Implementation of rapid assessment methods for water resource monitoring in the Sabie River, Mpumalanga, South Africa

By

BHEKISISA HEADMAN CELE

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LIST OF ACRONYMS

ASPT	Average Score per Taxa
BOD	Biological Oxygen Demand
BDCP	Blue Drop Certification Programme
CAP	Correctional Action Plan
CMAs	Catchment Management Agencies
CME	Compliance Monitoring and Evaluation
CRR	Cumulative Risk Rating
CWA	Clean Water Act
DEA	Department of Environmental Affairs
DO	Dissolved Oxygen
DWAF	Department of Water Affairs and Forestry
DWA	Department of Water Affairs
DWS	Department of Water and Sanitation
EC	Electrical Conductivity
EC	Ecological Category
EWQ	Environmental Water Quality
EWR	Environmental Water Requirement
EPA	Environmental Protection Agency
FAII	Fish Assemblage Integrity Index
FIFHA	Fish Invertebrate Flow Habitat Assessment
FRAI	Fish Response Assessment Index
GDCP	Green Drop Certification Programme
GDS	Green Drop Status

GHU	Geomorphic Habitat Unit
GI	Geomorphological Index
GSI	German Saprobic Index
HI	Hydrological Index
IHI	Index of Habitat Integrity
IUCMA	Inkomati-Usuthu Catchment Management Agency
IWMA	Inkomati Water Management Area
IWRM	Integrated Water Resource Management
KNP	Kruger National Park
MTPA	Mpumalanga Tourism and Parks Agency
MIRAI	Macro-Invertebrate Response Assessment Index
NAEHMP	National Aquatic Ecosystem Health Monitoring Programme
NEMA	National Environmental Act
NEMP	National Eutrophication Monitoring Programme
NMMP	National Microbial Monitoring Programme
NRMP	National Radioactivity Monitoring Programme
NTMP	National Toxicity Monitoring Programme
NWA	National Water Act
PAT	Progress Assessment Tool
PCA	Pearson's Correlation Analysis
PES	Present Ecological State
RDA	Redundancy Analysis
REC	Recommended Ecological Category
REMP	River Eco-Status Monitoring Programme
RHAM	Rapid Habitat Assessment Method
RHAMM	Rapid Habitat Assessment Method Model

RHP	River Health Programme
RIVDINT	River Data Integration
RQOs	Resource Quality Objectives
RQS	Resource Quality Services
RSA	Republic of South Africa
RVI	Riparian Vegetation Index
SABS	South African Bureau Standards
SANHP	South African Natural Heritage Programme
SANS	South African National Standards
SASS5	South African Scoring System version 5
SDP	Sabie at Discharge Point
SIC	Stones in Current
SLB	Sabie at Low Bridge
SSW	Sabie Sewage Works
SMP	Sabie Merry Pebbles
SOOC	Stones out of Current
SPSS	Statistical Package for the Social Scientists
TWQR	Target Water Quality Range
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
UKZN	University of KwaZulu-Natal
UN	United Nations
UNEP	United Nations Environmental Programme
VEGRAI	Vegetation Response Assessment Index
WMS	Water Management System
WQI	Water Quality Index

W_2RAP	Wastewater Risk Abatement Plan
WRC	Water Research Commission
WSA	Water Services Authority
WSAs	Water Services Associations
WWTPs	Wastewater Treatment Plants
WWTWs	Wastewater Treatment Works

LIST OF USED NOTATIONS

a.s.l.	Above sea level
Mi^3	Cubic miles
Km^3	Cubic kilometre
%	Percentage
M	Metre
M^2	Square metre
Km	Kilometre
Mm	Millimetre
mm/a	millimetre per annum
^{O}C	Degrees Celsius
Cfu/100ml	Colony Forming Units per 100 milli litre
Cm	Centimetre
Km^2	Square kilometre
Mg/l	Milligrams per litre
M^3/s	Cubic metres per second
Ml/d	Mega litres per day
mS/m	milli-Siemens per meter
>	Greater than
<	Less than
≤	Less or equal to
ppb	parts per billion
ppm	parts per million
PO_4	Phosphates

NO_2	Nitrites
NO_3	Nitrates
E. coli	*Escherichia coli*
NH_3	Ammonia
NH_4	Ammonium

SUMMARY

The Sabie River is one of the largest water resources within Mpumalanga Province, South Africa. It passes through the Kruger National Park (KNP) which is known to attract tourists. This water resource provides daily water for the needs of nearly 650 000 residents around the Sabie area. It was predicted that the waste water treatment works (WWTWs) from Sabie town have negative effects on water quality and the aquatic health of the Sabie River. The upper reaches of the Sabie River were monitored upstream and downstream of WWTWs. The study aim was to determine the impact of WWTWs on the downstream environment of Sabie River. The objectives were to determine the present ecological state (PES) of the Sabie River using macroinvertebrate taxa as bio-indicators, determine the impacts of WWTWs on water quality, determine the in-stream habitat availability using the Rapid Habitat Assessment Method (RHAM) and to determine and compare the seasonal variations in water quality and the biota. The methods used for the study included SASS 5 for macroinvertebrates, sampling water quality *in-situ* parameters (using a digital multi-water-quality meter) and *ex-situ* parameters for laboratory analysis and RHAM for habitat assessment. Sampling was done at four sites over two surveys, during dry and wet seasons. The data analysis followed the Eco-Status Models, i.e. Macroinvertebrate Response Assessment Index (MIRAI) for biota, Rapid Habitat Assessment Method Model (RHAMM) for RHAM data and water quality data. The data were measured against the historical data and Target Water Quality Ranges (TWQR) from the water quality guidelines of the Department of Water Affairs and Forestry. The results showed availability of habitat suitable for the biota, degradation of water quality which was not good for sensitive organisms (wet season with increased *E. coli* concentrations at the discharge point and downstream) and the site downstream of the WWTWs had declined ASPT and SASS Scores compared with the upstream site. A positive seasonal correlation between some taxa and water quality parameters was found. It indicated the macroinvertebrate similarities at the two sites below the WWTWs. No similarities were found between the upstream site of WWTWs and the downstream site. Seasonal variation was noted amongst sites during wet and dry seasons. It was concluded that the Sabie WWTWs has negative impacts on the Sabie River. The study results for the present study are important because they will provide information on WWTW's impacts on a water resource. The stringent conditions should be applied to ensure compliance with permits and prevent pollution. More studies that combine vegetation, MIRAI, water quality, fish and diatoms must be done in the Sabie River system.

CHAPTER 1: GENERAL INTRODUCTION

Samuel Taylor Coleridge (the Rime of the Ancient Mariner, speaker and a sailor) stated that "Water, water everywhere, but not a drop to drink" (www.earthlearningidea.com, 2017). This was because "Samuel" was surrounded by the salt water and could not find any fresh water to drink. This is practically very true because approximately 97.3% is made up of salt water (Golubev and Biswas, 1979) with 2.7% being freshwater of which only 1% of freshwater is fit for human consumption (www.earthlearningidea.com, 2017). This 1% is shared with animals. Some of the 1% is not readily usable as it is in the form of ice caps or glaciers (77.2% of the 1%), 22.4% is groundwater, some in the atmosphere and dams while some of the available freshwater is polluted (Golubev and Biswas, 1979).

Water is the most important resource as the basic requirement for survival on earth (Hossain, 2015). The survival of all the living organisms on earth such as plants, animals and even humans need a constant availability of water for their growth and survival, which means that there will be no life on earth without water (Nkosi and Odeku, 2014; Nkosi, 2015). This basic and crucial resource forms a link between the three serious matters such as food availability, energy and climate change (Lozán *et al*., 2007). The resource is the corner stone of the country's growth, development and the green economy (Savenije, 2002; DWA, 2012). We are mainly dependant on water availability for various practices such as agriculture, industry, energy generation and the production of many goods and services (DWA, 2012). Apart from being the most crucial resource for socio-economic development, water also maintains the integrity of healthy ecosystems such as the aquatic ecosystems where the aquatic biota, which includes fish and macroinvertebrate communities, live and reproduce (Chaplin, 2001; DWA, 2012).

It is important to know the origin of water as much as humans know about its importance for growth, social and economic development. The water that is utilised to produce food, to drink and to wash is found as rainwater and from surface water resources. This includes the rivers and reservoirs, such as dams, while some of the water comes from groundwater resources (DWAF, 1998a). The groundwater normally originates from springs and boreholes. The formation of water occurs though a cycle called the Water Cycle or Hydrological Cycle and is shown in Figure 1.1. The cycle goes through the formation of clouds and rain and then the water gets into rivers, groundwater and to the oceans (DWAF, 1998a). This is followed by evaporation, which is the process by which water goes back to the atmosphere in a vapour form (DWAF, 1998a). The unfortunate part is that water is a very limited resource, which is always not enough, and this is a global issue (Savenije, 2002).

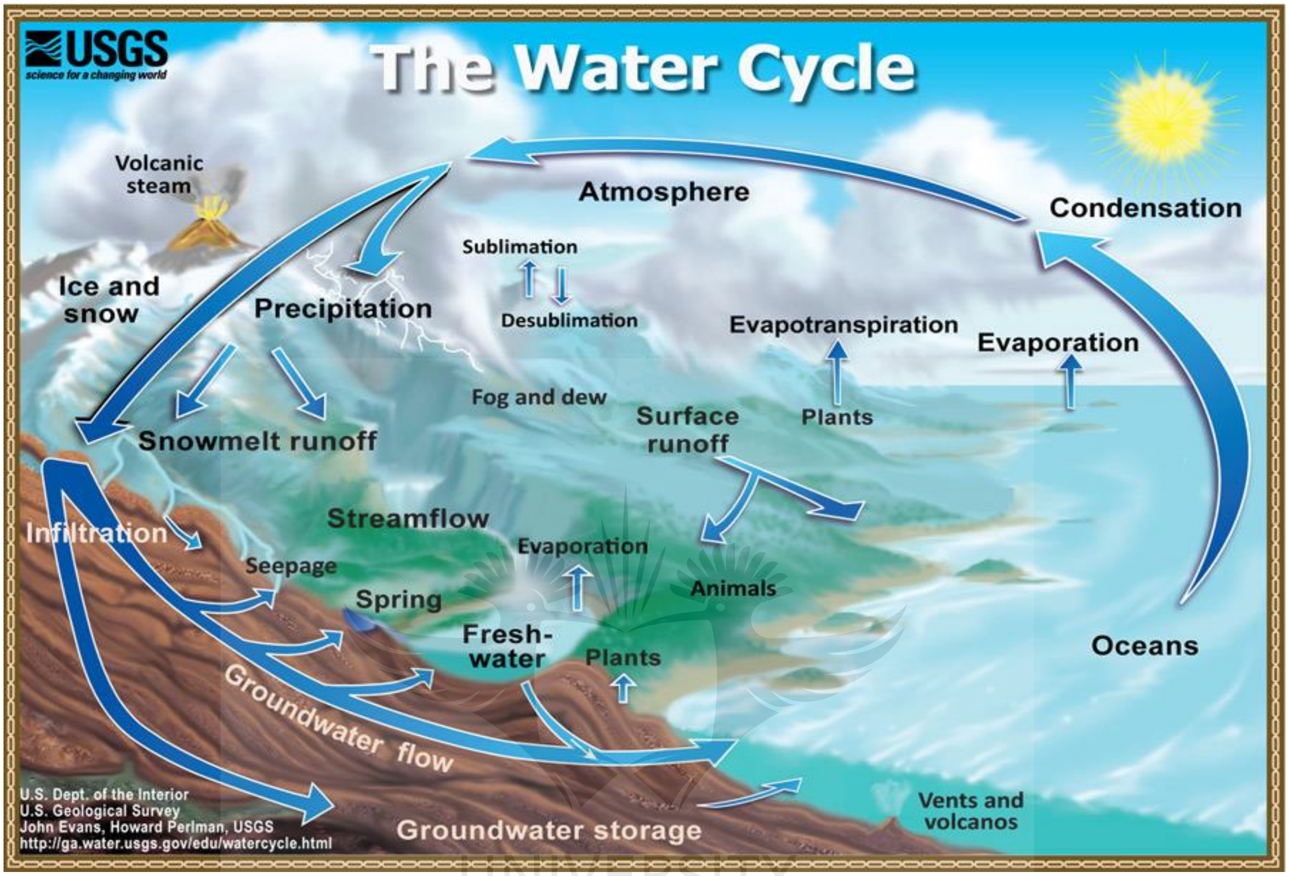


Figure 1.1: A summary of the Water Cycle (Source: Perlman, 2016b).

The issue of water as a very limited resource is represented by Figure 1.2. Figure 1.2 shows a blue sphere, which is the water that is available on earth. It can be noted that when comparing the earth's size and the blue sphere, the available water on earth is just a little drop in the ocean (Perlman, 2016b). One should not assume the amount of water on earth based on Figure 1.2 because water covers about 72% of the earth's surface (www.earthlearningidea.com, 2017). The sphere of water has a diameter of approximately 860 miles with a volume that is approximately 332,500,000 mi^3 or 1,386,000,000 km^3 and this represents the total of water found in the atmosphere, oceanic environments, ice caps, dams or lakes, river systems and groundwater (Perlman, 2016b).

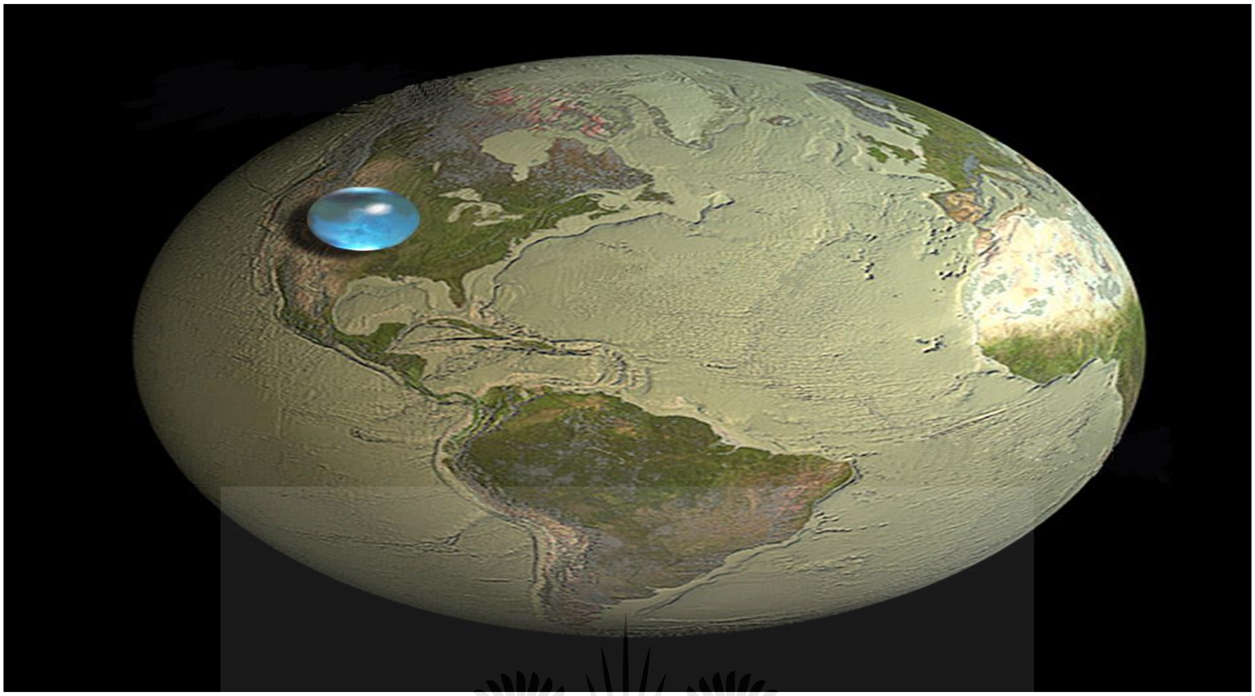


Figure 1.2: Image that represent the total amount of water on, in, and above the Earth (Source: Perlman, 2016a).

South Africa is regarded as the 30th driest country on the globe as it has been categorised as a semi-arid country (DEA, 2011; Nkosi and Odeku, 2014) and that cannot be disputed when looking at the water shortages that it has been and is still facing (DEA, 2011). To ensure that water is readily available where it is required for a specific use at a specific time, the country has been concentrating on the challenge of water shortages for a relatively long time (Colvin *et al*., 2013). South Africa is characterised by an annual average rainfall of about 450 mm/a, which is less than the world average rainfall of about 860 mm/a (Nkosi and Odeku, 2014). Figure 1.3 indicates that the rainfall is unevenly distributed in different regions within South Africa. This means the rain and water availability is not the same for the whole country with the north-western areas getting less rainfall compared with the south-eastern areas (DWA, 2009) and the quality of the relatively little available freshwater has been compromised by pollution from various anthropogenic activities which further minimises the freshwater that is fit for human use (Moosa, 2000).

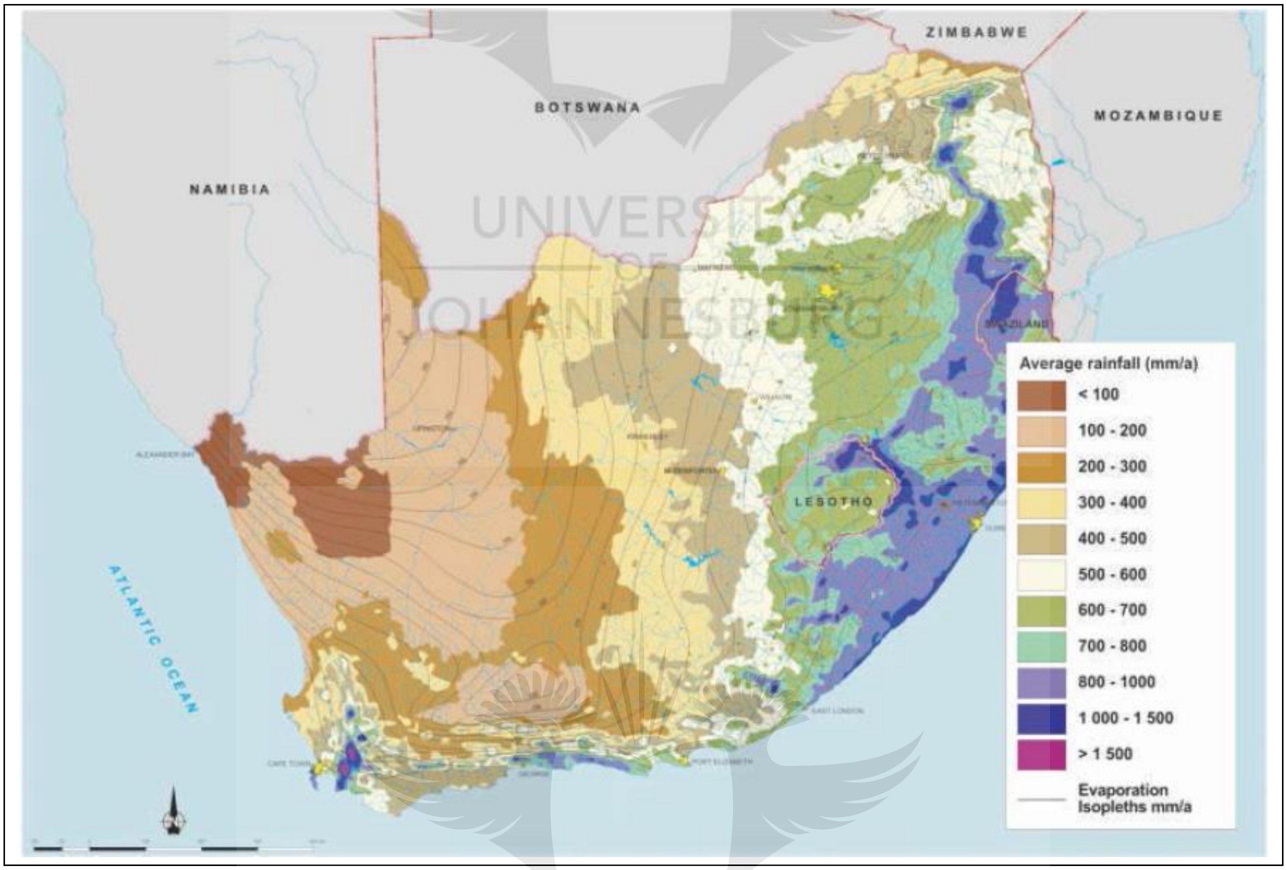


Figure 1.3: The map shows an average rainfall (mm/a) across the Republic of South Africa (DWA, 2009).

