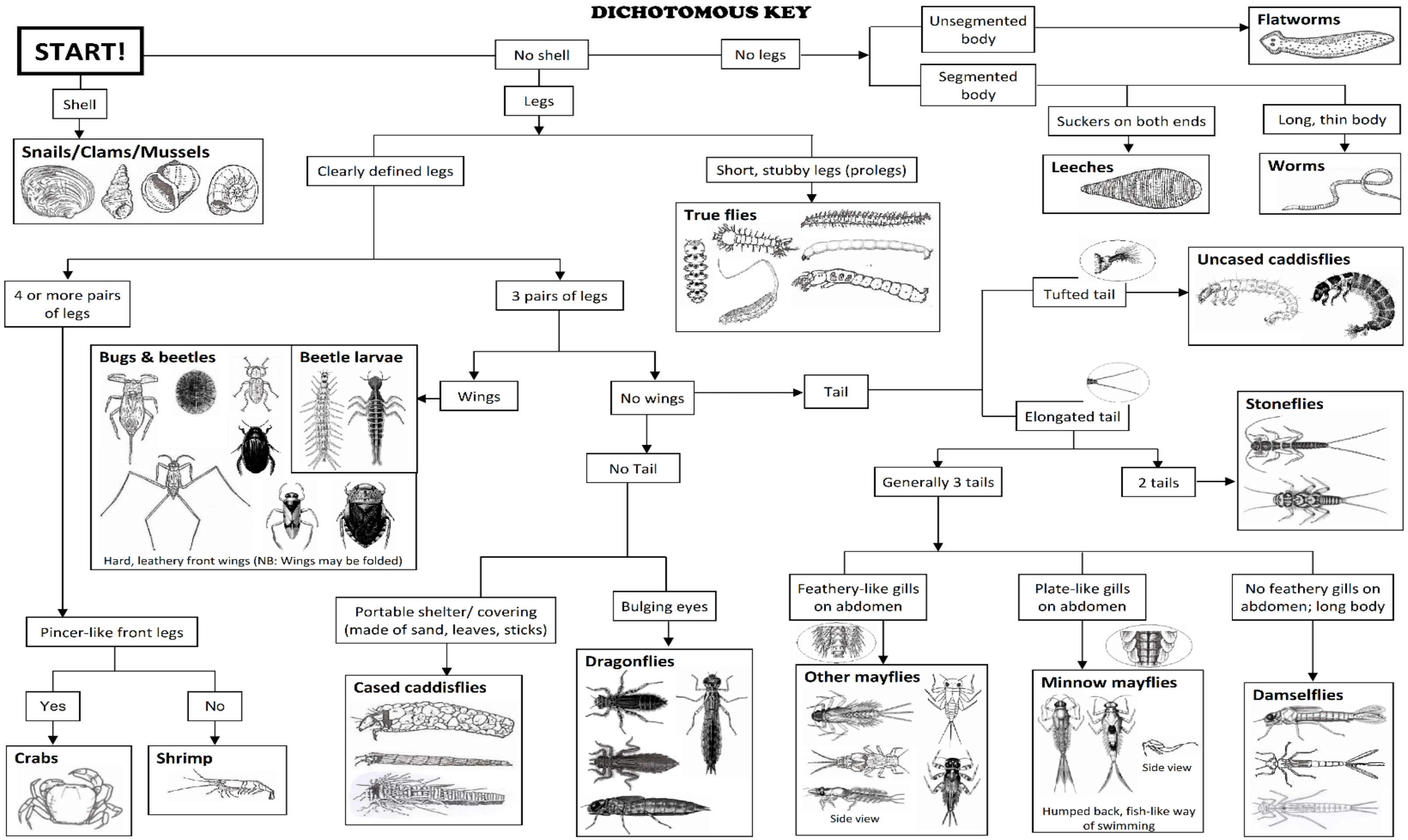
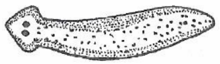
8. APPENDICES

Appendix 1. Mini-SASS dichotomous key (Graham *et al*., 2003).



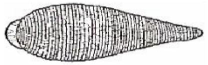
Appendix 2. Microinvertebrate groups (Graham *et al*., 2003).

Flat worms



Flat worms are characterised by their flattened shape and soft bodied, worm-like form. They have an arrow-shaped head with two dorsal eyespots and are generally mottled or dark grey in colour. Flatworms move with a gliding action and are generally scavengers or carnivores.

Leeches

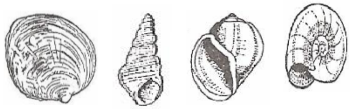


Leeches are segmented organisms that have very flexible bodies. When moving they expand to become long and thin, and then contract to become short and stubby. They have suckers on both ends of the body used for feeding and locomotion. Leeches are variable in colour, from grey, to red-brown and black. They swim with a fast, snaking movement and are found under stones, vegetation and debris.

Worms

Worms are long and segmented, with a cylindrical shape much like small earthworms. Their colouring is usually pink to brown. They are usually seen writhing around in debris, digesting the substrate they fed on.

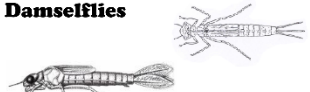
Snails / Clams / Mussels



Snails are molluscs with hard shells that vary in size, shape and colour. Habitats vary, with some snails, such as limpets, clinging to rocks, whereas clams and mussels are found in sand. The more common snails move over stones and vegetation. Some snails are host to bilharzia, a serious health hazard for humans.

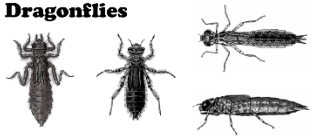
Images not to scale

Damselflies



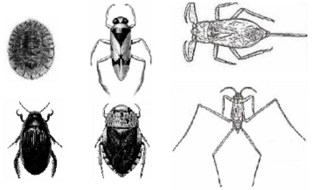
Damselflies have elongated bodies generally with three broad tails/gills on the tip of the abdomen. Damselflies are carnivorous and have a 'mask' over the lower part of the face, which hinges out to reveal a pair of pincers used to catch their prey. They are often found in vegetation growing on the edges of rivers.