In an endeavour to increase the understanding of water issues, different authors have defined "Water Quality" and "Water Pollution" in various ways. Water quality can be defined as "*the chemical, physical and biological characteristics of water, usually in respect to its suitability for a designated use.*" (DWAF, 1998a; Daniels *et al*., 2009) while pollution is "*the introduction of any substance property into the environment (including radiation, heat, noise and light) that has or results in direct harmful effects to humanity or the environment or that makes the environment less fit for its intended use*" (Moosa, 2000). The water quality characteristics are primarily governed by suspended or dissolved materials in water systems (DWAF, 1998a). The catchment's activities, land uses, and the geology of a catchment are known as the determining factors of the water quality (Van Veelen and Dhemba, 2011). This includes the anthropogenic impacts that reduce the quality of water such as an increase in urbanization, growth of the population, introduction of industries and climate change (Van Veelen and Dhemba, 2011). Halder and Islam (2015) noted that pollution from these factors can be so detrimental to the well-being of both the Earth and its inhabitants. In addition, the quality of water is measured based on its fitness for use, which means that a user is required to determine if the water can be used for a specific purpose or it cannot (Van Veelen and Dhemba, 2011). Dozier (2005) added that pollution occurs when a substance or material is introduced into the aquatic environment resulting in dirty water that is not safe for a specific use. According to Dozier (2005), pollution also occurs when there is an overload of something in a water resource, which will alter the communities of aquatic organisms. Due increases in water pollution in South Africa, as a result of various reasons, water pollution is of great concern and if left unattended will have dire consequences. Uncontrolled water pollution results in health hazards to human beings, animals and other living things (Nkosi, 2015).

The lack of water and drought conditions in most parts of South Africa are some of the country's biggest issues. A lack of education is regarded as the main reason that most South Africans do not really understand the health risks that can be caused by polluted river systems (Chola *et al*., 2015). A study conducted by Statistics South Africa in 2010 indicated about 60 000 diarrhoeal reports every 4 weeks in children younger than 5 years of age while 9,000 people died in comparison with 5,500 that used to happen many years ago (Statistics South Africa, 2012). One of the contributing factors is the poor environmental conditions such as polluted systems and/or poor sanitary conditions (Chola *et al*., 2015). South Africa has a constitution that values sustainability in the country's growth and the necessity for a suitable environment to ensure the well-being of current and future generations (King *et al*., 2008). There is therefore a need to prioritise the required interventions that will safeguard the aquatic ecosystems such as the Sabie River system.

The National Water Act of 1998 offers several sections with the aim of managing our water resources (RSA, 1998). King *et al*. (2008) stated that the Act "*makes provision for meeting the human basic needs and safeguarding the ecological integrity and recognises that South Africa's international obligations must be met*". In the Sabie River system, the impacts of the Sabie Wastewater Treatment Works (WWTWs) were assessed using the River Eco-Status Monitoring Programme (previously referred to as the River Health Programme), which intends to protect the rivers of our country. The rapid assessment method which includes the South African Scoring System version 5 (SASS5), Rapid Habitat Assessment Method (RHAM) and the water quality assessment, were applied to achieve the aims and the objectives of the study. The results of this study will indicate whether the treatment plant is affecting the water resource and whether the discharges are within the specified limits or water quality discharge standards as set out by the

Department of Water and Sanitation (DWS) (DWAF, 1984). It was noted that this could provide an idea as to whether the WWTWs is properly managed and provide information to managers, enhancing their ability to make informed decisions on water resource requirements for any further protection. This may also provide assurance on the safety of the water for use by the downstream users.

1.1 AN OVERVIEW OF THE STUDY AREA

The Sabie River system starts from Eastern slopes of the Drakensberg escarpment at approximately 2053 m a.s.l. This system also goes down to 120 m a.s.l and this is where it flows into the Coromana Dam in Mozambique at an estimated 175 km downstream from its source (MTPA, 2012). The Sabie River Sub-catchment occupies about 7 100 km^2 in size with a mean rainfall pattern p.a. that relates to its topography, which varies between 600 mm and 2 000 mm p.a. (Hill *et al*., 2001). It falls within the main ecoregion, Ecoregion 4.03, which is comprised of the upper part of the Drakensberg Escarpment at altitudes ranging from 1000 m and 2000 m a.s.l. (RHP, 2001). These altitudes have affected the vegetation cover of the Sabie River system from where it starts to the end in Mozambique, which has resulted to it being divided into 31 reaches (MTPA, 2012). The Sabie catchment falls within the Inkomati River basin, which is an international drainage basin occupied by South Africa, Swaziland and Mozambique (Figure 1.4). The major tributaries of the Sabie system include the Sand and Marite Rivers, followed by the Mac-Mac, Mutlumuvi and Motitsi Rivers (RHP, 2001). All these systems are cold-water mountain streams that are not wide in terms of the width, and are characterised by medium to steep slopes which results to their fast-flowing waters (RHP, 2001). The rock water pools, run-riffle-rapid overflow and waterfalls are all found in these systems in abundance (RHP, 2001).

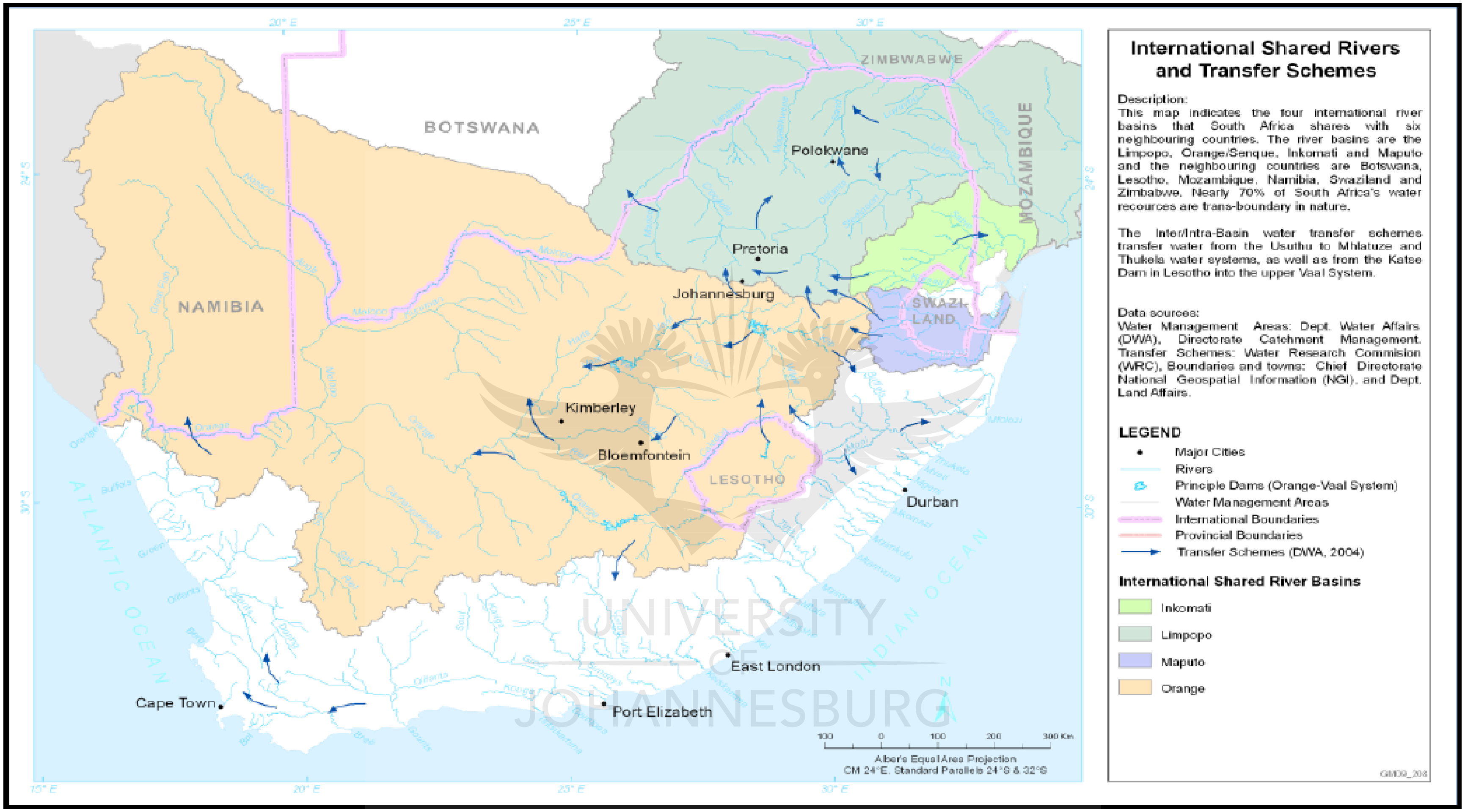
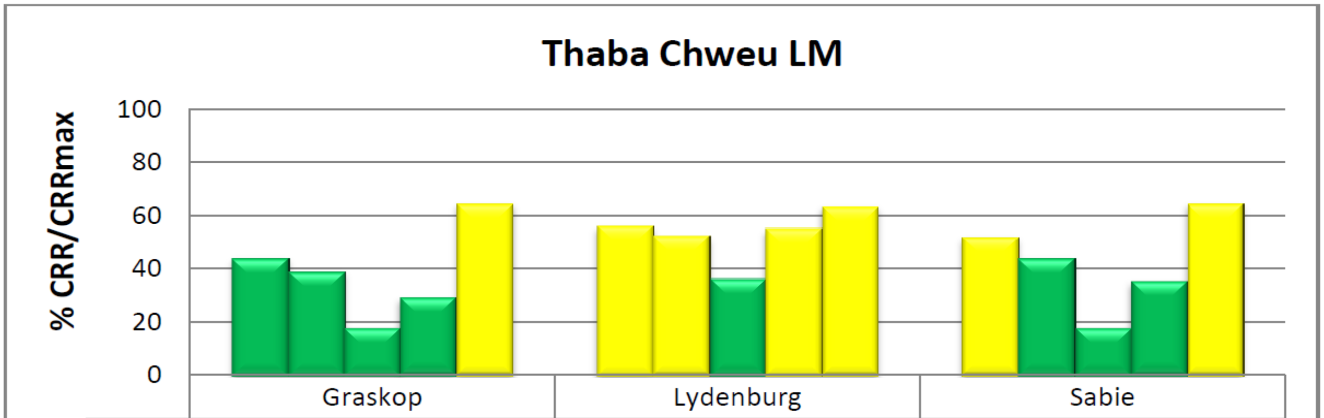


Figure 1.4: International Rivers shared by South Africa with neighbouring countries and transfer schemes (Source: DWA, 2012).

1.1.1 SURFACE WATER

The Sabie River system is the main system that provides water to the KNP, which makes this catchment the one of the most significant ecological systems in South Africa. This is also the most significant system as the entire catchment depends on it to supply water for domestic purposes and for ecological needs with the help of the Injaka Dam, which is in the Sabie River, upstream of the KNP (DWAF, 1997). This system comprises of only 28% of the catchment producing about 90% of the run-off (AWARD, 1998). The quality of water in the Sabie River system is generally in a good condition but the surrounding anthropogenic activities, such as forestry, in the upper part of the catchment and irrigation in the middle part, have created unnecessary water stresses in the river system. Some of the water stressors have been introduced because of the WWTWs in the catchment (AWARD, 1998). The Green Drop System (GDS) started in 2009 (and repeated in 2011 and 2013) where the municipal WWTWs within the country were assessed and being awarded with green drop (GD) status when they meet the requirements of the approach (DWS, 2014). The Sabie catchment belongs to the Thaba Chewu local municipality. The GD scores for 2009 were not available because Sabie did not participate on the assessment of their WWTWs. The GD scores for 2011 and 2013 were 77.1% and 79.0%, respectively (DWS, 2014). These scores were not enough to qualify for the award, which means that the water quality discharges do not comply, and results in water quality degradation.

In terms of the Risk Assessment Profile, Sabie WWTWs obtained a score of 52% in 2008 and 18% in 2012. The risk increased in 2013 and 2014 (from 35% to 65%). Only in 2012 was the most promising with low risk that was closer to the 10% as per the requirement of the Green Drop Status (Figure 1.5). The WWTWs within the catchment are generally increasing from low to medium risk, which is a worrying factor (see Figure 1.5), because the water quality may become critically degraded if something is not done.



	Graskop	Lydenburg	Sabie
2008	44	56	52
2011	39	52	44
2012	18	36	18
2013	29	55	35
2014	65	64	65

Figure 1.5: Results for the Risk Profile assessment of the Green Drop PAT for the WWTWs within Thaba Chewu local municipality for 5 years (Source: DWS, 2014).

1.1.2 NATURAL VEGETATION

The most abundant vegetation in the study area has been described as a mixture of the mountain grassland and Afromontane forest. This vegetation type is assumed to occur because of the effects of the altitude varieties in the catchment (RHP, 2001; MTPA, 2012). The vegetation types are distinguished in terms of the zones from the upper to the lower parts of the catchment.

The following are the natural vegetation types in the upper parts of the Sabie River catchment (Mucina and Rutherford, 2006; MTPA, 2012):

- ✓ Northern Escarpment Dolomite Grassland,
- ✓ Long Tom Pass Montane Grassland, and
- ✓ Northern Escarpment Quartzite Sourveld.

The natural vegetation types found in the middle parts of the catchment are as follows (Geldenhuys, 1992; Mucina and Rutherford, 2006; MTPA, 2012):

- ✓ Legogote Sour Bushveld,
- ✓ Subtropical Afromontane Forests, and

- ✓ Pretoriuskop Sour Bushveld.

The natural vegetation types found within the lower parts of the Sabie River catchment areas are as follows (Mucina and Rutherford, 2006; MTPA, 2012):

- ✓ Delagoa Lowveld,
- ✓ Granite Lowveld,
- ✓ Northern Lebombo Bushveld, and
- ✓ Sweet Arid Basalt Lowveld.

Due to several anthropogenic factors such as land degradation as a result of industrialization, mining, agriculture, formal and informal settlements (most of the above natural vegetation types are no longer found).

1.1.3 TERRAIN

In terms of the terrain or topography of the catchment, the grasslands are located on flat levels to regular coastal highlands and mountainous areas with an altitude ranging from 300 m - 2850 m a.s.l. with the Savanna which extends from an altitude of 2000 m to hundreds of meters down a.s.l. (Garner, 2006). The terrains of the Sabie River are characterised by cold mountain streams that have narrow widths and medium to steep slopes, which explains the reason why they are normally fast flowing systems (RHP, 2001).

1.1.4 GEOLOGY AND SOILS

The catchment is characterised by complex soils that are derived from the Transvaal Super-group. These soil types comprise of the dolomite series, black reef series and the Archaean-basement-complex (Garner, 2006). The soil types in the area are mainly affected by the geological materials. These include Nelspruit Granite which are the soil types that are formed from the granites and they are normally sandy-clay-loam to sandy-clay and Selati Shale which are the types of soils that are formed from the Selati shale and they are normally sandy-clay-loams with a rough sand-grade (Deall, 1989). The southern part of the Sabie catchment are characterised by the Black Reef Quartzite and Oaktree soils. The Black Reef Quartzite soils are the sandy soil types along the Escarpment Crest that have been derived from the materials of

Black Reef and these soil formations are normally known as sandy because they contain 78% of sandy and less loam soils but they are in fact Sandy-Loam. The other soil formations in the nearby areas “Plateau Interior” of Sabie are Oaktree soil formations, which show high amounts of clay in the subsoil (Deall, 1989). It been noted that the andesites, basalts, conglomerates granites, gneiss, irons, quartzites and shales are the main geological types in the catchment (RHP, 2001).

1.1.5 SURROUNDING LAND USES

The riparian areas of the catchment are being utilised for anthropogenic activities such as the dry land farming, agroforestry and nature reserves (Hill *et al*., 2001). The major impact that can eventually destroy the integrity of the riparian zones and vegetation includes the agroforestry near and within the riparian zones. Poor vegetation cover under the bigger trees results in a lack of bank stability and later causes soil erosion. Large volumes of water used by alien vegetation compared with indigenous vegetation have been noted (Hill *et al*., 2001). Alien plants in most areas dominate because they out compete the indigenous plants, which negatively affects the riparian biodiversity (RHP, 2001). Impacts of the trout farms negatively affects the in-stream health ecology because they lead to water diversion for weirs and dams, which interfere with the flow regime of the system, and this is the situation in the upper Sabie River system (DWAF, 2000). This also threatens the indigenous fish (such as the Rainbow trout, *Oncorhynchus mykiss*, which outcompetes and prey on the indigenous fish species) which interferes with the fish communities within the system and leads to nutrient loading into the river from the fish feed and waste (RHP, 2001). From Figure 1.6, it can be noted that agroforestry is the most dominant anthropogenic land use in the area.

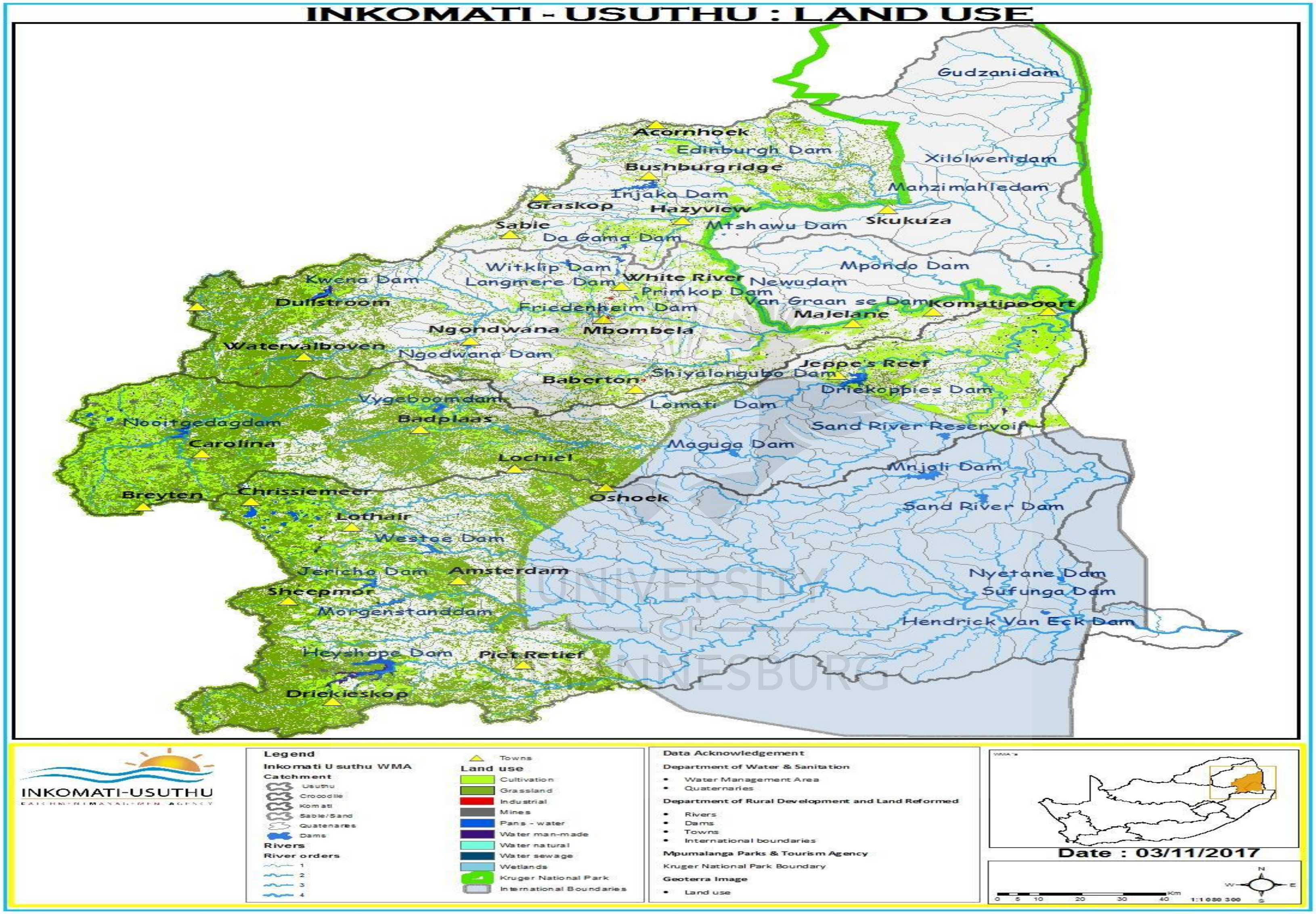


Figure 1.6: Landuse within the Inkomati Water Management Areas.

1.1.6 CLIMATE

The Sabie area is within a seasonally dry, subtropical region and is characterised by the warm and wet weather in summer with cool and dry winter. This area is in between the warmer Lowveld (east) and the Highveld highlands (west) (Deall, 1989). A variety of altitudes and reliefs has resulted to huge differences in rainfall of 600 to 1 200 mm p.a. (RHP, 2001). The temperatures around the town of Sabie and Graskop range from a minimum of -1°C to a maximum of 39 °C. The mean total precipitation has been recorded as 1105.6 mm p.a. in the Sabie area (Garner, 2006).

1.1.7 NATURAL HERITAGE SITES

In the Sabie area, there are more than 20 registered Natural Heritage Sites. These include the Mondi Cycad Reserve, Misty Mountain, In-De-Diepte Reserve, Waterval and Mount Sheba Nature Reserves (Sabie Source of Surprises, 2002). The heritage sites need to be registered with the South African Natural Heritage Programme (SANHP). SANHP is "a voluntary programme and participation at the sole discretion of the land owner". Some of the requirements to meet the registration criteria include "*stands of special plant communities, good examples of aquatic habitats, sensitive catchment areas, habitats of threatened or endangered species, as well as outstanding natural features*" (Sabie Source of Surprises, 2002).

The heritage resources within the IWMA have been combined with economic sectors such as conservation and tourism and they need to be protected to avoid degradation of their status (Sabie Source of Surprises, 2002; IWMA, 2008). Sabie Source of Surprises (2002) noted that these sectors will remain the most significant role players in terms of the economy within the Mpumalanga Province, which includes the IWMA status.

1.2 SITE SELECTION AND DESCRIPTION

The Sabie-Sand Catchment is shown in Figure 1.7 below. The Sabie River runs through Sabie, Hazyview and Skukuza in KNP with tributaries such as the Sand, Marite, Motitsi, Mac-Mac, Sabane and Klein Sabie (MTPA, 2012). The biomonitoring points are also shown, and they were selected from Sabie to the KNP, together with the tributaries. The research covers relatively a small portion of the upper Sabie River sub-catchment. The upper Sabie River system is under severe pressure because of the impacts such as agroforestry, timber and sawmills, trout farms and the WWTWs (MTPA, 2012). These impacts result to flow reduction, water quality disturbances and loss of indigenous fish species because of the introduction of the trout species (*Oncorhynchus mykiss*), which feed on and outcompete the indigenous species (MTPA, 2012).

Figure 1.8 shows the planned monitoring points for the study within the upper Sabie River sub-catchment in the mainstream. Four monitoring points/sites were selected and monitored to achieving the aims and objectives of this study. These sites are shown in Table 1.1, which includes the sampling sites above and below the discharge point of the Sabie WWTWs with one site located at the point of the discharge. Site (SMP) was selected and sampled in the Sabie River just below the Merry Pebbles Resort. The monitoring point at Merry Pebbles Resort was sampled above the WWTWs to compare its results with the site below the WWTWs. Only water quality was sampled for the Sabie Discharge Point (SDP) of the WWTWs. Two of the sites were sampled downstream of the WWTWs to check if there is a change compared with the upstream sampling sites. The two sites were SSW (Sabie Sewage Works, just 2-4 m from the discharge point) and SLB (Sabie Lower Bridge). The co-ordinates for the location of those four sites and details of what was monitored, and sampling methods are included in Table 1.1.

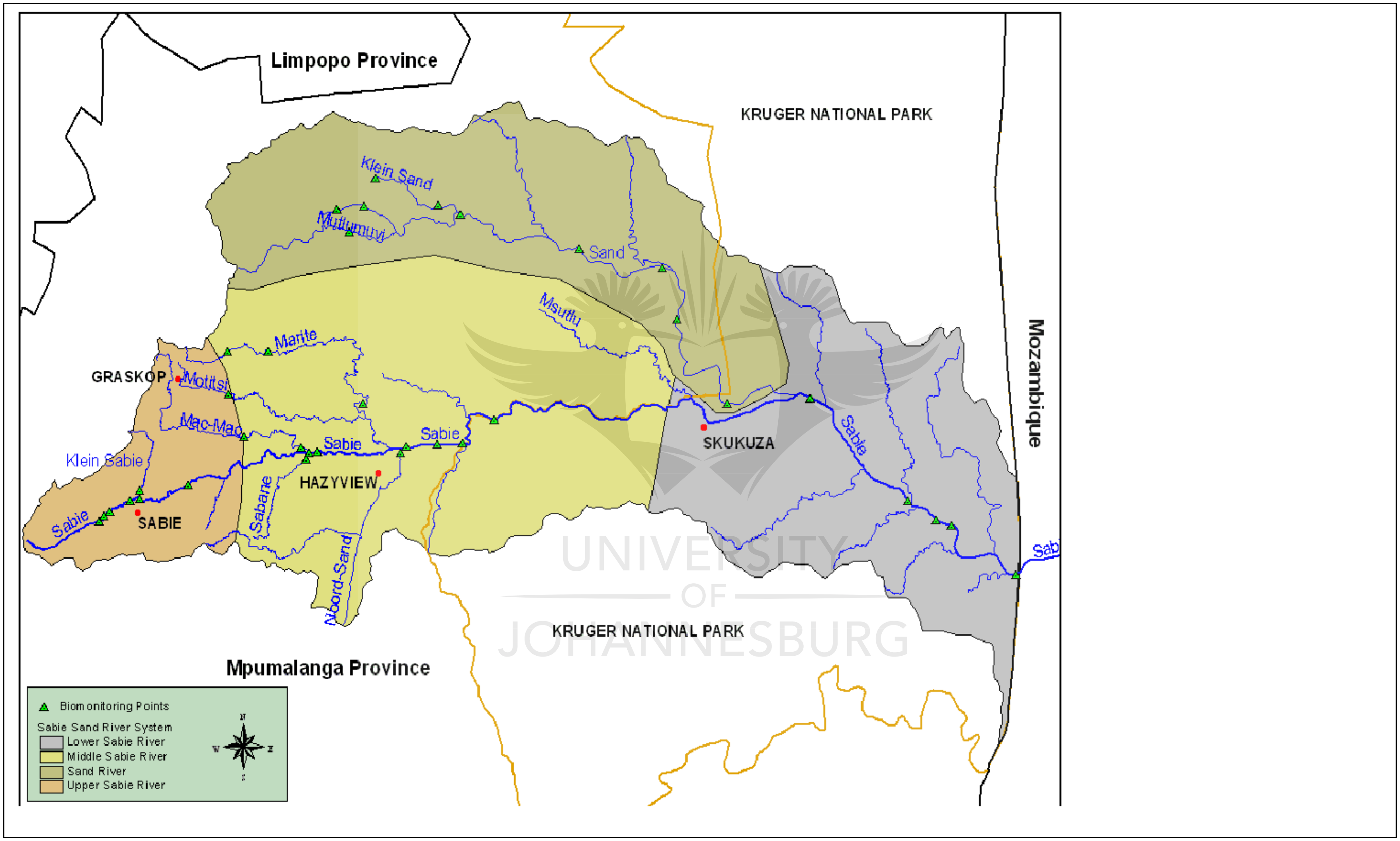


Figure 1.7: Map showing the Sabie River system, its tributaries and general biomonitoring points (Source: MTPA, 2012).

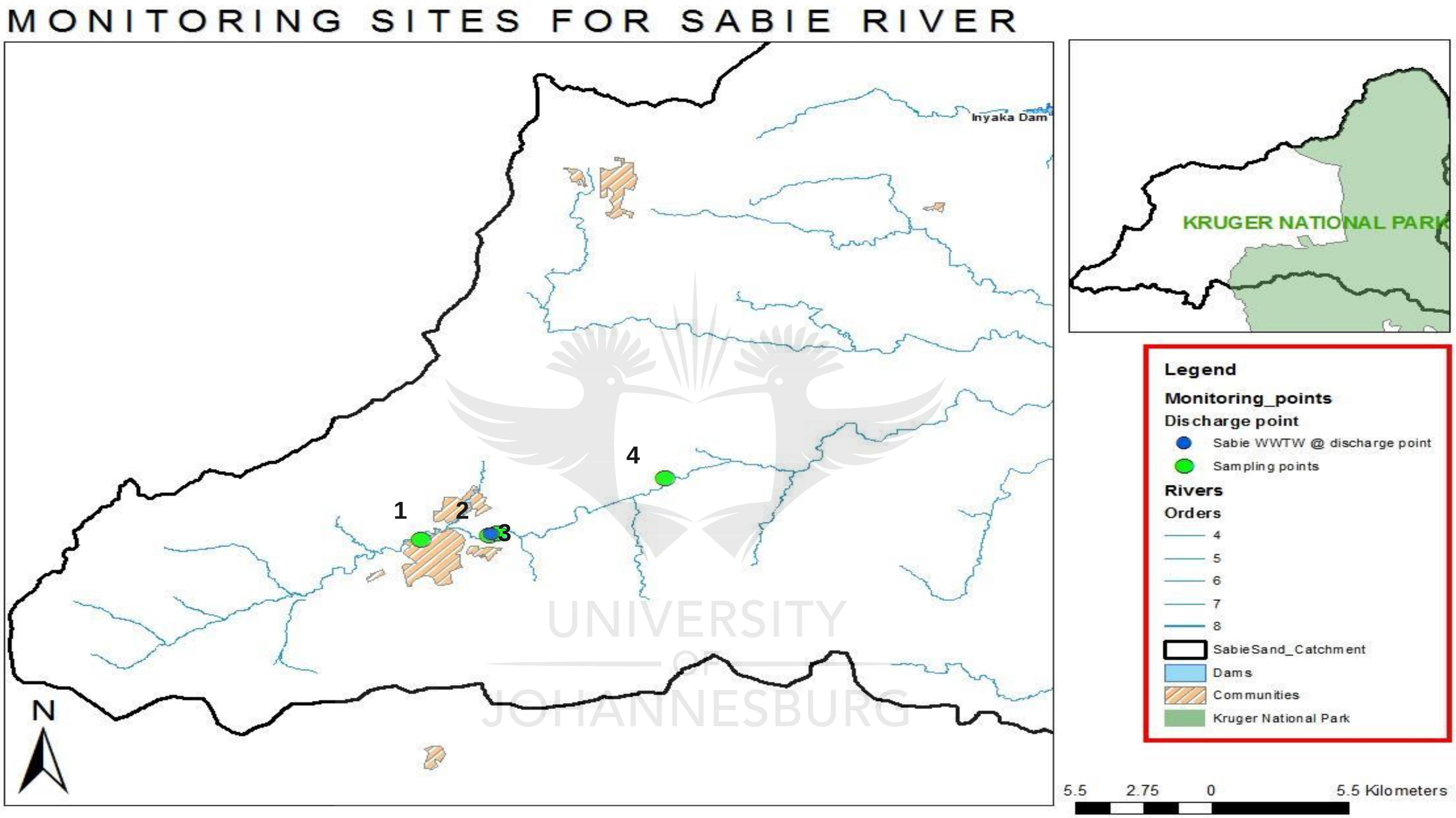


Figure 1.8: Map that shows Monitoring Sites (1. SMP, 2. SDP, 3. SSW and 4. SLB) for the Sabie River Study.

Table 1.1: Monitoring sites for Sabie River study.

			LATITUDE	LONGITUDE
SITE CODE	**SITE ID**	**METHOD TO BE USED**	**Decimal**	**Decimal**
X3SABI-CASTE	SMP	SASS 5, Water Quality and RHAM.	-25.09347	30.769298
X3SABI-DISCH	SDP	Water Quality.	-25.091497	30.79434
X3SABI-RIOOL	SSW	SASS 5, Water Quality and RHAM.	-25.090292	30.797078
X3SABI-BRUG1	SLB	SASS 5, Water Quality and RHAM.	-25.0657	30.85817

1.3 DESCRIPTION OF THE RESEARCH PROBLEM

The research was intended to monitor just a small part of the upstream area of the Sabie River above and below the Sabie WWTWs in the Sabie River. The research problem is that the WWTWs from the town of Sabie is likely to have a negative effect on the water quality and the aquatic health of the Sabie River. It is expected that this research, based on the expected results, will show that the WWTWs has impacted the Sabie River. The water quality was expected to be better upstream of the WWTWs compared with the downstream sites and the discharge point was expected to have extremely poor water quality. The Sabie system has been noted as a system with alien forestry plantations, infrastructures (formal and informal roads) and impoundments such as dams and gauging weirs (WRC, 2001). The above practices can alter the habitat structure of the ecosystem, interfere with the integrity of water and limit the habitat for the assemblage of in-stream biota (WRC, 2001). The interference with the habitat and water quality can cause disturbances in species richness and the variability for macroinvertebrate assemblages (WRC, 2001). In this instance, the ecosystems then become unable to deliver expected goods and services that play a role in the well-being of humans and to the progression of the nation's economy (RHP, 2004).

1.4 RATIONALE OF THE STUDY

The Sabie River is one the largest river systems within the Mpumalanga Province and it transects the KNP, an important conservation area that attracts tourists (Vieira, 2015). It was chosen for this study because of its importance to the surrounding community members of the Sabie area that depend on it, as it provides water for about 650 000 community members that live around the Sabie area (Vieira, 2015). Besides this fact, this system also benefits Mozambique and therefore means that any interventions to remediate the situation of this system will not only affect South Africa. Apart from it being regarded as the Mpumalanga Provinces most important water system, it is unfortunately influenced by numerous land use impacts which includes agriculture, alien tree plantations, very few mines and effluent treatment systems such as the WWTWs (Chunnet *et al*., 1990; Hill *et al*., 2001). This catchment includes South Africa, Swaziland and Mozambique. It forms part of the bigger Sabie-Sand Catchment, which displays most of the issues that affects our country. An example is the poor or lack of basic services (mostly in rural areas), lack of food for some communities, poorly serviced structure that are meant to provide water to the communities and inadequate water availability for ecological needs (Vieira, 2015).

1.5 RESEARCH QUESTIONS

The study attempted to answer the following research questions:

- ✓ What is the present ecological state of the Sabie River?
- ✓ Does the Sewage Works or WWTWs have negative impacts on water quality parameters and the macroinvertebrate community assemblages of the Sabie River sub-catchment?
- ✓ What is the condition of the instream habitat?

1.6 AIM OF THE PROJECT

The aim was to determine the impacts that the WWTWs has on the Sabie River by monitoring its aquatic health condition using biological indicators and water quality parameters.

1.7 OBJECTIVES OF THE PROJECT

The objectives of the study were as follows:

- ✓ To determine the present ecological state (PES) of the Sabie River by monitoring the macroinvertebrate taxa, abundance and diversity,
- ✓ To assess the impacts of WWTWs on water quality,
- ✓ Assess the instream habitat availability for the aquatic biota using the Rapid Habitat Assessment Method (RHAM),
- ✓ Assess the spatial and temporal trends of water quality and ecological state.

1.8 HYPOTHESIS

The hypothesis was that the Sabie WWTWs has a negative impact on the water quality and aquatic health of the Sabie River system.

1.9 CONCLUSION

The Sabie catchment is very important because it is an international drainage system, forming a linkage between South Africa, Swaziland and Mozambique. The whole catchment depends solely on the Sabie River system for water provision for human and ecological use, with the assistance of the Injaka Dam in the Sabie River (DWAF, 1997). This system comprises of only 28% of the catchment, which makes approximately 90% of the run-off (AWARD, 1998). The Sabie River is under severe pressure as a result the surrounding anthropogenic activities in the riparian zones such as agroforestry, including timber or sawmills, sewage treatment plants and trout farming. It is important to monitor the natural resources to make informed decisions on the level of disturbances in our systems and properly plan on how to resolve the issues and protect these water resources. The belief is that this study will provide information on the performance of the WWTWs in terms of the effluent quality being treated.

1.10 CHAPTER OUTLINE

Chapter 1: This is a **General Introductory** chapter which includes the description of the study area, site selection and description, research problem, study motivation, questions that relates to the study, aims, objectives and the hypothesis of the study, as well as the structure in which the study report is presented.

Chapter 2: This is a **Literature Review** chapter and it presents an overview of the South African legislation, biomonitoring in South Africa, aquatic macro-invertebrates, water quality and its monitoring index, Rapid Habitat Assessment Method and conclusion.