Dragonflies



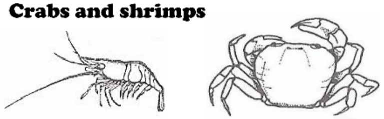
Dragonflies are robust creatures that are stout and have a large head and protruding eyes. Some have short legs whilst others have long legs. They do not have tails, but swim using 'jet propulsion' by forcefully ejecting water from the abdomen. Dragonfly nymphs are usually the largest organisms found in a sample and are the most powerful invertebrate predators in the water.

Bugs and Beetles



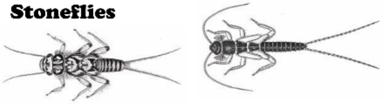
Bugs can be defined as having a piercing and sucking beak for mouthparts, and two pairs of membranous wings. Beetles on the other hand have 'jaws' and outer wings that are hardened to protect the inner wings. Some bugs and beetles are well adapted to swimming, such as water boatmen, backswimmers, pond skaters and water striders. Most bugs and beetles are carnivorous, but some feed on algae.

Crabs and shrimps



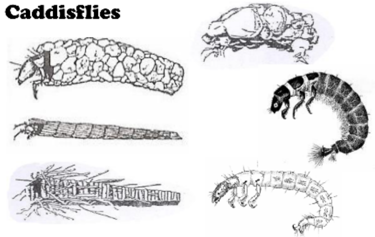
Crabs and shrimp form part of the order Decopoda (ten legs) and have bodies and legs hardened to form a tough shell. They have four or five pairs of legs. Their eyes that are carried on stalks and are movable. Crabs are scavengers that feed mainly on leaf litter but will feed on animals when given the chance. Shrimps are mostly scavengers or deposit feeders.

Stoneflies



The nymphs of adult stoneflies usually have two long tails and three pairs of legs, each having two claws at the tip. A characteristic feature of stonefly nymphs are the tufts of gills on the side of the body as well as gills between the two tails. Wing pads on the thorax are often dark and obvious. Some species run across the substrate very efficiently and are potent invertebrate predators. Other species are smaller and feed on plant material. Most live in well-oxygenated, clean water.

Caddisflies



The aquatic larvae of adult caddisflies have a hard head with three pairs of legs attached to an elongated, soft body. Finger-like gills on the abdomen and anal appendages can be seen with the naked eye. Some caddisflies construct portable shelters from sand grains, bits of vegetation and/or silk that are glued together to form a characteristic case shape. Most case-building types cannot swim whereas the caseless types swim freely across the substrate. Some feed on algae and detritus whereas others are predators.

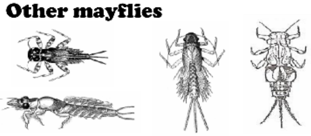
Mayflies

Mayfly nymphs vary greatly in shape and size and can survive for months in the water. However, the adults only live for a day or two. In this time, adults never feed, only mating and lay eggs in the water.

Minnow mayflies

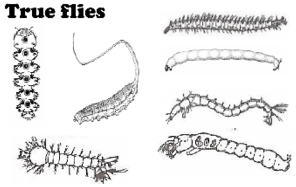
These mayflies have a narrow head and a small, slender, but not flattened body. They have leaf shaped gills on both sides of the abdomen and two but more commonly three tails, depending on the species.

Other mayflies



Other mayflies are characterised by an elongated body, large head, well-developed mouthparts and stout legs. They live in a variety of habitats, including burrowing in mud, crawling amongst decaying leaves, and scurrying over stones in fast flowing water.

True flies



Most fly larvae have a fairly indistinct head but elaborate tail ends. They often have small, soft legs (prolegs), segmented bodies and have the appearance of maggots. Some have bristles/spines and antennae. True flies live in a variety of habitats including sand, mud and stones in fast flowing water. They can either be carnivorous or filter feeders.

Images not to scale

Appendix 3. An example of the miniSASS data sheet used in current study (READ, 2016).

River health site: Please make sure that your GPS is set to dd mm ss.s and that the altitude setting is in meters										
Name:	Date:	Time:	RHP Site Code	River Name:	Site Description:	Altitude (m):	Municipality (District & Local):	Vehicle Reg.	Good for SASS Yes / No	DWAS Code:
Site Coordinates: S ddd mm ss.s E dd mm ss.s			**Temp (°C)**	**pH**	**DO (mg/ℓ)**	**DO (%)**	**Cond (mS/cm)**	**TDS (g/ℓ)**	**Salinity**	**Clarity (cm)**
Flow	**Water depth**	**River size**	**Water colour**	**Smell**	**Water disturbance Yes / No**		**Raparian disturbance**		**GROUPS**	**Sensitivity Score**
Dry	<10 cm	<1 m	Clear	None	Bridge		Lands		Flat worms	3
None/Pools	11–15 cm	1–2 m	Discoloured	Sewage	Livestock		Livestock		Worms	2
Low	16–30 cm	2–5 m	Silty	Chemical	Sewage		Village		Leeches	2
Medium	31–100cm	5–10 m	Brown	Nutrients	Silt		Mine		Crabs or shrimps	6
High	>101 cm	10–20 m	Green	Oil	Exotic tress		Industry		Stoneflies	17
Flood		20–50 m	Opaque	Diesel	Dam		Rubbish		Minnow mayflies	5
		50–100 m			Pump		Chicken farm		Other mayflies	11
		>100 m			Mine		Pig Farm		Damselflies	4
					Weir		Golf Course		Dragonflies	6
					Rubbish		Erosion		Bugs or beetles	5
			Other:	Other:	Other:		Other:		Caddisflies (cased or uncased)	9
			River Category		**NOTES: (Accessibility, Polluted, Pristine, General Remarks)**				True flies	2
Ecological Category			**Sandy Type**	**Rocky Type**					Snails	4
Unmodified (Natural condition)			>6.9	>7.9					**TOTAL SCORE**	
Largely natural/few modifications (Good Conditions)			5.8 to 6.9	6.8 to 7.9					**NUMBER OF GROUPS**	
Moderately modified (FAIR condition)			4.9 to 5.8	6.1 to 6.8						
Largely modified (Poor Condition)			4.3 to 4.9	5.1 to 6.1					**AVERAGE SCORE (** = Total Score + Number of Groups**)**	
Seriously/critically modified (Very Poor Condition)			<4.3	<5.1						
Signatures:	**Monitor:**		**Co-monitor**							