Chapter 3: This is the chapter that elaborates on the **Materials** used for the data collection and **Methodology** applied to conduct a study. It includes the research design, sampling of Eco-Classification determinants (Macroinvertebrates and Rapid Habitat Assessment Method) and Water Quality, data analysis.

Chapter 4: This chapter is about the **Results** and **Discussions** as it shows the research findings with those findings being discussed.

Chapter 5: This is the chapter where the **Concluding** remarks and **Recommendations** are drawn based on the study results.

Chapter 6: This chapter is about the **References** that have been included or cited in the text of the whole research report.

CHAPTER 2: LITERATURE REVIEW

Chapter 3 of The National Water Act, Act No. 36 of 1998, guides water resource management in South Africa, which deals with the protection of water resources (DWAF, 1998b). This is because of the formation of different monitoring programmes, which include the former River Health Programme (now the River Eco-Status Monitoring Programme). This chapter elaborates on various studies that have been conducted concerning legislation and water resource monitoring as part of water resource protection, because one needs to be well informed of the status of water resources to make informed decisions about the management.

2.1 AN OVERVIEW OF THE SOUTH AFRICAN LEGISLATION

The Constitution of the Republic of South Africa (RSA) is a legal corner-stone and guardian of all-natural resources (Nkosi, 2015). One of its duties is to safeguard preservation of water resources for the current and future generations. Legislation carries out measures such as a permit or water use authorisation and water use licensing with conditions for implementation by the holder of such authorisation (Nkosi, 2015). It is also important to note the RSA has two main laws that play a pivotal role in environmental management and they include "the National Environmental Management Act 107 of 1998, NEMA" and "the National Water Act 36 of 1998, NWA" (Bond and Stein, 2000). Both the NEMA and NWA have some similarities such as emphasising the concept of sustainable development (Bond and Stein, 2000). As is the case with the RSA Constitution, the application of these legal tools is solely dependent on the ability of the state's legal systems to provide assurance "based on the constitution" and the "right of access to courts or any other independent or impartial tribunal or forum" (RSA, 1996; Bond and Stein, 2000). This has been noted as a very important matter when it comes to the NWA, which is mandated to deal with the proper and effective management on the important and scarce resource called "Water".

The NWA (Act No. 36 of 1998) was announced in the Government Gazette No: 19182 (Volume 398) of the RSA. The Act provides guidance as to how "*to protect, use, develop, conserve, manage and control*" South Africa's water resources. It is the major lawful tool that relates to South Africa's water resources management (DWAF, 1998b). The Act signifies a central improvement for the legislation concerning the water resources of South Africa as a country and substitutes the former Water Act of 1956.

The NWA exists to serve a purpose of ensuring that the country's water resources are being utilised in a manner that includes a variety of aspects (RSA, 1998). These aspects include sustainability which caters for basic requirements of the existing human generations and for generations to come, encouraging equal access to water for all, correcting the bad outcomes of the past discrimination based on gender and race, facilitating socio-economic development, ensuring the aquatic ecosystems and biodiversity protection, pollution prevention and reduction and ensuring that the international obligations are being met (RSA, 1998). These are covered in different chapters and sections of the act, for example, pollution prevention is covered in chapter 3, section 19 of the National Water Act. However, the NWA forms the umbrella of the Water Supply and Sanitation Policy of 1994 together with the Water Services Act of 1997 (No. 108 of 1997), a legal document that entails the delivery of water for human use and for sanitation purposes (DWAF, 1998b).

Chapter 3 of NWA focuses on ways that assist in the "*protection of water resources*" (RSA, 1998). The impacts in water quality are then managed as a result of the existence of this chapter and this has been made to be the main factor worldwide, in emerging and established nations (Helmer and Hespanhol, 1997). The proper maintenance of good water quality reflects mostly on the physico-chemical parameters that clearly informs when the quality of water is suitable for use. These parameters need to include the ammonium, dissolved oxygen, nitrates and phosphates (Helmer and Hespanhol, 1997). To achieve the goal of maintaining good water quality in RSA's aquatic ecosystems, planning should contain detailed information of the detrimental influence of individual parameters in macro-invertebrates and fish (Helmer and Hespanhol, 1997). To achieve the requirements of Chapter 3 of the NWA, the Act explicitly dictates that the Minister must develop "*the national monitoring systems that monitor, record, assess and disseminate information on water resources*" (RSA, 1998). In the past, the decision-making of the country has generally not taken seriously, considering the objectives of monitoring networks and programmes for the water resource quality in South Africa (DWAF, 2004a).

The need for initiating specific monitoring programmes has been addressed to regularly assess the suitability of aquatic ecosystems for specific use as they are vulnerable to pollution (Helmer and Hespanhol, 1997). The United Nations Environmental Programme (UNEP) has been working together with the agencies of the United Nations (UN) in controlling the fresh water quality monitoring programme globally. These programmes play a pivotal role in producing data used in assisting in making water management decisions (Van Niekerk, 2004). The programme may determine or recommend the selection of monitoring sites, variables or parameters to be monitored, frequency, operational instruments, type of data and quality assurance procedure.

Many other national water quality monitoring programmes in RSA have been initiated in an endeavour to meet the needs of the National Water Act of 1998. These programmes include the National Eutrophication Monitoring Programme (NEMP), National Microbial Monitoring Programme (NMMP), the National Toxicity Monitoring Programme (NTMP), the National Radioactivity Monitoring Programme (NRMP) and the River Health Programme (RHP) (Van Niekerk, 2004; DWAF, 2004b). These separate monitoring programmes are characterized by their various monitoring parameters with selected sampling points and the use of various assessment methods, which requires different expertise (Van Niekerk, 2004).

2.2 BIOLOGICAL MONITORING IN SOUTH AFRICA

The term "Biomonitoring" (also known as biological monitoring) is a method of using the biotic factors (living organisms) and/or their responses in determining the ecological category or condition of the aquatic ecosystem (Li *et al*., 2010). In addition, "*Biomonitoring is a method of observing the impact of external factors on ecosystems and their development over a period, or of ascertaining differences between one location and another*" (Li *et al*., 2010). According to DWS (2016), this method was initially designed in 1994 as the River Health Programme (RHP) by the Department of Water Affairs and Forestry (DWAF). Numerous advancements have occurred which resulted to the change of the well-known RHP to become "The River Eco-Status Monitoring Programme (REMP)". The REMP has substituted the RHP in 2016 and it forms part of the bigger National Aquatic Ecosystem Health Monitoring Programme (NAEHMP), a programme that was predicted as a future programme to finally include the waterbodies such as wetlands and estuaries (DWS, 2016; Claassen, 2007).

The REMP plays a major role in providing a complete condition or state of an ecosystem. The results assist the authorities in making informed decision concerning the required management intervention that are needed to remediate a river system (Roux, 1997). Roux (1997) also suggested that the involvement of regional stakeholders is necessary for an effective operation and continued care of the programme. The information obtained using in-stream (such as the biota, which include the fish and invertebrates) and riparian (such as habitat integrity and geomorphology) biological information help to clarify how the water environment responds to disturbances or changes in the surrounding environment (Roux *et al*., 1999; Maseti, 2005; DWA, 2015b). The motivation was that the well-being of living organisms “biotic integrity” occupying the aquatic environments play a role in showing the straight forward and collective quantities for the entire ecosystem’s wellbeing (Roux *et al*., 1999). Karr and Dudley (1981) defined the term “Biotic integrity” as an ecosystem’s capability in helping and maintaining a stable, unified and adaptive assemblage of organisms. This must include a high diversity of species, structure and functional groups that are similar to the normal habitats of origin.

The REMP follows the EcoClassification-EcoStatus approach using the Eco-Status models and indices (DWS, 2016). Kleynhans and Louw (2007) and Ross and Ross (2016) have agreed that “*the **Eco-Status** is the sum of all the features and characteristics of the system together with its riparian zones that brings upon its ability to support the natural flora and fauna*”. This is an approach that has been accepted by the Department of Water and Sanitation (DWS) for application in both the REMP and Ecological Reserve determinations. The REMP produces data that are not ideal to fit into the Water Management System (WMS) (van Niekerk, 2004). These data can only be captured and kept in the Rivers Database, because the REMP data results from ecological investigations and is assessed using the Indices and analysed using models (van Niekerk, 2004). According to van Niekerk (2004), these methods interpret data in terms of the fulfilment of the Resource Quality Objectives (RQOs) and this involves the Recommended Ecological Category (REC) and/or Ecological Specifications (Eco-Specs).

The existing and approved Eco-Status models include the River Data Integration (RIVDINT), which uses the Index of Habitat Integrity model, fish, macroinvertebrates and vegetation and are all assessed at a quaternary reach level (DWA, 2015b). The models that have been implemented *in-situ* include the Macro Invertebrate Response Assessment Index (MIRAI), Fish Response Assessment Index (FRAI), Index of Habitat Integrity (IHI), Riparian Vegetation Response Assessment Index (VEGRAI), Rapid Habitat Assessment Method (RHAM), and the integrated EcoStatus (DWA, 2015b). The REMP data only included the indices with no models in the RHP, and these indices included the aquatic macroinvertebrates [South African Scoring System version 5 (SASS 5)], fish assemblages [Fish Assemblage Integrity Index (FAII)] and riparian vegetation [Riparian Vegetation Index (RVI)] and physical indicators which are habitat [Habitat Integrity Index

(HII)], geomorphology [Geomorphological Index (GI)], water quality [Water Quality Index (WQI)] and flow [Hydrological Index (HI)] (Maseti, 2005). According to Claassen (2007) and DWA (2015b), the objectives of the RHP were designed to quantify and report on the ecological state and trends of aquatic systems, to identify and report on problem areas, and communicate the information with stakeholders such as politicians, water resource managers, industries and the public. The EcoStatus in the case of REMP entails the specific objectives of each of the component categories which includes the category of the fish, macroinvertebrates, vegetation, etc. (Kleynhans and Louw, 2007) with the aim of integrating those categories into one Eco-Status category.

It is also important to take note that MIRAI has been upgraded to version 2 and FRAI has been upgraded to the Fish Invertebrate Flow Habitat Assessment (FIFHA). According to DWA (2015b) and DWS (2016), for the FIFHA model to be effectively utilised, it is necessary for the EWR site to have an availability of hydrology and hydraulics. The Rapid Habitat Assessment Method and Model (RHAMM) come into play when dealing with the EcoStatus (DWS, 2016). This is an assessment on a site level where a site must represent a Sub-Quaternary Reach and incorporate the other models such as MIRAI, FRAI, VEGRAI, IHI and a combined EcoStatus (DWA, 2015b).

The REMP (former RHP) was the initial assessment plan "*national monitoring programme*" which has undergone a thorough full design and application procedure (Hohls, 1996). Out of the REMP indices and models, the most important biological indicators include the Macro-invertebrates which is done by using the South African Scoring System version 5 (SASS5) protocol (Dickens and Graham, 2002) with its data being analysed by using the Macroinvertebrate Response Assessment Index (MIRAI) as one of the Eco-Status Models (Thirion, 2007).

2.3 THE AQUATIC MACROINVERTEBRATES

The assessment of the macroinvertebrates has been used as a monitoring tool of the aquatic biota since the early 1970's (Bonada *et al.,* 2006). These organisms have been tested to be ideal for the assessment of the ecological integrity of aquatic ecosystem. One of the main reasons for selecting these organisms is because of their generally sedentary behaviour and their ability to detect the surrounding environmental degradations. The South African Scoring System version 5 (SASS5) method was used for sampling the macroinvertebrate taxa (Dickens and Graham, 2002). According to Chutter (1998), the SASS method produces a SASS Score (the sum of the sensitivity scores for the biota found at a specific site), number of taxa (total number of taxa or biota found at a site) and the Average Score per Taxa or ASPT (calculated by dividing the SASS Score with the number of taxa). It has been suggested that the interpretation of the SASS5 results should consider, among other factors, the available quality and quantity of the biotopes or habitat (Dickens and Graham, 2002). During the interpretation of this data, the ASPT score has been recommended as the more reliable score compared with the SASS score (Chutter, 1998).

Macroinvertebrates and diatoms are known as the as bio-indicators or biological indicators which interact with the whole aquatic ecosystem (Li et al., 2010). They respond accordingly to the surrounding environmental changes and therefore provide an overview of the ecological present condition in rivers and streams (Li *et al*., 2010). The term bioindicator has been defined as "*an organism (or part of an organism or a community of organisms) that contains information on the quality of the environment (or a part of the environment)*" (Markert *et al*., 1999). Generally, the benthic macroinvertebrates have been noted as the main part of the macroenvironment and have been extensively utilized in biological assessments. This is because they can be seen with the naked eye, easily identified, they have a quick and seasonal life cycle and normally have inactive behaviours (Dickens and Graham, 2002). These organisms are big enough which makes them easy to distinguish and identify. They normally inhabit the benthic layer of the aquatic systems (Farrell-Poe, 2015).

Macroinvertebrates can be used to assess the river conditions due to distinct advantages (Rosenberg and Resh, 1993; Farrell-Poe, 2015). These advantages include the variability of species sensitivities during harsh conditions as the organisms in one community can respond to ecological stress. These organisms are largely non-mobile during their aquatic stage and represent the sampling site, which allows for an operative analysis of distractions and contaminants (Rosenberg and Resh, 1993). Another advantage is the fact that the macroinvertebrate data collection is very easy, no need for many sampling operators and expensive equipment, and with no negative impacts on the macroinvertebrate community (Rosenberg and Resh, 1993). These organisms are therefore known as constant assessors for the health of the water they inhabit (Hawkes, 1979). Many benefits have resulted in macro-invertebrates being utilised to check the quality of water (Dallas, 2000), and these have been summarised by Rosenberg and Resh (1993). These include the fact that the macroinvertebrates are ubiquitous in rivers and become influenced by ecological disturbances in various water bodies and habitats. Different species of the macroinvertebrates differ in terms of sensitivity to environmental disturbances and respond in different ways (Dallas, 2000). These organisms are largely non-mobile in their aquatic phase and fully represent the sampled location, which effectively permits spatial analysis of disturbance and pollutants. They have longer life-span to permit clarification in temporal alterations that result from ecological degradation. Their life-spans are also short enough to ensure observation of recolonization patterns following the specific degradation event (Dallas, 2000). They are comparatively not difficult to identify to a family level and experienced biologists and technicians can easily detect the disturbances by looking at the available macro-invertebrate groups. Lastly, the macroinvertebrate sampling method is easy to follow and conduct, need very few personnel and inexpensive gear and has no detrimental effect on the resident biota (Dallas, 2000; Li *et al*., 2010).

2.4 WATER QUALITY AND THE MONITORING INDEX

Water quality is defined as water fitness for consumption by human beings and this water is known to be clean or uncontaminated and fit for drinking (Dallas and Day, 2004). The quality of the drinking water must comply with the South African National Standard (SANS) 241 (Hodgson and Manus, 2006). This is very important because failure to comply may result in potential high risk to human health and this includes the infants that are highly sensitive to poor water quality and the elderly people (Hodgson and Manus, 2006). It is unfortunate that unacceptable, poor drinking water quality has become a norm, especially in the rural areas of South Africa. Hodgson and Manus, (2006) noted this occurrence because of the absence of adequate asset control, capacity in Water Service Associations (WSAs) which included education, budget, staff and expertise, poor management of drinking water services monitoring, poor understanding of the need for the proper management of drinking water quality by WSAs, and no interventions in place to effectively deal with poor drinking water quality once it was found.

Palmer *et al*. (2004) stated that "*the environmental water quality (EWQ) approach was initiated as a method that combines the use of water physico-chemistry, biological monitoring and eco-toxicity data to measure the EWQ health*" and therefore contributes in making informed management decisions. Managers within the mining and industrial environments, also utilise the data from this approach. This method can be used when dealing with the Integrated Water Resource Management (IWRM), point and non-point sources of water quality degradation, licensing of wastewater discharge and setting Resource Quality Objectives (RQO). According to Dallas and Day (2004), "*rivers are longitudinal systems driven by water flows and are divided into zones which differ according to their physical, chemical and biological characteristics*". Within these zones, good quality of water assists in regulating aquatic population structure, presence of different biotopes for sampling, rate at which water flows, water quality changes and historical dispersal of the biota (Dallas and Day, 2004).

At the beginning of the 1970's, the "Water Quality Index (WQI)" was initially made to relate the water fitness for use in different countries (Etim *et al*., 2013). The major reason for creating the WQI was to measure the fitness of water mainly for two uses, which included human consumption and agriculture (Stoner, 1978). The index assesses the parameters which significantly impact the fitness of water in river systems. The parameters comprise aluminium (Al), ammonium (NH^{4+}), biological oxygen demand (BOD), calcium (Ca), chlorides (Cl), dissolved oxygen (DO), electrical conductivity (EC), faecal coliforms (F. Coli), fluoride (F), free and saline ammonia (N), magnesium (Mg), nitrates and nitrites (N), phosphates (PO_4), potential of hydrogen (pH), potassium (K), sulphate (SO_4), temperature, total alkalinity ($CaCO_3$), total dissolved solids (TDS), turbidity or total suspended solids (TSS) and zinc (Zn). Following the monitoring of water fitness in rivers, the water quality results play a role in determining if the water is fit for different purposes, if temporal monitoring is necessary and in comparisons with other aquatic systems (Dallas and Day, 2004; Palmer *et al*., 2004; Etim *et al*., 2013).

2.5 STUDIES THAT RELATE TO THE WWTW, MONITORING AND LEGISLATION

Studies in South Africa and internationally have shown the impacts of the WWTWs in human health and the environment. A study that was conducted in Greece has shown severe effects to the public that live near the municipal WWTWs (Vantarakis *et al*., 2016). These included respiratory and skin diseases, serious and dangerous symptoms of headaches, concentration difficulties and feeling of tiredness for no reason. This was as a result of air quality disturbances due to physico-chemical and biological factors from the WWTWs that affects the health and general living conditions of the surrounding community (Vantarakis *et al*., 2016). This study together with other studies by the Department of Occupational Health, Medical College of Ohio, in America, Boston University, School of Medicine and other stakeholders have shown similar results of negative impacts of WWTW (Vantarakis *et al*., 2016; Khuder *et al*., 1998; McCunney, 1986). These studies fully agree with McCunney (1986) in that "*the WWTWs generate aerosols that contains the pathogenic organisms*". These pathogens are being inhaled by nearby communities and result in health risks and even death.

The treatment plants increase the health hazards and result in transmission of infectious diseases to plant workers and surrounding community members (McCunney, 1986). All the impacts that have been mentioned in the above studies corresponds with those of Sebokeng WWTW in South Africa (Envirolution Consulting (Pty) Ltd, 2011). It has been suggested that to protect the communities in urban areas from increased diseases from WWTW, the sewage wastewater should be well-treated (Vantarakis *et al*., 2016). Envirolution Consulting (Pty) Ltd (2011) added "*Wastewater works contribute to emissions which includes the hydrogen sulphide (H_2S), benzene, ethyl benzene, toluene and xylene, odours, and greenhouse gases into the atmosphere and the Sebokeng works is certainly no exception*". When reflecting on the legislation, it can be noted that the South African Water Act of 1956 (Act No. 54 of 1956) provided for the enforcement of effluent treatment to specific standards of discharging into a water resource as approved by DWAF (Mema, 2009).

The WWTWs play an important role in the management of water resources and well-treated effluent avoids severe disturbances to water quality in water bodies, which permits the incorporation of treated waste into water supply systems (DWS, 2014). The South African municipal treatment plants tend to be malfunctioning because of the ineffective management by authorities, limited budget, skills and expertise, resulting in severe disturbances in the water quality of the receiving resource (DWS, 2014). A study that was done by Naidoo and Olaniran (2013) in Kwa-Zulu Natal showed that while trying to improve water sources and sanitation, rapid population growth has also increased issues. The increased population growth has caused more pressure on sanitation systems and more WWTWs were built, but the capacities could not handle the effluent loads, leading to poorly treated effluent being discharged to a water resource. This has resulted in the demand for very strict monitoring of the discharges from the WWTWs to water resources to improve the quality of the discharge. During the study, the microbiological indicators were noted, and the conclusion was that the poorly treated discharges consequently pose health risks to aquatic biota and the surrounding public (Naidoo and Olaniran, 2013). The downstream inhabitants are always at increased risk of diseases due to contaminated water, which leads to the degradation of physico-chemical water quality parameters (Naidoo and Olaniran, 2013).

The influence of WWTWs on the structure of the macroinvertebrate community was tested in Germany, using the German Saprobic Index (GSI). The results showed that the WWTWs were the main reason of oxygen reduction, even after the use of a wide range of improved technological equipment in managing wastewater in many countries (Bunzel *et al*., 2012). Another study in United States where the macroinvertebrates such as the dragonflies and damsel flies were used as the biological indicator organisms that only occupy, develop and reproduce in unpolluted systems that are clean and healthy (Spellman, 2014). These organisms were the most preferred biological indicators due to advantages such as ease to sample, no special protocol needed, visibility to the naked eye, and relatively cheap equipment required (Spellman, 2014). It is for these reasons that aquatic macroinvertebrates are used in South Africa and various other countries. Studies by Bunzel *et al*. (2012) in Europe, Fourie *et al*. (2014) in the Skeerpoort River and in Norway by Nesheim and Platjouw (2016) are evidence of this.

Water quality was also used in the USA to assess the presence of pollutants such as poisonous metals, high nitrogen and phosphorus contents or any organic material that may threaten the aquatic life and human population downstream of the point sources (Neshein and Platjouw, 2016). Five main pollution causes were noted to threaten the water quality in aquatic ecosystems. These pollutants include agricultural activities, WWTWs, habitat and flow regime disturbances, water abstraction, and urban storm water runoff. The limits and standards for water quality parameters were developed in different countries to protect the well-being of the public. Studies by Nesheim and Platjouw (2016) have shown that "*pollutants can remain in the water column without causing any adverse effect on organisms using the aquatic system as habitat, on people consuming those organisms or water, and on other current or potential beneficial uses*". Nesheim and Platjouw (2016) added that the lowermost element of water quality state shows a complete state of water quality and provides a clue on any further management procedures that may be needed, this is known as the precautionary approach. Habitat assessment methods have been used worldwide and not only in South Africa. This method has been and is still being widely used in the USA to determine if water quality disturbances and habitat degradation affect macroinvertebrate communities in a negative matter (Resh *et al.,* 1995).

It must be noted that not all countries make use of their own Water Acts as the legal tool for the management and protection of water resources. The USA make use of the Clean Water Act (CWA) that was established in 1972, for restoration and maintenance of chemical, physical, and biological integrity of water for the whole country, and the Safe Drinking Water Act (SDWA) was also established in 1974 for supply of drinking water for people (Spellman, 2014).

South Africa has made interventions in trying to protect and manage water resources while implementing Chapter 3 of the NWA. Monitoring programmes and management plans have been developed. These include the on-going biomonitoring programmes such as the REMP and the NMMP, and the programme that looks at the nutrient loads called the NEMP. The NEMP together with the NMMP have been discontinued within the Inkomati-Usuthu Water Management Area (WMA). The contract that was granted to the IUCMA by DWS expired and could not be renewed due to capacity issues within the IUCMA, but the plans are to bring these two programmes back after budget and personnel matters have been resolved. The REMP is on-going with relatively few issues of concern. The DWS and the Catchment Management Agencies (CMAs) have been attending to pollution incidences as per the requirement of Section 20 of the NWA. The IUCMA conduct site inspections and audits of water users, such as the mining and industrial sectors. During this process, each of the water users are normally inspected two to three times a year and this depends on the severity of the possible impacts of that specific activity to a water resource (van der Merwe-Botha and Manus, 2011).

The Department and the CMAs have been dealing with non-compliance issues for many years. Several directives in South Africa and specifically within the Inkomati-Usuthu WMA have been issued in terms of Section 20. 4 (d) of the NWA (See example on Appendix A) by the IUCMA. For any of the water users who fail to comply with the directive(s), the matter becomes a legal matter and can end up in court (DWS, 2014). Unfortunately, there are very few cases that have been successful out of many cases that have been opened to date. The Department has also made progress through the development of the Green Drop System (GDS) and the Blue Drop System (DWS, 2014).

The Minister of DWS has introduced a regulation of an award-based ideological term in the water sector during the National Municipal Indaba held in Johannesburg in September 2008 (DWS, 2014). The newly introduced idea comprised of two main programmes called the Green Drop Certification Programme (GDCP) and the Blue Drop Certification Programme (BDCP). The GDCP was based on awarding the municipalities for excelling in managing the quality of the wastewater while the BDCP aimed at awarding and regulating the drinking water quality management to ensure that the quality meets the standards in terms of the SANS 241. In addition, this has resulted in the formation of the No Drop Certification Programme to look at the Water Use

Efficiency and Demand Management (DWS, 2014). Some of the most important requirements in the GDS include effluent quality compliance, waste water asset management, operations, maintenance and management skills, and the total score should be excellent (i.e. 90-100%) and no green drop status if the score is less than 90% (see Table 2.1) (DWA, 2015a).

Table 2.1: Colour Codes of the final Green Drop Scores (DWA, 2010).

COLOUR CODES	PERCENTAGE	ACTION BY WATER SERVICES INSTITUTE (WSI)
Green	90 – 100%	Excellent: need to maintain the status.
Orange	70 – 89%	Good State: maintain and improve excellent status.
Yellow	40 – 69%	Poor Performance: sufficient chance to improve and need attention.
Red	0 – 39%	Critical State: need urgent attention.

The WWTWs collect sewage and operate 24 hours a day, 7 days a week for the whole year. This makes it difficult to manage the untreated sewage qualities and quantities that are being discharged into surface water resources, which may affect the ground water and pose human health risks. This situation has been scrutinized, which has led to the development of the Wastewater Risk Abatement Plan (W_2RAP) as a method of assessing and dealing with the possible risks. The W_2RAP has become the most significant method that improves the service delivery of municipalities (van der Merwe-Botha and Manus, 2011). As indicated in Table 2.2, a high percentage risk assessment profile (e.g. 90-100%) means that WWTWs of a specific municipality is performing well in terms of the effluent treatment. When risk assessment of the WWTWs provide a low percentage (e.g. <50%), it means that the WWTWs are failing in terms of effluent treatment (DWS, 2014). The risk (risk of damage or contamination), in this context, refers to the possible damages to humans and aquatic biota that may occur if they can contaminate with poorly treated water from the WWTWs. The approach or regulation ensures the functioning of the WWTWs. Nationally, the risk assessment of the treatment plant is obtained by calculating the value of the Cumulative Risk Rating (CRR) and the results for the CRR are published every 2 years to check the performance of each of all the WWTWs facilities in the country (van der Merwe-Botha and Manus, 2011). This is found by using the following formula (van der Merwe-Botha and Manus, 2011):

CRR = A x B + C + D

In the above formula, A represents the "*Design capacity of plant, which also represents the hydraulic loading onto the receiving water body*", B represent the "*Operational flow exceeding-, on- and below capacity*", C represents the "*Number of non-compliance trends in terms of effluent quality as discharged to receiving water body*" and D, which represents the "*Compliance or non-compliance in terms of technical skills*" (terrain of the Sabie catchment Area). The amount of the CCR variations is found by determining the deviations of CRR% before reaching the highest CRR value. These deviations of CCR% are found by using the following formula (DWS, 2014):

CRR value / CRR $_{max}$ X100 = CRR% deviation

This method is not used as the full GD assessment but as a method of determining the performance of the Green Drop Risk Profile which has become the most important means of collecting, assessing and report the risk profile called the "Green Drop Progress Assessment Tool (PAT)" (van der Merwe-Botha and Manus, 2011; DWS, 2014).

Table 2.2: Colour Codes for different CRR Classes (DWS, 2014).

COLOUR CODES	RISK CLASSES
1. Red	90 – 100%: Critical Risk
2. Orange	70 – 89%: High Risk
3. Yellow	50 – 69%: Medium Risk
4. Green	<50: Low Risk

Table 2.3 summarizes the national GDS performance for all the nine provinces within the Republic of South Africa. Municipalities from each province have various challenges, which is the reason why they also differ in terms of performance. Some municipalities have been performing excellently in the country (e.g. Western Cape with 19 GD Awards and 65% of Average GDS) while Free State, Limpopo and Northern Cape Provinces have never received any GD Award, which means they are the worst performers (DWS, 2017b).

Table 2.3: Summary of Provincial Green Drop performances (DWS, 2017b).

SOUTH AFRICA: COMPARATIVE ANALYSIS: GREEN DROP SCORES							
Province	Number of Works	Provincial Green Drop Score	Risk Profile [CRR as % of CRR (Max)]	Average Green Drop Score	Green Drops Awarded	% Systems that achieved >50%	Position on Performance log
WC	155	83.1%	62.0%	65.0%	19	75.0%	1
KZ	143	82.0%	55.0%	61.0%	11	66.0%	2
GT	56	78.8%	57.0%	68.0%	5	68.0%	3
EC	123	67.2%	78.0%	33.0%	3	26.0%	4
MP	76	56.0%	73.0%	42.0%	1	41.0%	5
NW	35	50.0%	76.0%	29.0%	1	17.0%	6
FS	95	31.5%	83.0%	24.0%	0	12.0%	7
LP	67	24.0%	79.0%	24.0%	0	15.0%	8
NC	71	23.0%	76.0%	26.0%	0	13.0%	9
SA Total	821				40		

The municipal WWTWs are being assessed in terms of their performance nationally and provincially. The national CRR/CRR $_{max}$ % deviation (see Figure 2.1) comprises of the risk profiles for different provinces and the Risk performance for the Mpumalanga provincial municipal WWTWs are compared to each other (see Figure 2.2 and Figure 2.3) for 2013 and 2014. These assessments assist with valuable information that is required to make informed decisions, strategies and policies at different stages (DWS, 2014). Figure 2.1 shows that during the latest risk assessment for PAT in 2014, the Western Cape Province got the lowest score in the terms of the risk assessment with 57.7% while North West was the highest (86.1%) and Mpumalanga was also high on the risk performance list (84.2%). This means that the national risk performance of the South African WWTWs falls between a medium to high-risk profile. It must be noted that the lower the risk assessment score means that the system performs better and stands a chance of receiving the green drop status. The Western Cape performed better than other provinces (with lower rick score), but did not perform well because it could not qualify for the green drop status. It could only qualify if the risk score was at least 10% or less (DWS, 2014). A comparison can be done on the municipal WWTWs within the Mpumalanga Province (i.e. Figures 2.2 and 2.3) in 2013 and 2014. In 2013, the WWTWs within Thaba Chewu local municipality performed the best with low risk of 39.8% (<50%) while Msukaligwa local municipality performed the worst with 96.3% (critical risk). In 2014, the WWTWs within the jurisdiction of Mbombela local municipality performed better than others with 58% (still not good enough) and Thaba Chewu became number 3 with 64 % (very bad compared to 2013 assessment) while Msukaligwa became worse at 98% of the risk performance. The department has tried to solve the water issues and these risk profile values aim at encouraging WWTW's to perform better by rectifying their previous mistakes, but little to no improvement has been noted (DWS, 2014).

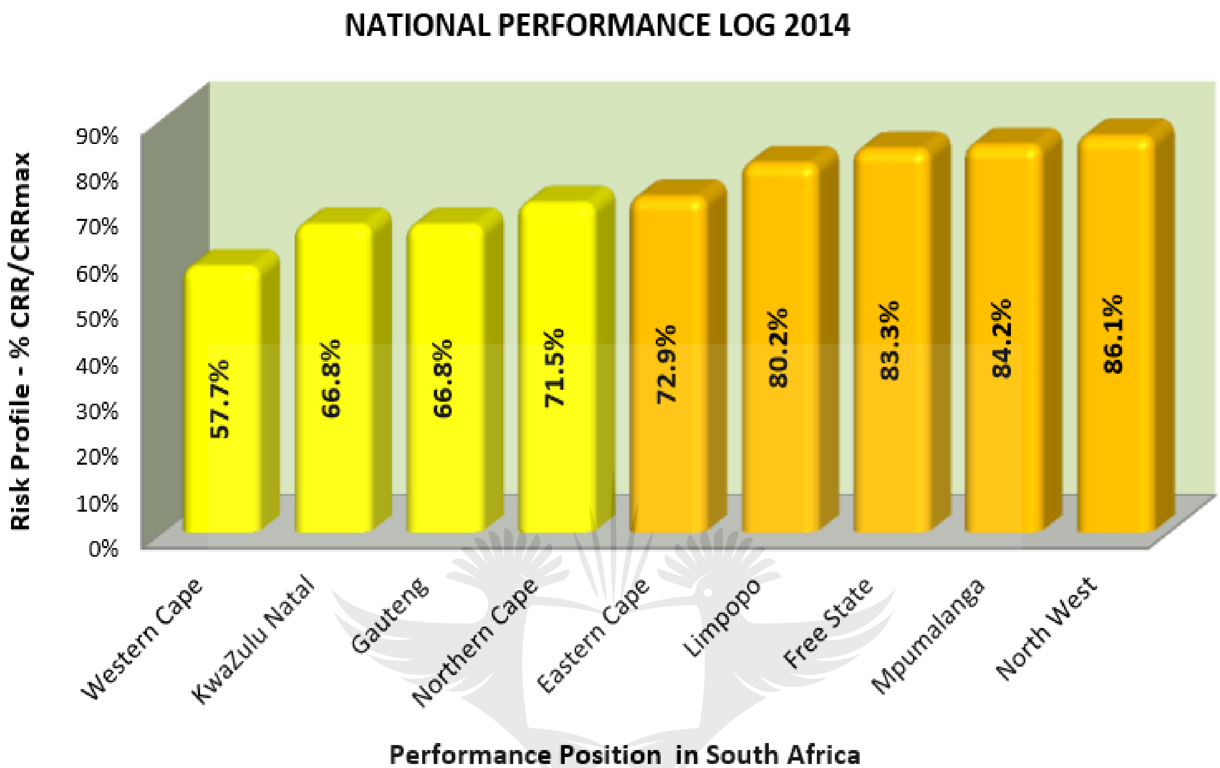


Figure 2.1: National municipal performance of the respective provinces in terms of the Risk Profile combined provinces in South African (Source: DWS, 2014).

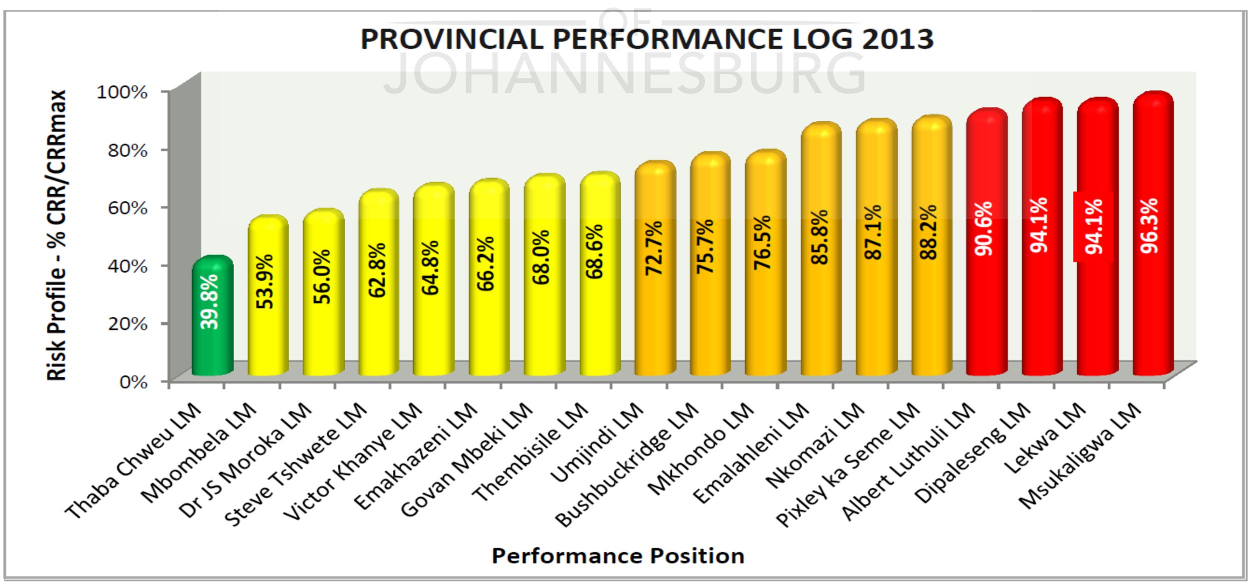


Figure 2.2: Provincial Performance in terms of the Risk Profile Assessment for each of the municipal WWTWs in Mpumalanga (Source: DWS, 2014).

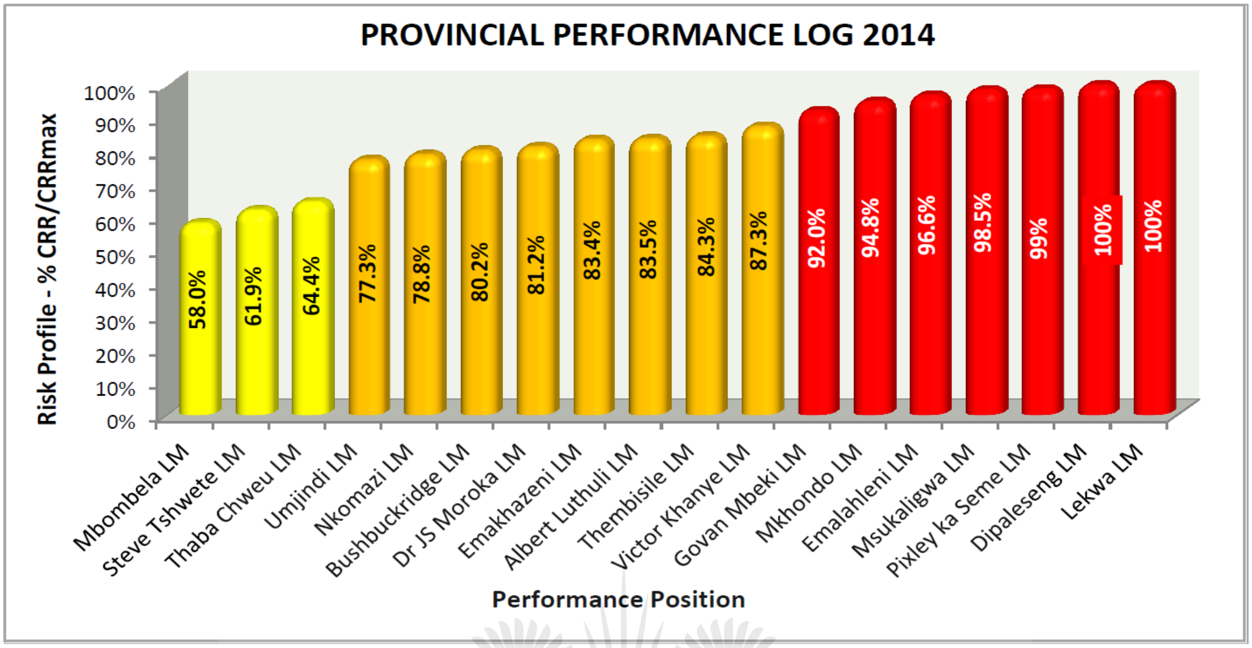


Figure 2.3: Provincial Performance in terms of the Risk Assessment for each of the municipal WWTWs in Mpumalanga (Source: DWS, 2014).