Appendix 4. Sites and surveys in the Crocodile River System

Site	Survey No.	Code:	River Name	Date	Sampling Time	Site Description	Coordinates		Altitude (m)	Good for SASS (Yes / No)
							S ddd mm ss.s	E ddd mm ss.s		
Site 1	1	A2CROC SOUTP	Cricodile River	2017.02.23	13:29	Upstream site of before confluence	-24.643617	27.371017	1040	Yes
	2	A2CROC SOUTP	Cricodile River	2017.07.12	12:10	Upstream site of before confluence	-24.643617	27.371017	1040	Yes
	3	A2CROC SOUTP	Cricodile River	2017.11.08	11:58	Upstream site of before confluence	-24.643617	27.371017	1040	Yes
	4	A2CROC SOUTP	Cricodile River	2018.05.24	13:06	Upstream site of before confluence	-24.643617	27.371017	1040	Yes
Site 2	1	A2CROC SOUTP	Cricodile River	2017.02.24	11:41	Downstream of Rooikuilspruit confluence with Crocodile River (At the Ben Alberts Bridge)	-24.640717	27.3684	1040	Yes
	2	A2CROC SOUTP	Cricodile River	2017.07.12	10:31	Downstream of Rooikuilspruit confluence with Crocodile River (At the Ben Alberts Bridge)	-24.640717	27.3684	1040	Yes
	3	A2CROC SOUTP	Cricodile River	2017.11.09	11:01	Downstream of Rooikuilspruit confluence with Crocodile River (At the Ben Alberts Bridge)	-24.640717	27.3684	1040	Yes
	4	A2CROC SOUTP	Cricodile River	2018.05.25	11:18	Downstream of Rooikuilspruit confluence with Crocodile River (At the Ben Alberts Bridge)	-24.640717	27.3684	1040	Yes

Site 3	**1**	A2CROC VAALK	Cricodile River	2017.02.25	08:42	Upstream of Bierspruit confluence with Crocodile River	-24.6451	27.345883	1039	Yes
	2	A2CROC VAALK	Cricodile River	2017.07.13	08:02	Upstream of Bierspruit confluence with Crocodile River	-24.6451	27.345883	1039	Yes
	3	A2CROC VAALK	Cricodile River	2017.11.10	09:29	Upstream of Bierspruit confluence with Crocodile River	-24.6451	27.345883	1039	Yes
	4	A2CROC VAALK	Cricodile River	2018.05.26	09:34	Upstream of Bierspruit confluence with Crocodile River	-24.6451	27.345883	1039	Yes
Site 4	**1**	A2CROC BRITS	Cricodile River	2017.02.23	10:54	Downstream of Bierspruit confluence with Crocodile River	-24.644717	27.325033	1049	Yes
	2	A2CROC BRITS	Cricodile River	2017.07.13	09:11	Downstream of Bierspruit confluence with Crocodile River	-24.644717	27.325033	1049	Yes
	3	A2CROC BRITS	Cricodile River	2017.11.08	10:13	Downstream of Bierspruit confluence with Crocodile River	-24.644717	27.325033	1049	Yes
	4	A2CROC BRITS	Cricodile River	2018.05.24	10:36	Downstream of Bierspruit confluence with Crocodile River	-24.644717	27.325033	1049	Yes

Appendix 5. River site aesthetics in the Crocodile River System

Site	Survey No.	Code:	River Name	Date	Sampling Time	River site aesthetics						
						Flow	**Water Depth (cm)**	**River Size (m)**	**Water Colour**	**Smell**	**Water Disturbance (Instream)**	**Riparian disturbance**
Site 1	**1**	A2CROC SOUTP	Cricodile River	2017.02.23	13:29	High	31-100cm	20-50cm	Opaque	None	Livestock, Sewerage, Excotic trees	Livestock, Chicken farm
	2	A2CROC SOUTP	Cricodile River	2017.07.12	12:10	Medium	31-100cm	20-50cm	Opaque	None	Livestock, Sewerage, Excotic trees	Livestock, Chicken farm
	3	A2CROC SOUTP	Cricodile River	2017.11.08	11:58	High	31-100cm	20-50cm	Opaque	None	Livestock, Sewerage, Excotic trees	Livestock, Chicken farm
	4	A2CROC SOUTP	Cricodile River	2018.05.24	13:06	Medium	31-100cm	20-50cm	Opaque	None	Livestock, Sewerage, Excotic trees	Livestock, Chicken farm
Site 2	**1**	A2CROC SOUTP	Cricodile River	2017.02.24	11:41	Medium	31-100cm	10-20cm	Green	Sewerage	Bridge, Livestock, Sewerage, Excotic trees, Rubbish	Lands, Livestock, Rubbish
	2	A2CROC SOUTP	Cricodile River	2017.07.12	10:31	Medium	31-100cm	10-20cm	Green	Sewerage	Bridge, Livestock, Sewerage, Excotic trees, Rubbish	Lands, Livestock, Rubbish
	3	A2CROC SOUTP	Cricodile River	2017.11.09	11:01	Medium	31-100cm	10-20cm	Green	Sewerage	Bridge, Livestock, Sewerage, Excotic trees, Rubbish	Lands, Livestock, Rubbish

	4	A2CROC SOUTP	Cricodile River	2018.05.25	11:18	Medium	31-100cm	10-20cm	Green	Sewerage	Bridge, Livestock, Sewerage, Excotic trees, Rubbish	Lands, Livestock, Rubbish
Site 3	**1**	A2CROC VAALK	Cricodile River	2017.02.25	08:42	Medium	31-100cm	10-20cm	Green	Sewerage	Livestock, Sewerage, Excotic trees,	Lands, Livestock
	2	A2CROC VAALK	Cricodile River	2017.07.13	08:02	Medium	31-100cm	10-20cm	Green	Sewerage	Livestock, Sewerage, Excotic trees,	Lands, Livestock
	3	A2CROC VAALK	Cricodile River	2017.11.10	09:29	Medium	16-30cm	10-20cm	Green	Sewerage	Livestock, Sewerage, Excotic trees,	Livestock, Sewerage, Excotic trees,
	4	A2CROC VAALK	Cricodile River	2018.05.26	09:34	Medium	16-30cm	10-20cm	Green	Sewerage	Livestock, Sewerage, Excotic trees,	Livestock, Sewerage, Excotic trees,
Site 4	**1**	A2CROC BRITS	Cricodile River	2017.02.23	10:54	Medium	16-30cm	10-20cm	Green	Sewerage	Bridge, Livestock, Sewerage, Exotic trees	Lands, Livestock, Industry, Chicken Farm
	2	A2CROC BRITS	Cricodile River	2017.07.13	09:11	Medium	16-30cm	10-20cm	Green	Sewerage	Bridge, Livestock, Sewerage, Exotic trees	Lands, Livestock, Industry, Chicken Farm
	3	A2CROC BRITS	Cricodile River	2017.11.08	10:13	Medium	16-30cm	10-20cm	Green	Sewerage	Bridge, Livestock, Sewerage, Exotic trees	Lands, Livestock, Industry, Chicken Farm