CHAPTER 3: MATERIALS AND METHODS

3.1 RESEARCH METHODOLOGY

This section will provide information on the research methods of the study. It will further explain the materials and/or equipment used to collect the data. This part is divided into research design, sampling of Eco-Classification determinants such Macroinvertebrates and Rapid Habitat Assessment Method, and water quality sampling methods and finally a method of determining the risks (Cumulative Risk Ratio: CRR) of the WWTWs.

3.1.1 RESEARCH DESIGN

During this study, the *in-situ* data were collected, which included the water quality variables, macro-invertebrates and for habitat availability. These data were analysed by using various EcoStatus Models such as the MIRAI and RHAM. From the EcoStatus model ecological classes or categories in the form of a category were assigned. Although a quantitative study was followed, the results produced a categorical state, which is qualitative (Maree, 2007). The aim for utilising this research design was because "*it allows for the causal effect relationship and is recommended when a researcher is looking for relatively quick results*" (Maree, 2007).

3.2 SAMPLING METHODS AND MATERIALS

3.2.1 MACRO-INVERTEBRATE SAMPLING (SASS5 METHOD)

Three sites were selected for the assessment of the macroinvertebrates, i.e. one site upstream of the WWTWs and two sites at the downstream of the WWTWs. These sites were monitored twice, once during low flow (July 2016) and during high flow (May 2017) seasons. The collection of data took place between July 2016 and May 2017. This was conducted in Sabie River where one sample was taken from the upstream of the Sabie WWTWs and the other two from the downstream of the WWTWs. The macroinvertebrate assessment was conducted following the

South African Scoring System Version 5 (SASS5) sampling method/protocol (Dickens and Graham, 2002).

The following three biotopes for macro-invertebrate sampling were selected and sampled:

✓ **Stones (S) Biotopes:**

The stone habitats were sampled as stones-in-current (SIC) and stones-out-of-current (SOOC) and their samples were collected in a different way. The SIC can be defined as the stones that are easy to move such as cobbles and pebbles (with average size ranging from approximately 2 – 25 cm) found where there is high flow of water, and bedrocks and boulders that exceeds the size of 25 cm which can be difficult to move or cannot be moved, while SOOC also includes moveable cobbles, pebbles and the bedrocks, but are found where there is limited, or no water movement and sediments and silt can settle (Dickens and Graham, 2002).

Sampling for SIC habitats was performed by placing the SASS net closer to the feet but far enough to avoiding sediment to settle in the net instead of the biota while kicking the stones. Sample were collected facing to the downstream while the net was facing the upstream (opposing the current) and this was done to dislodge the biota and move it with the current and settle into the net while kicking. Samples were collected on boulders or bedrocks by scraping them with the feet or wader and again placed the net to face the current while scrapping and again avoid sediment from settling into the net. The kicking or sampling of stones was carried out for 2 min where unattached stones were present and up to a maximum of 5 minutes where there were boulders or bedrocks. The SOOC were sample by kicking the loose stones and scrapping the boulders or bedrocks using hands and feet while sweeping with the net in a swept or scrapped area and the actual kicking and scraping of the habitats continued for about 1 min within a $1m^2$ of the riverbed.

✓ **Vegetation (Veg) Biotopes:**

This biotope includes the sampling of the marginal and aquatic vegetation. The marginal vegetation is the overhanging or vegetation that grows at the margins/edges of the stream both in current (MVegIC) and out of current (MVegOOC) (Dickens and Graham, 2002). The vegetation, which includes reeds and grasses, was sampled by sweeping with the net for a length of approximately 2 m where the net was vigorously shaken at various velocities and vegetation. The net was kept under the water level to prevent sampling terrestrial organisms.

Aquatic vegetation refers to the vegetation such as the water hyacinth, water lily and filamentous algae that grows in/under water or found floating on the water surface (Dickens and Graham, 2002). To sample the biota in this biotope, the net was pushed through the vegetation under water several times and this sampling was done over an area of approximately 1 m^2.

- ✓ **Gravel, Sand and Mud (GSM) Biotope:**

This biotope comprises the gravel (small stones of less than 2 cm in size), sand (sand particles of less than 2 mm in size) and mud (mud, silt and clay particles of less than 0.06 mm in size) (Dickens and Graham, 2002). GSM was sampled by stirring and sweeping the substrate for 1 min.

- ✓ **Hand-picking and visual observation:**

This was done to be able to find the biota or specimens that might have been missed during the sampling. The actual hand picking, and visual observation continued for about 1 min.

After completion of sample collection, each of the samples for the three biotopes were put into different dishes/trays (approximately 30 x 45 cm size and 10 cm deep) that were half-filled with clean water and the net was caped to put the sample into the tray. The SIC and SOOC were combined into their specific tray, and similarly with MVegIC and MVegOOC, and GSM in and out of current. Clean and adequate water was added to dip the samples into different trays and the samples were cleared of the fine sediments for the ease of identification. The net was shaken in the water to ensure that no attached biota onto the net. Most of the macroinvertebrates appear from the wood debris after some time and therefore the samples were required to be put aside while examining the other biotopes and the macro-invertebrates in each of the three trays were identified for 15 min each (Dickens and Graham, 2002). All the identified macroinvertebrates were recorded onto a standardised SASS5 data sheet and the macroinvertebrates were immediately released back to the river after being identified and recorded.

3.2.2 WATER SAMPLING

The water quality sampling was done as a method of measuring and relating the fitness of water for particular purposes such as human consumption, agriculture (Stoner, 1978) and for the aquatic ecosystems. It determines the number of parameters for water fitness, which significantly influence our riverine ecology. Water quality sampling was conducted in accordance with the two main programmes, the National Microbial Monitoring Programme (NMMP) and Chemical Monitoring Programme (NCMP). The NMMP is a monitoring programme that was "*designed to focus on potential high-risk areas where there would be a high possibility of the water being* *faecally polluted and where it would pose a major risk to the health of water users in that area*" while the NCMP is a programme that allows water samples to be "*taken mostly at existing gauging stations by hydrologist servicing the gauging stations and Reservoirs, and samples are posted to RQS for basic salts analyses*" (van Niekerk, 2004). The monitoring that was used for this study was a combination of the two programmes, but mostly, the Physico-chemical Monitoring Programme. Grab water samples were collected with a sample collection 1L bottle (chemically prepared for collection of water samples), labelled, kept cool into the cooler box with ice blocks and taken to the research laboratory for examination to check the physico-chemical concentrations in water. The *In-situ* water quality meter (YSI559-Multi Probe: manufactured by Cole-Parmer, USA) was used for some of the chemical parameters measurements such as the temperature, dissolved oxygen (DO) and electrical conductivity (EC) while other variables such as the potential of hydrogen (pH), nitrates and nitrites (N), ammonium, phosphates (PO_4), total dissolved solids (TDS), turbidity or total suspended solids (TSS), potassium (K), chlorides (Cl), total alkalinity ($CaC0_3$), calcium (Ca), fluoride (F), and magnesium (Mg) were analysed by the Regen Waters laboratory (South African National Accreditation System Accreditation No. T0156).

3.2.3 HABITAT ASSESSMENT METHOD (RHAM)

The method of Rapid Habitat Assessment was developed by Dr CJ Kleynhans as Rapid Habitat Assessment Method (RHAM) (DWAF, 2009) and was used for this study. This method plays a role when collecting data that relates to habitat in profitable means for Ecological Water Requirement (EWR) monitoring (DWAF, 2009).

The RHAM monitoring involves equipment such as a measuring tape, two (2) sticks/poles which must be placed at the right and left banks or water edges, information page to record data and a plank to measure the depths. The baseline monitoring procedure was followed with the application of RHAM and is normally not applicable at rainy times of year. Its monitoring was done by following the major stages, which included marking the left and right edges of the river, a straight line that cuts through the river was done and the discharge was measured.

The process is about taking note of the cross-section and point values in the data sheets, taking note of all related information about the site, classify the representative Geomorphic Habitat Units (GHU), identify the major GHU of the river, identify sensitive GHU for the biota, determine significant GHU, choose extra GHU if needed with the identification of the benchmark for the upper limit of the GHU. The cross-sectional measurements of the GHU included the utilisation of initial guidelines of approximating a suitable cross-section, making decisions about how many cross-sections are required and how long is each cross- section located from one another (DWAF, 2009).

During the assessment, similar cross-sections were chosen at the time of recording the values of the discharge. The measuring tape was pulled to pass over the width of the river flow with an active width being separated into similar intervals across the river. Flow velocity and depth of the river system were recorded at those intervals and that done by following the procedure according to the RHAM manual as designed by Dr CJ Kleynhans (DWAF, 2009). The data recordings were taken from either the left-hand banks (LHB) and stop at the right-hand bank (RHB) or RHB and stop at the LHB on the opposite bank. The data was recorded at each measured point. The information was then moved from the data sheets for each site and re-recorded to the RHAM model (excel sheet) to determine the flow values of the river system (DWAF, 2009).

3.2.4 DATA ANALYSIS

The data were analysed or interpreted using the Eco-Status method known as the MIRAI that is used to analyse the data for the macroinvertebrates was used. The results of the MIRAI model were used to determine the Ecological Class/Category (EC) for each the three sites. The model has been successfully used as an approved and ideal approach of assessing the water quality in rivers (Thirion, 2007; Thirion, 2016). The general description of the ecological categories (EC) for Eco-Status components is shown in Table 3.

The data for the water quality was compared with the old data from DWS and/or IUCMA and this was done to determine if the fitness of water for specific uses is deteriorating or improving. The water quality was further analysed based on the water quality guidelines volume 7 and volume 8 (DWAF, 1996a and b), Resource Quality Objectives (RQOs) where they are available (RSA, 2016) and South African National Standards for drinking water quality (SABS, 2015) in the absence of both the TWQR and RQOs.

The Rapid Habitat Assessment Model (RHAMM) was used for the interpretation and analysis of the RHAM data. All the procedures about the model were followed according the RHAM manual (DWAF, 2009).

Table 3.1: Generic ecological categories for Eco-Status components (Kleynhans and Louw, 2007).

ECOLOGICAL CLASS	ECOLOGICAL STATE	DESCRIPTION	SCORE (% OF TOTAL)
A	Natural	No measurable modification, natural.	90-100
B	Good	Largely natural with few modifications.	80-89
C	Fair	Moderately modified.	60-79
D	Poor	Largely modified.	40-59
E	Unacceptable	Seriously modified.	20-39
F	Unacceptable	Critically modified.	0-19

The risk profile percentage was calculated as Cumulative Risk Rating or Ratio (CRR) = (A x B) + C +D, where each risk element carries a different weight in proportion to the severity of the risk element:

- ✓ A represents a design capacity of the WWTP which also represent the hydraulic loading onto the receiving water resource (Appendix B: Table A),
- ✓ B represents the operational flow exceedance for the capacity of WWTP (Appendix B: Table B),
- ✓ C represents a number of non-compliant parameters for the WWTP in term of the quality of effluent (Appendix B: Table C), and
- ✓ D represents a compliance or non-compliance in terms of the technical skills (Appendix B: Table D).

3.2.5 STATISTICAL ANALYSIS

Historical data were represented in graphical format using Microsoft Excel "Excel version 2010". Line graphs and polynomial lines were used to indicate monthly trends. A Principal Component Analysis (PCA) was performed to determine the spatial and temporal trends of water quality and macroinvertebrate assemblage. Principal Component Analysis (PCA) can be defined as "*variable-reduction technique that shares many similarities to exploratory factor analysis*" (Laerd, 2013). It is also a "*mathematical procedure that transforms a number of (possibly) correlated variables into a (smaller) number of uncorrelated variables called principal components*" (Atchley, 2007). The distance between the sampling sites in the diagram indicated the similarity of sites as they were measured by their Euclidean distance. The Euclidean distance indicates that, in a PCA plot, the length of the arrow is related to the strength of the correlation. The similarities and dissimilarities were also identified using the PCA. The multivariate statistical analysis was performed using CANOCO 5, supplied by the Microcomputer Power in USA.

CHAPTER 4: RESULTS AND DISCUSSIONS

The findings are explained in detail and the discussions are included to ensure proper understanding of the results. The results also include the assessment of the risks for the WWTP that was assessed during the study using the historical and the most recent data.

4.1 WATER QUALITY

4.1.1 WATER QUALITY FOR HISTORICAL AND MOST RECENT DATA

The historical water quality data for the selected points in the Sabie River were accessed from the Water Management System (WMS) database of the DWS with the assistance of the DWS officials from Resource Quality Services (RQS) (DWS, 2017a). These data were collected from the upstream of the WWTWs, at the point of discharge and downstream of the WWTWs with the assessment focusing on the main stem of the Sabie River system. The data availability had several gaps in terms of the dates and months, caused by the Department of Water Affairs and Sanitations failure to sample regularly, failure to sample all the selected parameters or faulty equipment. Due to this problem, selected data dates from January to December 2015 with one data set for 2016 and one for 2017. The 2016 and 2017 data were included with 2015 data in Table 4.1.1 for ease of comparison to see if the water quality is improving or declining. Out of the water quality variables analysed, only five variables have been chosen for this study to show if the WWTWs discharges the final effluent that complies with the discharge limits (DWAF, 1984). The variables included the *Escherichia coli* (*E. coli*), potential of hydrogen (pH), nitrites (NO_2^-) and nitrates (NO_3^-), ammonia (NH_3) and phosphates (PO_4).

Table 4.1.1: Water quality for historical and the most recent data, 2015 data accessed from the Water Management System (WMS) database of the DWS (DWS, 2017a)

E. coli														
Site ID	**Jan-15**	**Feb-15**	**Mar-15**	**Apr-15**	**May-15**	**Jun-15**	**Jul-15**	**Aug-15**	**Sep-15**	**Oct-15**	**Nov-15**	**Dec-15**	**Jul-16**	**May-17**
SMP	20	62	168	258	126	10	25	200	240	370	320	1.2	225	2350
SDP	0	3200	2430	330000	0	0	2	486000	0	13000	2340	3	8164	>484000
SSW	<1	2100	46800	3300	1	354	18	12000	17	1600	231	<0.2	770	4333
SLB	1	153	20	180	13	64	26	7	14	400	46	<0.2	39	165
pH														
Site ID	**Jan-15**	**Feb-15**	**Mar-15**	**Apr-15**	**May-15**	**Jun-15**	**Jul-15**	**Aug-15**	**Sep-15**	**Oct-15**	**Nov-15**	**Dec-15**	**Jul-16**	**May-17**
SMP	7.83	7.8	7.94	8.18	8.05	8.12	8.32	8.16	7.62	7.65	7.19	7.17	8.38	7.87
SDP	7.58	7.58	7.73	8.27	8.24	8.04	8.12	7.58	7.14	7.66	7.69	7.41	7.91	7.46
SSW	8.2	7.94	8.07	8.39	8.33	8.03	8.35	8.24	8.22	7.83	8.52	8.09	8.44	7.78
SLB	7.83	7.78	7.51	7.86	7.92	8.06	8.34	8.01	7.49	7.4	7.39	7.19	8.32	7.64
NH_3														
Site ID	**Jan-15**	**Feb-15**	**Mar-15**	**Apr-15**	**May-15**	**Jun-15**	**Jul-15**	**Aug-15**	**Sep-15**	**Oct-15**	**Nov-15**	**Dec-15**	**Jul-16**	**May-17**
SMP	<0.1	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	0.16	<0.03	<0.03	<0.1	<0.1	<0.2	0.1
SDP	4.3	2.6	10	13	11	11	0.13	3.5	7.7	<0.03	4.1	5.4	15	4.1
SSW	<0.1	<0.1	<0.1	<0.1	0.32	0.23	<0.1	<0.1	<0.03	0.14	<0.1	<0.1	<0.2	0.1
SLB	<0.1	<0.1	<0.1	<0.1	0.28	<0.1	<0.1	<0.1	0.06	0.16	<0.1	<0.1	<0.2	0.1
$NO_2 + NO_3$														
Site ID	**Jan-15**	**Feb-15**	**Mar-15**	**Apr-15**	**May-15**	**Jun-15**	**Jul-15**	**Aug-15**	**Sep-15**	**Oct-15**	**Nov-15**	**Dec-15**	**Jul-16**	**May-17**
SMP	<0.2	<0.2	<0.2	NR	0.44	0.33	0.52	<0.2	0.36	0.28	0.79	0.37	0.16	5.63
SDP	8.4	8.6	2	NR	1	0.77	18	6.7	5.1	17	8.2	7.8	13.6	18.07
SSW	<0.2	<0.2	<0.2	NR	0.46	0.32	0.89	0.66	0.38	0.41	0.81	0.38	0.48	8.98
SLB	<0.2	<0.2	<0.2	NR	0.33	<0.2	<0.2	<0.2	0.25	0.097	0.68	<0.2	0.51	0.58
PO_4														
Site ID	**Jan-15**	**Feb-15**	**Mar-15**	**Apr-15**	**May-15**	**Jun-15**	**Jul-15**	**Aug-15**	**Sep-15**	**Oct-15**	**Nov-15**	**Dec-15**	**Jul-16**	**17-May**
SMP	<0.2	<0.2	<0.2	<0.2	<0.2	0.73	<0.2	0.49	<0.2	<0.2	1.2	1.2	<0.1	>0.1
SDP	1.2	1.4	2.5	2.1	1.7	1.5	2.2	3.4	1.9	2.2	2.5	3	1.99	2.73
SSW	<0.2	<0.2	<0.2	<0.2	<0.2	1.5	<0.2	0.23	<0.2	<0.2	1.1	<0.2	<0.1	>0.1
SLB	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.55	<0.2	0.74	2.6	<0.2	<0.1	>0.1

4.1.1.1 *Escherichia coli* (*E. coli*)

The data in Table 4.1.1 shows that the discharge point (SDP) had extremely high *E. coli* concentrations, especially in August 2015 (486000 cfu/100ml) and May 2017 (>484000 cfu/100ml). The site just below the WWTWs (SSW) also had very high *E. coli* concentrations during March (468000 cfu/100ml) and August 2015 (12000 cfu/100ml). The results indicate that the WWTWs was not functioning and not treating the effluent. When comparing the sites upstream (SMP) and furthest downstream (SLB) of the WWTWs, the results indicate that the upper site (SMP) has higher *E. coli* concentrations than the lowest site (SLB), for instance, during May 2017. During this month, the concentration of the *E. coli* at the upper site (SMP) was 2350 cfu/100ml and 165 cfu/100ml at the lowest site (SLB). The higher *E. coli* concentrations at the upstream site could be due to the upstream activities such as the Trout farm, which has potential to add faecal coliforms into the water body. A similar incidence was noted in Zaringol stream (Golestan, Iran) where the trout farm degraded the water quality, resulting in increased concentrations of faecal coliforms into the water resource (Kohanestani *et al.*, 2013). The lowest site has no developments and there are other small tributaries that join the Sabie River with limited or no negative impacts as they do not originate from any developments except the plantations. The lower *E. coli* concentrations at the lowest site have been noted to occur because of the unimpacted streams that join the Sabie River and the dilution effect (proper mixing with good water quality from other streams or tributaries).

The historical water quality data illustrated in Figure 4.1.1 shows the upstream point with the highest *E. coli* concentrations that were recorded during the October and November assessments of 2015 with more than 300 cfu/100ml. At the discharge point, Figure 4.1.1 shows the highest peaks of nearly 500000 cfu/100ml and more than 300000 cfu/100ml *E. coli* concentrations during August and April, respectively. The *E. coli* concentrations, just below the WWTWs, were very high in March 2015 and were nearly 50000 cfu/100ml. The lowest site (SLB) was noted to have the lowest *E. coli* concentrations of 20 cfu/100ml. The line graph (Figure 4.1.1) shows a straight line and float during some months (for instance, SDP during January to March and May to July 2015), this is because of the detection limit of the laboratory which is 0.1 cfu/100ml or 0.2 cfu/100ml. The Polynomials shows unstable or fluctuations in terms of the *E. coli* concentrations. This can be attributed by the seasonal flow variations of the river system. A positive line in a graph is an indication of increased *E. coli* concentrations (as in SMP, SDP and SSW) while a negative line indicates a decrease in *E. coli* concentrations (Greenfield *et al.,* 2010). The *E. coli* shows the presence of bacterial pathogens (van Blommestein, 2012). *E. coli* can be found at high concentrations in contaminated and poorly treated water systems and when consumed, it can result in diseases such as typhoid fever, cholera and gastroenteritis (van Blommestein, 2012). The *E. coli* infection is very dangerous at its high concentrations in water (van Blommestein, 2012). This requires that the discharges be well treated according to specified limits before discharging to any receiving water body to avoid health risks to humans and the environment.

Numerous studies have been conducted on water quality of various WWTWs. The results have shown that malfunctioning or inadequate WWTWs are the major threats to the downstream water users (Popa *et al*., 2012). Bloetscher and Gokgoz (2001) did a study in south Florida USA WWTWs, focussing on coliform bacterial penetration into the municipal filters of WWTWs. An elevation in the amounts of bacteria were noted on the first assessment following a backwash. The study found that the new treatment technologies fail to assist the operator with a clear indication if there were bacterial coliforms present, and which species (Bloetscher and Gokgoz, 2001). The WWTWs in southern Florida were found to have a good performance in terms of treating effluent. This was found after routine monitoring was undertaken where there were no non-compliance issues in terms of the water quality limits and the discharge standards. The study was concluded with "*no adverse health effects from the current priority pollutants or nutrients are anticipated, and no adverse impacts should be expected in the receiving waters*" (Bloetscher and Gokgoz, 2001).

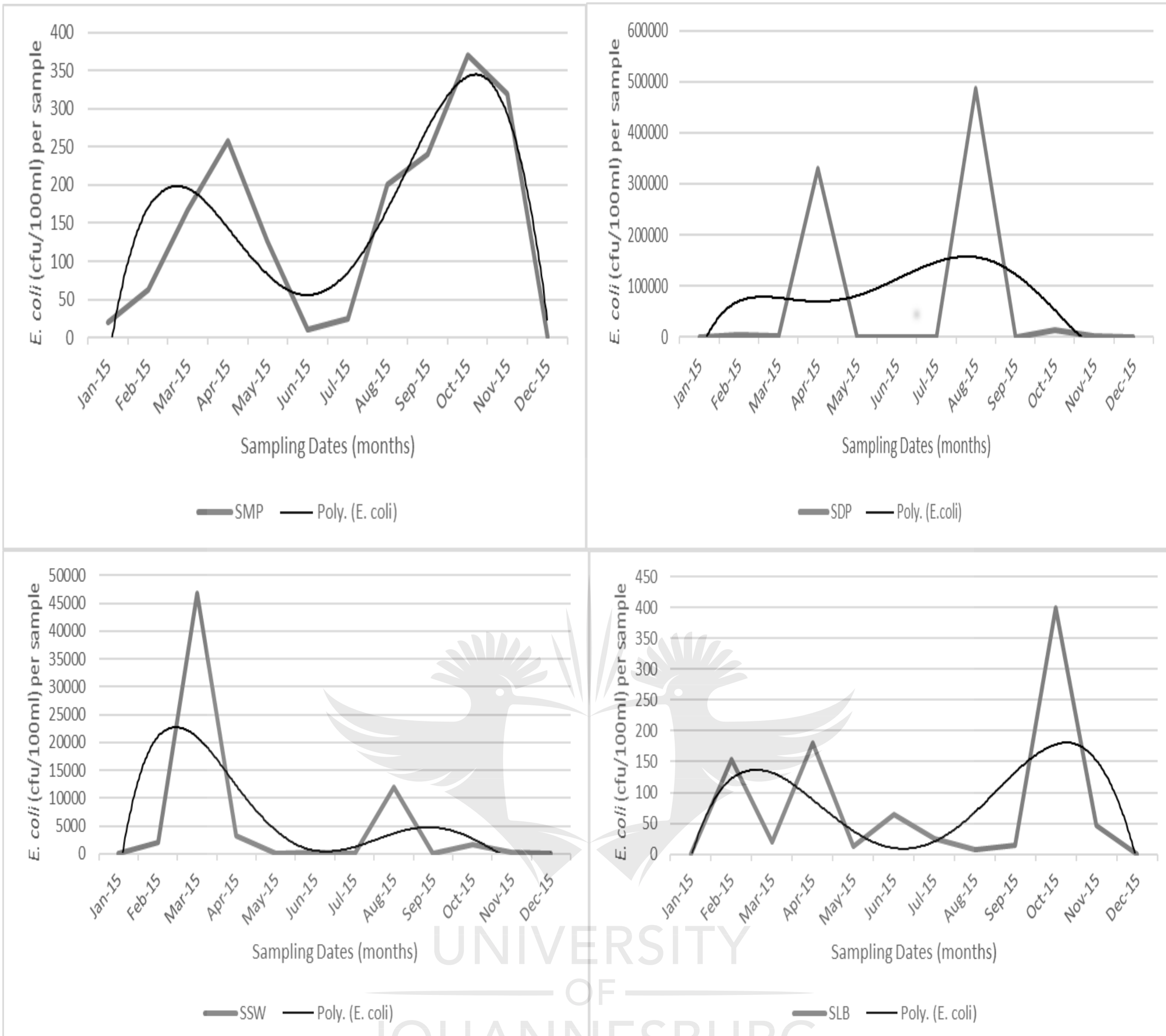


Figure 4.1.1: *E. coli* concentrations for historical (January to December 2015) water quality data for sites SMP, SDP, SSW and SLB in the Sabie River, South Africa.

4.1.1.2 Potential of hydrogen (pH)

The data in Table 4.1.1 of historical water quality data in terms of pH for the selected points showed compliance with the discharge limits of 5.5 to 9.5 (DWAF, 1984). The SSW (site that is located immediately downstream of the WWTWs) had the highest pH levels of up to more than 8.40 units. The present study also found that the pH units go up to above 8.0 but in May 2017, the pH levels were less than 8. The data in Figure 4.1.2.2 showed variations in terms of the pH. This may be attributed to changes in other water quality constituents such as the total dissolved solids (TDS), carbon dioxide and temperature (WHO, 2003), nutrients, and the flow changes. The pH values in relation to its effects to the environment are summarised in Figure 4.1.2.1.

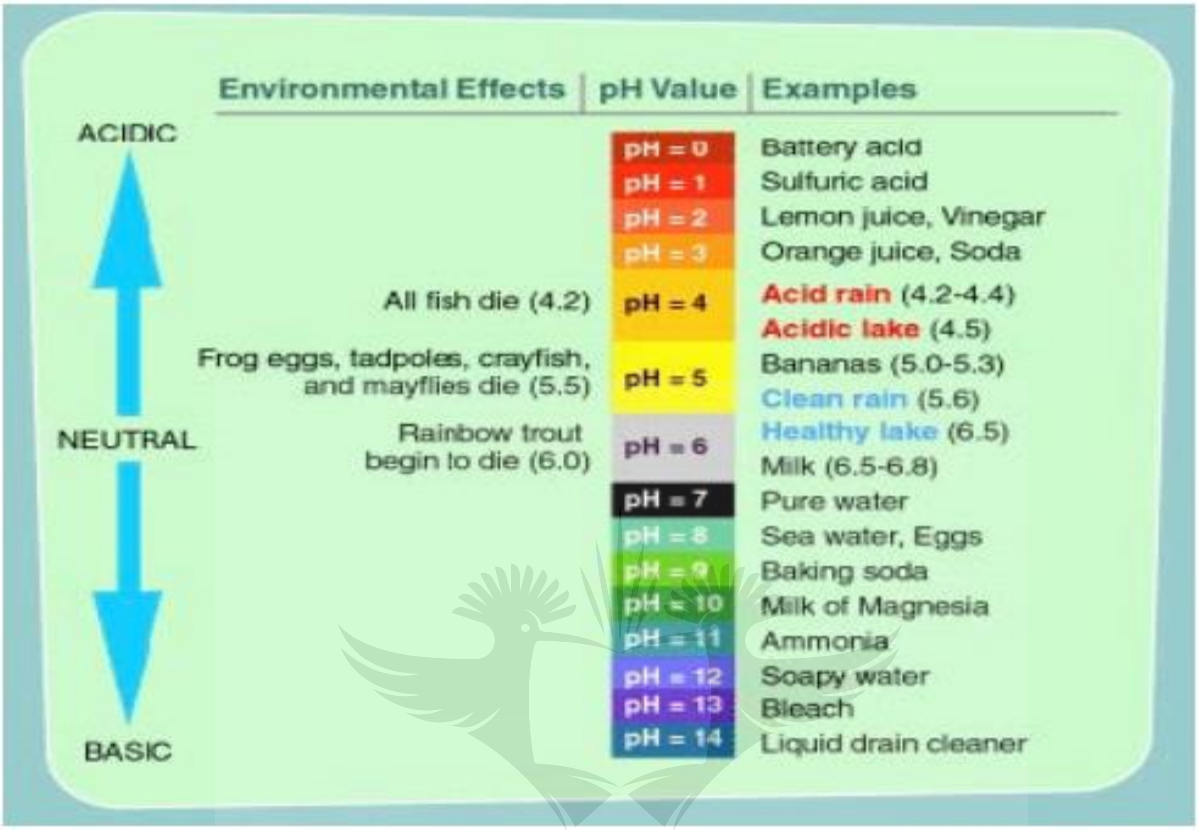


Figure 4.1.2.1: Summary of environmental effects in relation to the values of pH (Source: SDWF, 2017).

The toxicity of metals such as copper and zinc depend on pH levels (Wilde *et al*., 2006). To avoid the corrosiveness and/or any severe effects of very low or very high pH to the environment, it must always be kept within the required standard by ensuring regular monitoring (van Blommestein, 2012). A study conducted by Myllynen *et al*. (1997) in Perhonjoki River, Western Finland, to check if the low pH can reduce hatchability and death of the lampreys (*Lampetra fluviatilis*) indicated that water with low pH indeed results to the mortality of *Lampetra fluviatilis* and newly hatched larvae at pH levels that are less than five. Riba *et al*. (2004) determined the effects of pH on metals in the Huelva estuary and the Guadalquivir River in southern Spain and found that there was a severe impact relating to pH in the toxicity of the heavy metals. This was noted at the pH levels of 5 and 6.5 units. The graphs in Figure 4.1.2.2 indicate positive lines although fluctuating trends ranging between the pH of 7 and 8.5 units. In Table 4.1.2, it is indicated that the discharge limits should be between 5.5 – 9.5 units for pH (DWAF, 1984), but it can be noted that even the pH within these specified values can be problematic in terms on promoting the toxic effects of certain metals such as copper. The pH levels in table 4.1.1 range between 7.4 and 8.52 for all the sites from January 2015 to May 2017. This is good when compared with the TWQR for South Africa (DWAF, 1996a), but the above studies have indicated that these values can be problematic in terms of promoting the toxicity of metals.

Figure 4.1.2.2: pH units and historical (January to December 2015) water quality data for sites SMP, SDP, SSW and SLB in the Sabie River, South Africa.

4.1.1.3 Ammonia (NH_3), Nitrites and Nitrates

The water quality results for the ammonia in the present study will be discussed together with nitrites and nitrates because they are closely related. In Table 4.1.1, the NH_3 concentrations for sites SMP, SSW AND SLB were found to be less than 1 mg/l. The monitoring site (SDP) at the discharge point generally did not comply with the discharge limits of ≤ 1 mg/l (DWAF, 1984). The nitrates and nitrites concentrations for sites SMP and SSW did not comply with TWQR of 0.05 mg/l during the wet season (DWAF, 1996a and b). Site SLB complied with the drinking water quality standard of ≤ 1 mg/l for all sampling months (SABS, 2015). The site (SDP) at the discharge point generally did not comply with the TWQR and drinking water standards of 0.05 mg/l and ≤ 1 mg/l (DWAF, 1996a and b; SABS, 2015). The line graph in Figure 4.1.3 indicates the fluctuations showing variations in the concentrations of ammonia for all four sites. All the lines in the graphs indicated a positive trend to show increase in NH_3 concentrations in the Sabie River. The line graphs for nitrites and nitrates were also fluctuating in Figure 4.1.4 and on a positive axis for all sites and samples, except for one sample at site SDP that was on a negative axis line during April 2015.

Ammonia, nitrite, and nitrate are known to be very toxic and can interfere with the wellbeing of the endangered freshwater fish called Topeka shiner (*Notropis topeka*) (Adelman *et al*., 1999). Antweiler *et al.* (1995) conducted research in Mississippi River in USA to determine the effects of ammonia, nitrite, and nitrate on aquatic life. The results indicated severe toxicity of nitrogen related compounds (ammonia, nitrites and nitrates) to aquatic organisms such as fish and macro-invertebrates at concentrations 10 mg/l of nitrites and nitrates (Antweiler *et al*., 1995). The site SDP indicated extremely high concentrations of NH_3 with a maximum of 15 mg/l and also extremely high concentrations of nitrates and nitrites with the highest concentrations being 18.07 mg/l. This means that when comparing these two studies, the Sabie WWTWs discharges extremely harmful concentrations of nitrites and nitrates, much higher than the concentrations reported by Antweiler *et al*. (1995). The Sabie WWTWs discharge effluent did not comply with the discharge limits (DWAF, 1984).

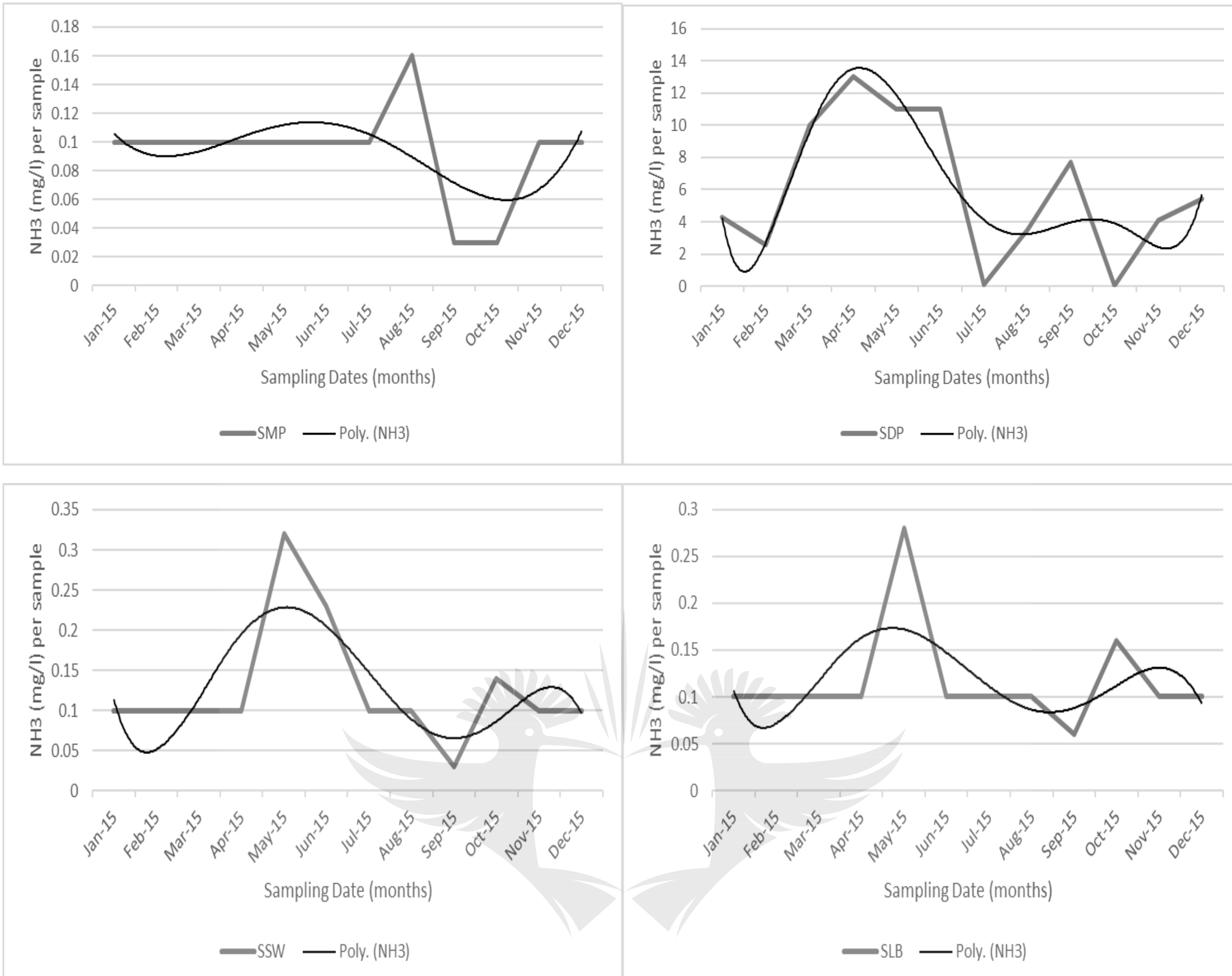


Figure 4.1.3: NH_3 concentration's historical (January to December 2015) water quality data for sites SMP, SDP, SSW and SLB in the Sabie River, South Africa.