	4	A2CROC BRITS	Cricodile River	2018.05.24	10:36	Medium	16-30cm	10-20cm	Green	Sewerage	Bridge, Livestock, Sewerage, Exotic trees	Lands, Livestock, Industry, Chicken Farm

Appendix 6. Water quality parameters measured in the Crocodile River System

Site	**Survey No.**	**Code:**	**River Name**	**Date**	**Sampling Time**	**Water Quality Parameters**						
						Temp (°C)	**pH**	**DO (mg/l)**	**DO (%)**	**EC (µS/cm)**	**TDS (g/l)**	**Salinity (ppm)**
Site 1	**1**	A2CROC SOUTP	Cricodile River	2017.02.23	13:29	26.94	8.73	3.08	46.4	0.2654	0.277	0.21
	2	A2CROC SOUTP	Cricodile River	2017.07.12	12:10	19.3	8.17	5.43	59.2	0.341	0.281	0.25
	3	A2CROC SOUTP	Cricodile River	2017.11.08	11:58	20.4	8.22	5.12	49.1	0.299	0.277	0.22
	4	A2CROC SOUTP	Cricodile River	2018.05.24	13:06	21.9	8.3	5.79	59.6	0.282	0.229	0.22
Site 2	**1**	A2CROC SOUTP	Cricodile River	2017.02.24	11:41	26.95	10.01	1.78	22.04	0.602	0.376	0.28
	2	A2CROC SOUTP	Cricodile River	2017.07.12	10:31	20.1	9.56	2.11	26.5	0.61	0.382	0.27
	3	A2CROC SOUTP	Cricodile River	2017.11.09	11:01	25.32	9.97	2.03	25.3	0.598	0.412	0.3
	4	A2CROC SOUTP	Cricodile River	2018.05.25	11:18	23.6	9.62	2.1	24.9	0.601	0.463	0.29
Site 3	**1**	A2CROC VAALK	Cricodile River	2017.02.25	08:42	26.32	9.8	2.16	26.9	0.629	0.395	0.24
	2	A2CROC VAALK	Cricodile River	2017.07.13	08:02	19.41	9.43	2.23	30.5	0.537	0.383	0.24
	3	A2CROC VAALK	Cricodile River	2017.11.10	09:29	24.59	9.62	1.89	33.2	0.548	0.352	0.26
	4	A2CROC VAALK	Cricodile River	2018.05.26	09:34	25.6	10.11	2.09	32.9	0.556	0.366	0.23
Site 4	**1**	A2CROC BRITS	Cricodile River	2017.02.23	10:54	26.88	9.75	1.82	22.4	0.592	0.381	0.28

	2	A2CROC BRITS	Cricodile River	2017.07.13	09:11	22.56	9.88	2.44	29.86	0.513	0.401	0.26
	3	A2CROC BRITS	Cricodile River	2017.11.08	10:13	25.54	9.48	2.83	30.21	0.568	0.422	0.27
	4	A2CROC BRITS	Cricodile River	2018.05.24	10:36	24.7	10.21	1.78	21.3	0.529	0.485	0.27

Appendix 7. Mini SASS scores for selected sampling sites in the Crocodile River System

Site	**Survey No.**	**Date**	**Sampling Time**	**Mini SASS Scores (Macroinvertebrate Groups and their Sensitivity Scores)**													
				Flat Worms (3)	**Worms (2)**	**Leeches (2)**	**Crabs / Shrimps (6)**	**Stoneflies (17)**	**Minnow mayflies (5)**	**Other mayflies (11)**	**Damselflies (4)**	**Dragonflies (6)**	**Bugs / Beetles (5)**	**Caddisflies (9)**	**True flies (2)**	**Snails (4)**	**Total Score**
Site 1	**1**	2017.02.23	13:29		2	2	6		5	11	4		5		2		37
	2	2017.07.12	12:10		2		6		5		4		5		2		24
	3	2017.11.08	11:58		2	2	6		5	11	4	6	5		2		43
	4	2018.05.24	13:06		2	2	6		5	11	4		5		2		37
Site 2	**1**	2017.02.24	11:41		2	2	6		5		4		5		2		26
	2	2017.07.12	10:31		2	2			5		4		5		2		20
	3	2017.11.09	11:01		2	2	6		5		4				2		21
	4	2018.05.25	11:18		2	2			5		4		5		2		20
Site 3	**1**	2017.02.25	08:42		2	2			5		4		5		2		20
	2	2017.07.13	08:02		2	2			5		4				2		15
	3	2017.11.10	09:29		2	2			5		4				2		15
	4	2018.05.26	09:34		2				5		4				2		15

Site 4	**1**	2017.02.23	10:54		2	2	6				4					4	18
	2	2017.07.13	09:11		2						4						6
	3	2017.11.08	10:13		2						4						6
	4	2018.05.24	10:36		2	2					4					4	12

Appendix 8. Sites and surveys in the Marico River System

Site	**Survey No.**	**Code:**	**River Name**	**Date**	**Sampling Time**	**Site Description**	**Coordinates**		**Altitude (m)**	**Good for SASS (Yes / No)**
							S ddd mm ss.s	**E ddd mm ss.s**		
Site 1	**1**	A3GMAR-Verge	Marico River	2017.03.09	09:36	At Bridge over W side of the road - Vergenoeg	-25.64158667	26.43184	1124	Yes
	2	A3GMAR-Verge	Marico River	2017.07.04	09:55	At Bridge over W side of the road - Vergenoeg	-25.641715	26.431691	1124	Yes
	3	A3GMAR-Verge	Marico River	2017.10.02	09:57	At Bridge over W side of the road - Vergenoeg	-25.641715	26.431691	1124	Yes
	4	A3GMAR-Verge	Marico River	2018.02.14	09:21	At Bridge over W side of the road - Vergenoeg	-25.641715	26.431691	1124	Yes
Site 2	**1**	A3GMAR-Wonde	Marico River	2017.03.10	10:05	Marico Town Bridge	-25.58902778	26.41252778	1089	Yes
	2	A3GMAR-Wonde	Marico River	2017.07.04	10:35	Marico Town Bridge	-25.58902778	26.41252778	1089	Yes
	3	A3GMAR-Wonde	Marico River	2017.10.01	09:10	Marico Town Bridge	-25.58902778	26.41252778	1089	Yes
	4	A3GMAR-Wonde	Marico River	2018.02.14	10:01	Marico Town	-25.58902778	26.41252778	1089	Yes

						Bridge				
Site 3	**1**	A3GMAR-Mash	Marico River	2017.03.09	08:30	Above bridge next to road	-26.24355	25.35283	1092	Yes
	2	A3GMAR-Mash	Marico River	2017.07.04	08:50	Above bridge next to road	-26.243444	25.352572	1091	Yes
	3	A3GMAR-Mash	Marico River	2017.10.02	08:43	Above bridge next to road	-26.2434445	25.3525666	1091	Yes
	4	A3GMAR-Mash	Marico River	2018.02.21	08:48	Above bridge next to road	-25.58902778	26.41252778	1091	Yes
Site 4	**1**	A3GMAR-River	Marico River	2017.03.09	11:05	Under the bridge	-25.64261111	26.41319444	1123	Yes
	2	A3GMAR-River	Marico River	2017.07.04	11:03	Under the bridge	-25.64261111	26.41319444	1123	Yes
	3	A3GMAR-River	Marico River	2017.10.01	10:41	Under the bridge	-25.642773	26.41255	1123	Yes
	4	A3GMAR-River	Marico River	2018.02.21	10:37	Under the bridge	-25.58902778	26.41252778	1123	Yes

Appendix 9. River site aesthetics in the Marico River System

Site	Survey No.	Code:	River Name	Date	Sampling Time	River site aesthetics						
						Flow	Water Depth (cm)	River Size (m)	Water Colour	Smell	Water Disturbance (Instream)	Riparian disturbance
Site 1	**1**	A3GMAR-Verge	Marico River	2017.03.09	09:36	Medium	16-30cm	2-5cm	Opaque	None	Bridge Silt Exotic trees Weir	Lands Livestock
	2	A3GMAR-Verge	Marico River	2017.07.04	09:55	Medium	16-30cm	2-5cm	Opaque	None	Bridge Silt Exotic trees Weir	Lands Livestock
	3	A3GMAR-Verge	Marico River	2017.10.02	09:57	Medium	16-30cm	2-5cm	Opaque	None	Bridge Silt Exotic trees Weir	Lands Livestock

	4	A3GMAR-Verge	Marico River	2018.02.14	09:21	Medium	16-30cm	2-5cm	Clear	None	Bridge Silt Exotic trees Weir	Lands Livestock
Site 2	**1**	A3GMAR-Wonde	Marico River	2017.03.10	10:05	Medium	16-30cm	2-5m	Brown	None	Bridge Livestock Silt Exotic trees Weir	Livestock Erosion
	2	A3GMAR-Wonde	Marico River	2017.07.04	10:35	Medium	16-30cm	2-5m	Opaque	None	Bridge Livestock Silt Exotic trees Weir	Livestock Erosion
	3	A3GMAR-Wonde	Marico River	2017.10.01	09:10	Medium	16-30cm	2-5m	Opaque	None	Bridge Livestock Silt Exotic trees Weir	Livestock Erosion
	4	A3GMAR-Wonde	Marico River	2018.02.14	10:01	Medium	16-30cm	2-5m	Clear	None	Bridge Livestock Silt Exotic trees Weir	Livestock Erosion
Site 3	**1**	A3GMAR-Mash	Marico River	2017.03.09	08:30	Medium	16-30cm	2-5cm	Opaque	None	Livestock Exotic trees	Lands Livestock
	2	A3GMAR-Mash	Marico River	2017.07.04	08:50	Medium	16-30cm	2-5cm	Opaque	None	Livestock Exotic trees	Lands Livestock
	3	A3GMAR-Mash	Marico River	2017.10.02	08:43	Medium	16-30cm	2-5cm	Opaque	None	Livestock Exotic trees	Lands Livestock
	4	A3GMAR-Mash	Marico River	2018.02.21	08:48	Medium	16-30cm	2-5cm	Opaque	None	Bridge Silt Exotic trees Weir	Lands Livestock
Site 4	**1**	A3GMAR-River	Marico River	2017.03.09	11:05	Medium	16-30cm	2-5cm	Opaque	None	Bridge Silt Exotic trees Weir	Lands Livestock
	2	A3GMAR-River	Marico River	2017.07.04	11:03	Medium	16-30cm	2-5cm	Opaque	None	Bridge Silt Exotic trees Weir	Lands Livestock
	3	A3GMAR-River	Marico River	2017.10.01	10:41	Medium	16-30cm	2-5cm	Clear	None	Bridge Silt Exotic trees	Lands

											Weir	Livestock
	4	A3GMAR-River	Marico River	2018.02.21	10:37	Medium	16-30cm	2-5m	Brown	None	Bridge Livestock Silt Exotic trees Weir	Livestock Erosion

Appendix 10. Water quality parameters measured in the Marico River System

Site	**Survey No.**	**Code:**	**River Name**	**Date**	**Sampling Time**	**Water Quality Parameters**						
						Temp (°C)	**pH**	**DO (mg/l)**	**DO (%)**	**EC (µS/cm)**	**TDS (g/l)**	**Salinity (ppm)**
Site 1	**1**	A3GMAR-Verge	Marico River	2017.03.09	09:36	22.7	9.44	2.97	34.7	0.269	0.183	0.13
	2	A3GMAR-Verge	Marico River	2017.07.04	09:55	9.71	8.26	7.38	68.3	0.138	0.126	0.09
	3	A3GMAR-Verge	Marico River	2017.10.02	09:57	19.5	8.98	8.2	64.3	0.184	0.131	0.11
	4	A3GMAR-Verge	Marico River	2018.02.14	09:21	20.1	8.89	7.72	57.2	0.218	0.139	0.12
Site 2	**1**	A3GMAR-Wonde	Marico River	2017.03.10	10:05	23.01	9.58	2.86	33.6	0.283	0.191	0.14
	2	A3GMAR-Wonde	Marico River	2017.07.04	10:35	11.88	8.35	4.93	63.4	0.215	0.186	0.14
	3	A3GMAR-Wonde	Marico River	2017.10.01	09:10	16.7	8.56	7.29	51.6	0.232	0.189	0.13
	4	A3GMAR-Wonde	Marico River	2018.02.14	10:01	18.45	8.61	5.11	45.6	0.221	0.19	0.13
Site 3	**1**	A3GMAR-Mash	Marico River	2017.03.09	08:30	18.56	8.91	7.95	71.3	0.19	0.171	0.09
	2	A3GMAR-Mash	Marico River	2017.07.04	08:50	10.52	8.23	7.4	65.7	0.17	0.153	0.11
	3	A3GMAR-Mash	Marico River	2017.10.02	08:43	9.59	8.31	7.51	66.9	0.18	0.162	0.1
	4	A3GMAR-Mash	Marico River	2018.02.21	08:48	19.44	8.12	6.25	59.8	0.18	0.168	0.12
Site 4	**1**	A3GMAR-River	Marico River	2017.03.09	11:05	21.56	8.78	4.89	51.2	0.21	0.133	0.11

	2	A3GMAR-River	Marico River	2017.07.04	11:03	11.85	8.39	5.67	52.2	0.271	0.176	0.13
	3	A3GMAR-River	Marico River	2017.10.01	10:41	17.18	8.41	6.27	58.91	0.22	0.161	0.12
	4	A3GMAR-River	Marico River	2018.02.21	10:37	20.1	8.4	5.98	60.21	0.2	0.142	0.11

Appendix 11. Mini SASS scores for selected sampling sites in the Marico River System

Site	**Survey No.**	**Date**	**Sampling Time**	**Mini SASS Scores (Macroinvertebrate Groups and their Sensitivity Scores)**														
				Flat Worms (3)	**Worms (2)**	**Leeches (2)**	**Crabs / Shrimps (6)**	**Stoneflies (17)**	**Minnow mayflies (5)**	**Other mayflies (11)**	**Damselflies (4)**	**Dragonflies (6)**	**Bugs / Beetles (5)**	**Caddisflies (9)**	**True flies (2)**	**Snails (4)**	**Total Score**	**Average Score**
Site 1	**1**	2017.03.09	09:36		2		6	17		11	4	6	5			4	55	6.9
	2	2017.07.04	09:55				6	17	5	11	4	6	5	9	2		65	7.2
	3	2017.10.02	09:57		2		6	17	5	11	4	6	5	9	2		67	6.7
	4	2018.02.14	09:21		2			17	5	11	4	6	5	9	2		61	6.8
Site 2	**1**	2017.03.10	10:05		2	2	6		5	11	4		5	9	2	4	50	5.0
	2	2017.07.04	10:35		2	2	6	17	5	11	4	6	5	9	2	4	73	6.1
	3	2017.10.01	09:10		2		6	17		11	4	6		9	2	4	61	6.8
	4	2018.02.14	10:01		2		6	17	5	11	4	6	5	9	2	4	71	6.5
Site 3	**1**	2017.03.09	08:30			2				11	4	6	5	9		4	41	5.9
	2	2017.07.04	08:50		2					11	4	6	5	9	2	4	43	5.4
	3	2017.10.02	08:43		2	2				11	4	6	5	9	2	4	45	5.0
	4	2018.02.21	08:48		2					11		6	5	9	2	4	39	5.6

Site 4	**1**	2017.03.09	11:05			2	6	17	5	11		6		9	2	4	62	6.9
	2	2017.07.04	11:03		2	2	6	17	5	11	4	6	5	9	2	4	73	6.1
	3	2017.10.01	10:41			2	6	17	5	11	4	6	5	9	2	4	71	6.5
	4	2018.02.21	10:37		2	2	6	17	5	11		6	5	9	2	4	69	6.3

Appendix 12. Seasonal site specific temperatures.

Sampling site	Autumn	Winter	Spring	Summer	AVE	STD
Site 1	22.7	9.71	19.5	20.1	18.00	5.70
Site 2	23.01	11.88	16.7	18.45	17.51	4.60
Site 3	18.56	9.59	10.52	19.44	14.53	5.19
Site 4	21.56	11.85	17.18	20.1	17.67	4.29
Site 5	21.9	19.3	20.4	26.94	22.14	3.38
Site 6	23.6	20.1	25.32	26.95	23.99	2.93
Site 7	25.6	19.41	24.59	26.32	23.98	3.13
Site 8	24.7	22.56	25.54	26.88	24.92	1.81
TWQR (Max)	25.6	22.56	25.54	26.95		
TWQR (Min)	18.56	9.59	10.52	18.45		

Appendix 13. Seasonal site specific pH

Sampling site	**Autumn**	**Winter**	**Spring**	**Summer**	**Min**	**Max**	**STD**
Site 1	9.44	8.26	8.98	8.89	8.26	9.44	0.49
Site 2	9.58	8.35	8.56	8.61	8.35	9.58	0.55
Site 3	8.91	8.23	8.31	8.12	8.12	8.91	0.35
Site 4	8.78	8.39	8.41	8.4	8.39	8.78	0.19
Site 5	5.79	8.17	5.12	8.73	5.12	8.73	1.77
Site 6	2.1	9.56	2.03	10.01	2.03	10.01	4.46
Site 7	2.09	9.43	1.89	9.8	1.89	9.80	4.41
Site 8	1.78	9.88	2.83	9.75	1.78	9.88	4.36
TWQR (Max)	**9.58**	**9.88**	**8.98**	**10.01**		**Min**	**Max**
TWQR (Min)	**1.78**	**8.17**	**1.89**	**8.12**	**Marico**	8.12	9.58
					Crocodile	1.78	10.01

.

Appendix 14. Seasonal site specific dissolved oxygen (%)

Sampling site	**Autumn**	**Winter**	**Spring**	**Summer**	**AVE**	**STD**
Site 1	34.7	68.3	64.3	57.2	56.13	15.00
Site 2	33.6	63.4	51.6	45.6	48.55	12.41
Site 3	71.3	65.7	66.9	59.8	65.93	4.74
Site 4	51.2	52.2	58.91	60.21	55.63	4.59
Site 5	59.6	59.2	49.1	46.4	53.58	6.82
Site 6	24.9	22.04	26.5	25.3	24.69	1.89

Site 7	32.9	26.9	30.5	33.2	30.88	2.91
Site 8	21.3	22.4	29.86	30.21	25.94	4.75
TWQR (Min)	21.3	22.04	26.5	25.3		
TWQR (Max)	71.3	68.3	66.9	60.21		

Appendix 15: Seasonal site specific dissolved oxygen (mg/l)

Sampling site	**Autumn**	**Winter**	**Spring**	**Summer**	**AVE**	**STD**
Site 1	2.97	7.38	8.2	7.72	6.57	2.42
Site 2	2.86	4.93	8.2	5.11	5.28	2.20
Site 3	7.95	7.4	8.2	6.25	7.45	0.87
Site 4	4.89	5.67	8.2	5.98	6.19	1.42
Site 5	5.79	5.43	8.2	3.08	5.63	2.10
Site 6	2.1	1.78	2.11	2.03	2.01	0.15
Site 7	2.09	2.16	2.23	1.89	2.09	0.15
Site 8	1.78	1.82	2.44	2.83	2.22	0.51
TWQR (Max)	1.78	1.78	2.11	1.89		
TWQR (Min)	7.95	7.4	8.2	7.72		

Appendix 16. Seasonal site specific total dissolved solids (mg/l)

Sampling site	Autumn	Winter	Spring	Summer	AVE	STD
Site 1	0.183	0.126	0.131	0.139	0.145	0.03
Site 2	0.191	0.186	0.189	0.19	0.189	0.00
Site 3	0.171	0.153	0.162	0.168	0.164	0.01
Site 4	0.133	0.176	0.161	0.142	0.153	0.02
Site 5	0.229	0.281	0.277	0.277	0.266	0.02
Site 6	0.463	0.376	0.382	0.412	0.408	0.04
Site 7	0.366	0.395	0.383	0.352	0.374	0.02
Site 8	0.485	0.381	0.401	0.422	0.422	0.05
TWQR (Max)	0.485	0.126	0.131	0.139	0.145	
TWQR (Min)	0.133	0.395	0.401	0.422	0.422	

Appendix 17. Seasonal site specific electrical conductivity (µS/cm)

Sampling site	Autumn	Winter	Spring	Summer	AVE	STD
Site 1	0.269	0.138	0.184	0.218	0.20225	0.06
Site 2	0.283	0.215	0.232	0.221	0.23775	0.03
Site 3	0.19	0.17	0.18	0.18	0.18000	0.01
Site 4	0.21	0.271	0.22	0.2	0.22525	0.03
Site 5	0.282	0.341	0.299	0.2654	0.29685	0.03
Site 6	0.601	0.602	0.61	0.598	0.60275	0.01
Site 7	0.556	0.629	0.537	0.548	0.56750	0.04
Site 8	0.529	0.592	0.513	0.568	0.55050	0.04
TWQR (Max)	0.601	0.629	0.61	0.598		
TWQR (Min)	0.19	0.138	0.18	0.18		

Appendix 18. Seasonal site specific salinity (ppm)

Sampling site	Autumn	Winter	Spring	Summer	AVE	STD
Site 1	0.22	0.25	0.22	0.21	0.225	0.02
Site 2	0.29	0.28	0.27	0.3	0.285	0.01
Site 3	0.23	0.24	0.24	0.26	0.243	0.01
Site 4	0.27	0.28	0.26	0.27	0.270	0.01
Site 5	0.13	0.09	0.11	0.12	0.113	0.02
Site 6	0.14	0.14	0.13	0.13	0.135	0.01
Site 7	0.09	0.11	0.1	0.12	0.105	0.01
Site 8	0.11	0.13	0.12	0.11	0.118	0.01
TWQR (Max)	0.29	0.28	0.27	0.3		
TWQR (Min)	0.09	0.09	0.1	0.11		

Appendix 19. Seasonal mini SASS scores per river site.

Name of River	**Sampling Sites**	**Surveys**				**MIN**	**MAX**	**STDev.**
		Autumn	**Winter**	**Spring**	**Summer**			
Marico River	**S1**	6.9	7.2	6.7	6.8	6.7	7.2	4.49
	S2	5.0	6.1	6.8	6.5	5.0	6.8	4.12
	S3	5.9	5.4	5.0	5.6	5.0	5.9	3.09
	S4	6.9	6.1	6.5	6.3	6.1	6.9	4.38
Crocodile River	**S5**	2.8	2.0	3.3	2.8	2.0	3.3	2.64
	S6	1.5	2.0	1.5	1.6	1.5	2.0	1.53
	S7	1.0	1.5	1.2	1.2	1.0	1.5	1.35
	S8	0.9	1.4	0.5	0.5	0.5	1.4	1.55

Appendix 20. Descriptive statistics for seasonal temperature values

Temperature

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
autumn	8	22.7037	2.15125	.76058	20.9053	24.5022	18.56	25.60
winter	8	15.5500	5.28598	1.86887	11.1308	19.9692	9.59	22.56
spring	8	19.9688	5.19859	1.83798	15.6226	24.3149	10.52	25.54
summer	8	23.1475	3.91380	1.38374	19.8755	26.4195	18.45	26.95
Total	32	20.3425	5.13306	.90741	18.4918	22.1932	9.59	26.95

Appendix 21. Multiple comparisons seasonal temperature readings (Post Hoc Test)

Dependent Variable: Temp

Tukey HSD

(I) Season	(J) Season	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
autumn	winter	7.15375*	2.16380	.013	1.2459	13.0616
	spring	2.73500	2.16380	.593	-3.1729	8.6429
	summer	-.44375	2.16380	.997	-6.3516	5.4641
winter	autumn	-7.15375*	2.16380	.013	-13.0616	-1.2459
	spring	-4.41875	2.16380	.197	-10.3266	1.4891
	summer	-7.59750*	2.16380	.008	-13.5054	-1.6896
spring	autumn	-2.73500	2.16380	.593	-8.6429	3.1729
	winter	4.41875	2.16380	.197	-1.4891	10.3266
	summer	-3.17875	2.16380	.469	-9.0866	2.7291
summer	autumn	.44375	2.16380	.997	-5.4641	6.3516
	winter	7.59750*	2.16380	.008	1.6896	13.5054
	spring	3.17875	2.16380	.469	-2.7291	9.0866

*. The mean difference is significant at the 0.05 level.

Appendix 22. Evaluation of homogeneous subsets of temperature readings

Tukey HSD[a]

Season	N	Subset for alpha = 0.05	
		1	2
winter	8	15.5500	
spring	8	19.9688	19.9688
autumn	8		22.7037
summer	8		23.1475
Sig.		.197	.469

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 8.000.

Appendix 23. Descriptive statistics for seasonal pH values

pH

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
autumn	8	6.0588	3.56910	1.26187	3.0749	9.0426	1.78	9.58
winter	8	8.7838	.70940	.25081	8.1907	9.3768	8.17	9.88
spring	8	5.7663	3.15362	1.11497	3.1298	8.4027	1.89	8.98
summer	8	9.0388	.71535	.25291	8.4407	9.6368	8.12	10.01
Total	32	7.4119	2.77334	.49026	6.4120	8.4118	1.78	10.01

Appendix 24. Multiple comparisons seasonal pH readings (Post Hoc Test)

Dependent Variable: pH

Tukey HSD

(I) Season	(J) Season	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Autumn	winter	-2.72500	1.21704	.137	-6.0479	.5979
	spring	.29250	1.21704	.995	-3.0304	3.6154
	summer	-2.98000	1.21704	.091	-6.3029	.3429
Winter	autumn	2.72500	1.21704	.137	-.5979	6.0479
	spring	3.01750	1.21704	.085	-.3054	6.3404
	summer	-.25500	1.21704	.997	-3.5779	3.0679
Spring	autumn	-.29250	1.21704	.995	-3.6154	3.0304
	winter	-3.01750	1.21704	.085	-6.3404	.3054
	summer	-3.27250	1.21704	.055	-6.5954	.0504
Summer	autumn	2.98000	1.21704	.091	-.3429	6.3029
	winter	.25500	1.21704	.997	-3.0679	3.5779
	spring	3.27250	1.21704	.055	-.0504	6.5954

*. The mean difference is significant at the 0.05 level.

Appendix 25. Evaluation of homogeneous subsets of pH readings

Season	N	Subset for alpha = 0.05
		1
Spring	8	5.7663
Autumn	8	6.0588
Winter	8	8.7838
Summer	8	9.0388
Sig.		.055

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 8.000.

Appendix 26. Descriptive statistics for seasonal dissolved oxygen values

Dissolved Oxygen

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
autumn	8	41.1875	17.62777	6.23236	26.4503	55.9247	21.30	71.30
winter	8	47.5175	20.27754	7.16919	30.5651	64.4699	22.04	68.30
spring	8	47.2088	16.25093	5.74557	33.6226	60.7949	26.50	66.90
summer	8	44.7400	13.87226	4.90458	33.1425	56.3375	25.30	60.21
Total	32	45.1634	16.51475	2.91942	39.2092	51.1176	21.30	71.30

Appendix 27. Multiple comparisons seasonal dissolved oxygen readings (Post Hoc Test)

Dependent Variable: DO

Tukey HSD

					95% Confidence Interval	
(I) Season	(J) Season	Mean Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound
autumn	winter	-6.33000	8.58214	.881	-29.7619	17.1019
	spring	-6.02125	8.58214	.896	-29.4532	17.4107
	summer	-3.55250	8.58214	.976	-26.9844	19.8794
winter	autumn	6.33000	8.58214	.881	-17.1019	29.7619
	spring	.30875	8.58214	1.000	-23.1232	23.7407
	summer	2.77750	8.58214	.988	-20.6544	26.2094
spring	autumn	6.02125	8.58214	.896	-17.4107	29.4532
	winter	-.30875	8.58214	1.000	-23.7407	23.1232
	summer	2.46875	8.58214	.992	-20.9632	25.9007
summer	autumn	3.55250	8.58214	.976	-19.8794	26.9844
	winter	-2.77750	8.58214	.988	-26.2094	20.6544
	spring	-2.46875	8.58214	.992	-25.9007	20.9632

*. The mean difference is significant at the 0.05 level.

Appendix 28. Evaluation of homogeneous subsets of dissolved oxygen readings

Season	N	Subset for alpha = 0.05
		1
Autumn	8	41.1875
Summer	8	44.7400
Spring	8	47.2088
Winter	8	47.5175
Sig.		.881

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 8.000.

Appendix 29. Descriptive statistics for seasonal TDS values

TDS

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
autumn	8	.27763	.139533	.049332	.16097	.39428	.133	.485
winter	8	.25925	.112565	.039798	.16514	.35336	.126	.395
spring	8	.26075	.114184	.040370	.16529	.35621	.131	.401
summer	8	.26275	.119505	.042251	.16284	.36266	.139	.422
Total	32	.26509	.116112	.020526	.22323	.30696	.126	.485

Appendix 30. Multiple comparisons seasonal TDS readings (Post Hoc Test)

Dependent Variable: TDS

Tukey HSD

(I) Season	(J) Season	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
autumn	winter	.018375	.060961	.990	-.14807	.18482
	spring	.016875	.060961	.992	-.14957	.18332
	summer	.014875	.060961	.995	-.15157	.18132
winter	autumn	-.018375	.060961	.990	-.18482	.14807
	spring	-.001500	.060961	1.000	-.16794	.16494
	summer	-.003500	.060961	1.000	-.16994	.16294
spring	autumn	-.016875	.060961	.992	-.18332	.14957
	winter	.001500	.060961	1.000	-.16494	.16794
	summer	-.002000	.060961	1.000	-.16844	.16444
summer	autumn	-.014875	.060961	.995	-.18132	.15157
	winter	.003500	.060961	1.000	-.16294	.16994
	spring	.002000	.060961	1.000	-.16444	.16844

*. The mean difference is significant at the 0.05 level.

Appendix 31. Evaluation of homogeneous subsets of TDS readings

Season	N	Subset for alpha = 0.05
		1
winter	8	.25925
spring	8	.26075
summer	8	.26275
autumn	8	.27763
Sig.		.990

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 8.000.