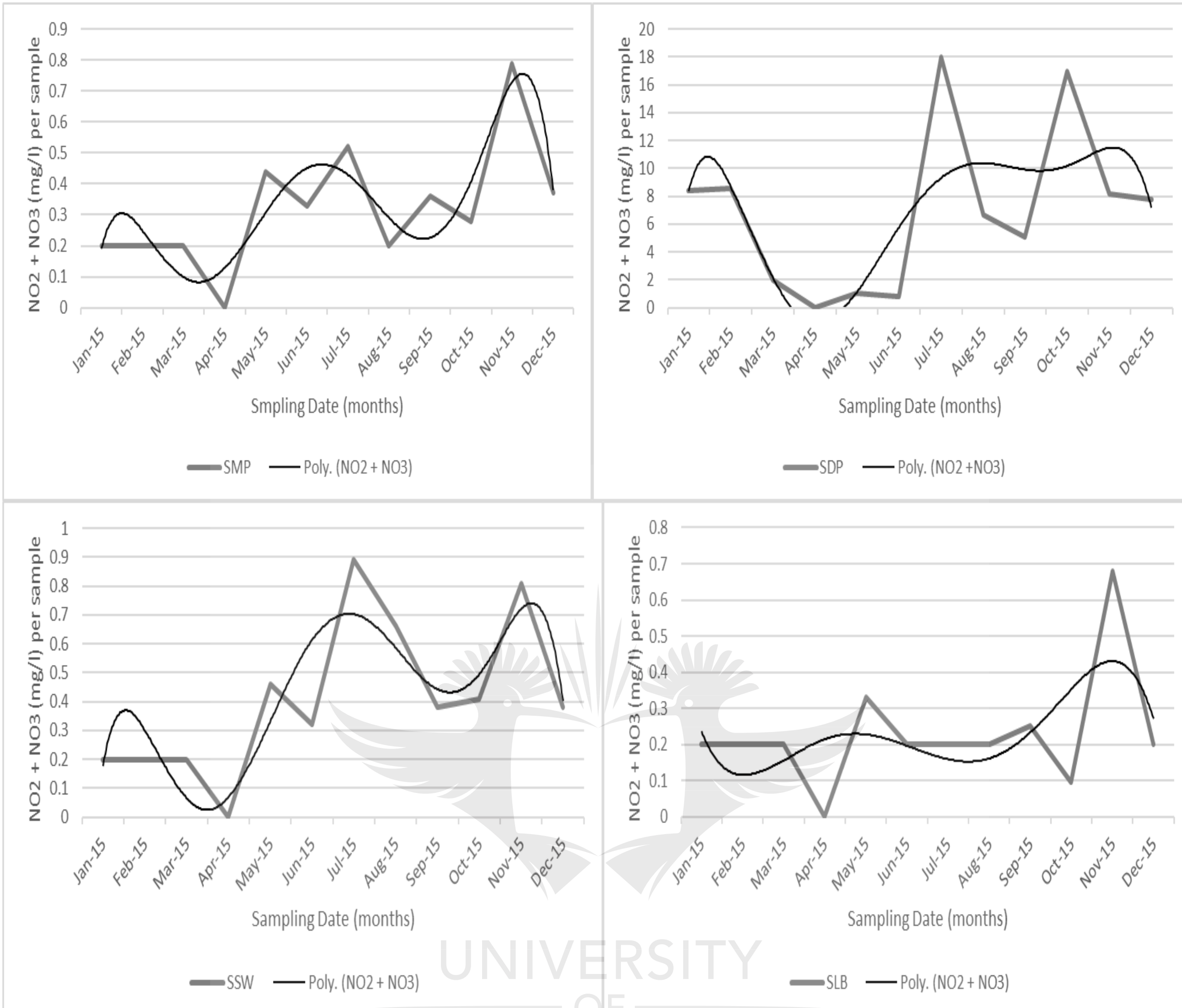


Figure 4.1.4: NO_2^- + NO_3^- concentration's historical (January to December 2015) water quality data for sites SMP, SDP, SSW and SLB in the Sabie River.

4.1.1.4 Phosphates (PO_4)

Phosphates are formed from an element called phosphorus. Phosphorus is a nutrient or element that is required for the existence of life on earth as it is responsible for growth and development of plants and animals (living organisms) (Kotoski, 1997). The findings of this study have shown that sites SMP, SSW and SLB did not comply with the TWQR of 0.075 mg/l and the RQOs of 0.015 mg/l (DWAF, 1996a and b; RSA, 2016). The site at the discharge point also failed to comply with the discharge limits of ≤1 mg/l (DWAF, 1984). Therefore, only high concentrations of PO_4 were observed at site SDP (Table 4.1.1) from January 2015 to May 2017 and can be attributed to poor treatment of effluent by the Sabie WWTWs. This is because not all the WWTWs are able to treat phosphates, but some are able to remove phosphorus from the effluent (EPA, 2017a). In most cases, "*secondary treatment can only remove 1-2 mg/l, so a large excess of phosphorous is discharged in the final effluent, causing eutrophication in surface waters*" (Lenntech, 1998).

Figure 4.1.5 shows the line graph and the polynomial lines for the historical water quality data for four monitoring points as sampled from January to December 2015. There was no variation for sites SMP during the months of January to May and September to October 2015, SSW during the months of January to May and July to October 2015, and SLB during January to July 2015. The straight lines are due to readings below the detection limits for the laboratory, which do not detect below 0.1 mg/l and/or 0.2 mg/l. The phosphate concentrations ranged between 0.2 to 1.2 mg/l for site SMP, 1 to 3.4 mg/l for site SDP, 0.2 to 1.5 mg/l and 0 to 2.6 mg/l for site SLB. These graphs, irrespective of how much data complies, indicated that the discharge point has high PO_4 concentrations that are above the discharge limits (DWAF, 1984) and that endangers the environment. The line graphs for all the sites fluctuated, which makes it impossible to conclude as to whether the PO_4 concentrations were improving or declining in the Sabie River.

According to Kotoski (1997), the phosphates stimulate the growth of aquatic plants and algae, which provides food for fish. This in turn contributes to increased population growth rate of fish with better quality of water (Howard *et al*., 2006). High phosphate concentrations lead to reduced concentrations of oxygen in the water (Kotoski, 1997). High concentrations of phosphates lead to eutrophication. Eutrophication promotes the growth of unwanted aquatic plants and when these plants die, they decompose and use high concentrations of oxygen (Kotoski, 1997; Shock and Pratt, 2003). A study was conducted by Litke (1999) in six rivers which include the Upper Snake River Basin and the Great Salt Lake Basin in the USA. The focus of the study was to assess the effects of phosphates on water quality. The study indicated that phosphates were very toxic and that resulted in mortality of aquatic organisms, which included macro-invertebrates and fish. The toxicity was found at concentrations of more than 0.1 mg/l (Litke, 1999). The toxicity of phosphates can speed up the aging process in mammals by contributing to tissue damage resulting in eventual death. Kotoski (1997), emphasized that "*Phosphates are not toxic to people or animals unless they are present in very high levels*". The site at the discharge point (SDP) had phosphate concentrations, ranging from 1.2 to 3.4 mg/l which was more than the 0.1 mg/l that was noted by Litke (1999) and this means the phosphate concentrations at the discharge point were found to be toxic.

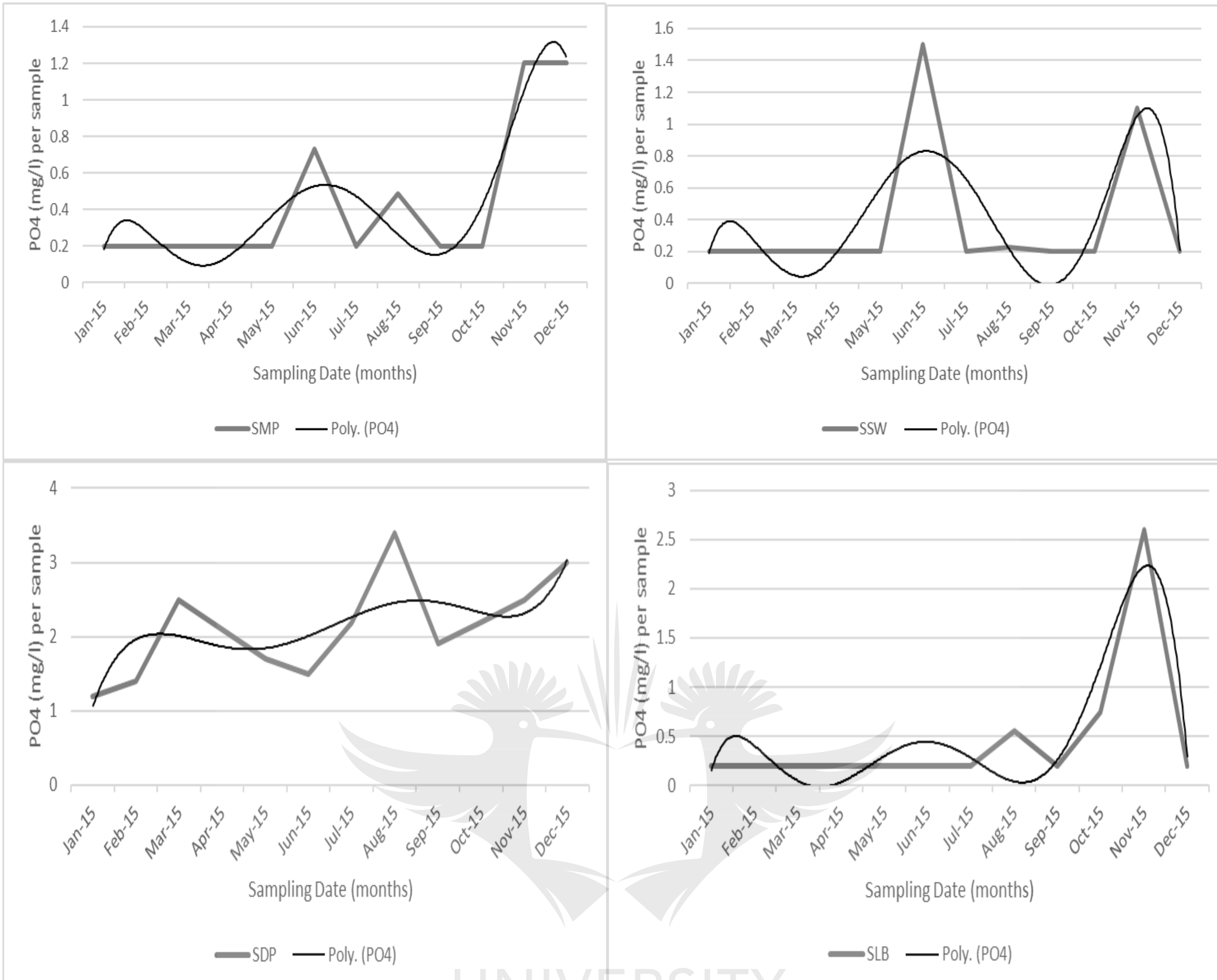


Figure 4.1.5: PO_4 concentration's historical (January to December 2015) water quality data for sites SMP, SDP, SSW and SLB in the Sabie River.

4.1.2 DETERMINING THE RISK USING THE RISK-BASED REGULATORY APPROACH

The proper management of the WWTWs has become a challenge for South African Municipalities, which makes it difficult to provide necessary water services to the public as expected (Burges, 2015). The poorly treated or untreated discharges to a water resource pose health hazards to the human population, damages the environment and this make it very important for the WWTWs to be in a good operational state (Mara, 2003; Burges, 2015).

The cumulative risk ratio or rating (CRR) was calculated for the Sabie River WWTWs to determine its current risk profile. One of the requirements of this WWTWs was that the final effluent being discharged to the Sabie River should comply with the effluent discharge limits (DWAF, 1984). During this process, eight water quality parameters were selected with sampling dates and data from March 2016 to February 2017. The water quality variables included the pH, conductivity, chemical oxygen demand, phosphates, nitrites and nitrates, ammonia, suspended solids and *E. coli*. The data were then compared with the WWTWs discharge limits as per the requirements by DWS (DWAF, 1984). Table 4.1.2 shows that out of the eight selected parameters, only three complied to the required standards. No discharge limits for nitrites and nitrates to comply with in terms of the effluent discharge limits by DWAF (1984) were available. The nitrites and nitrates were then compared against the target water quality range (TWQR) of 0.05 mg/l for aquatic ecosystem (DWAF, 1996a) and the levels did not comply, which indicated poor discharge into Sabie River in terms of the nitrites and nitrates.

Table 4.1.2: Water quality for discharge point (SDP) to calculate the CRR for March 2016 to February 2017 data.

Parameters	Discharge Limits	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16	Jan-17	Feb-17	Average	Comply (Y/N)
pH (Units)	5.5-9.5	7.19	7.06	6.97	6.99	7.91	7.09	7.18	7.17	7.58	7.46	7.39	7.79	7.315	Y
EC (Ms/m)	≤ 75	31.5	34.8	38.6	39.3	39.9	41.9	47.9	40.3	50.4	48.0	11.7	44.3	39.05	Y
COD (mg/l)	≤ 75	42	142	52	185	108	<0.4	77	34	404	109	<10	95	124.8	N
PO_4 (mg/l)	≤ 1	1.33	1.53	1.65	1.24	1.99	1.92	2.86	2.05	3.33	1.48	0.29	2.92	1.88	N
$NO_2^-+NO_3^-$ (mg/l)	TWQR=0.05	13.3	13.5	14.2	14.3	13.6	18.3	<0.1	11.5	<0.1	<0.1	0.3	<0.1	12.375	N
NH_3 (mg/l)	≤ 1	<0.20	0.49	1.58	0.24	1.36	0.21	14.5	2.44	22.6	17.5	1.59	16.3	7.1645455	N
SS (mg/l)	≤ 90	18.4	304	31.6	44.8	76.4	10.4	24.8	13.6	360	64.8	8.4	63	85.016667	Y
E.coli (cfu/100ml)	≤ 0	11199	92080	0	2755	8164	11199	0	0	>484000	0	20400	200	13272.455	N

Most of the information for calculating the CRR (Table 4.1.3) was obtained from the Thaba Chweu Local Municipality at the Sabie WWTWs. The calculation included the design capacity, operational flows, quality of the effluent and technical skills and used the formula: Cumulative Risk Rating (CRR) = A x B + C + D (DWA, 2012). As indicated in Table 4.1.3, the percentage (%) of the CRR was then calculated as % $CRR/CRR_{maximum}$ and the % CRR was found to be 24%. The Sabie WWTWs was found to be a low risk to the downstream environment in terms of human and aquatic life. It must be noted that, although the Sabie WWTWs was found to be a low risk to human and aquatic life, it cannot qualify for the green drop status because its green drop score needed to be 90% and was calculated as 100 – 24% = 76%.

Table 4.1.3: The Risk Profile of the Sabie River WWTWs and CRR for the discharge from March 2016 to February 2017.

CRR (Risk) COMPONENT	CRR (Actual)	CRR (Max) that can be reached	Reason for CRR Score
A: Design Capacity	1	1	Design capacity is 2 Ml/d
B: Operational Flow	0	5	Flow is 1.6 Ml/d which is less than design capacity
C: Effluent Quality	3	8	3 out of 8 parameters are complying
D: Technical Skills	1	4	they comply in terms of the tech skills
CRR	4	17	4/17*100= 24%
%CRR/CRRmax			24%

4.1.3 WATER QUALITY: DRY AND WET SEASONS

The water quality was sampled during the dry and wet seasons respectively to determine the seasonal variation in the Sabie River. The water quality parameters that were selected are shown in Table 4.1.4. The compliance of the parameters was compared to the Target Water Quality Range (TWQR) and Resource Quality Objectives (RQOs and drinking water quality standards (SANS 241) (DWAF, 1996a and b; RSA, 2016). The water quality parameters are discussed as follows:

4.1.3.1 Water Temperature

The water temperature of the Sabie River system was sampled *in situ* for all four (4) monitoring points during the dry and wet seasons. In natural rivers, the water temperature of the water resource is governed by the surrounding features of the catchment, climate, and hydrological flows (DWAF, 2005). High water temperatures result in a decline in oxygen solubility, promote high toxic behaviour of some chemical variables, and negatively affect the aquatic biota (Wepener, 2016). Aquatic organisms require optimal water temperatures for general health, growth and normal reproductive behaviour, while high water temperatures increase the metabolic rates. A very high or very low water temperature can lead to a decrease in number of aquatic organisms until none of them exist (Perlman, 2016b; Wepener, 2016).

In Table 4.1.4, the water temperature for the sites complied with the TWQR limits as the water temperature range was found to be between 12 and 17ºC. The highest water temperature of 17.2ºC was recorded during the dry season at SSW while the lowest was recorded at SLB of 12.3ºC during the wet season. It must be noted that water temperatures can change because of the change in depth. In this study, low water temperatures were found during the high flows while high water temperature were found during the low flows. This is because there is no proper mixing of water with the sunlight heating the low flowing water, resulting in high water temperatures (EPA, 2017b). The low flows generally worsen the impacts of water pollution. According to EPA (2017b), "*winds, bank storage, spring seepage, tributary streams and the warming effect of the sun have greater impacts on stream water temperatures during low-flow periods*". The opposite occurs during the high flows when the water velocity is high which promotes dilution or mixing and lowers the effects of sunlight, resulting in low water temperatures (EPA, 2017b).

4.1.3.2 pH

The pH of water was measured *in-situ* in all four-selected sites in the Sabie River during respective high and low flow seasons. pH is the potential of hydrogen and measures the amount of hydrogen ion concentrations in a water resource. The pH of less than 7 is considered acidic, pH of 7 is neutral and pH of water above 7 is alkaline, which means that pH can also be defined as a measure of the acidity and alkalinity of water (Wurts, 2003). The pH has harmful effects when it is below 5.0 and above 9.6 units. Low pH levels result to the vulnerability of the fish species to fungal infection and some other physical damage and the reproduction in fish species may be impaired due to pH levels that are below 5.0 units and may die at pH levels below 4.0 units (Fondriest Environmental, 2013). Low levels of pH have been found to accelerate the solubility of heavy metals (Fondriest Environmental, 2013). pH levels that are less than 5.0 units can disrupt the functioning of fish gills and damage the body of macroinvertebrates. When those levels exceed 10.0 units, the aquatic biota such as fish and macroinvertebrates can die (Fondriest Environmental, 2013; Wepener, 2016).

In Table 4.1.4, the TWQR for pH levels of an aquatic environment must range between 6 and 9 units and the discharge limits must be 5.5 to 9.5 (DWAF, 1996a and b). The present study found that all the monitoring points were within the specified limits for both the discharge and the aquatic environment in terms of the TWQR. This therefore means that the monitoring points within the Sabie River in Table 4.1.4 complied with the TWQR in terms of the pH during the study period (DWAF, 1996a and b).

4.1.3.3 Electrical conductivity and total dissolved solids

The electrical conductivity (EC) and the total dissolved solids (TDS) were measured *in situ* for all four-monitoring points during respective high and low flow seasons. The EC is the measure of the ability of water to conduct electricity and provides an idea of the amount of the TDS in water (DWAF, 1996a and b), while the TDS is the sum of all the organic salts dissolved in water. Both the EC and TDS may exist because of the availability of ions such as magnesium (Mg), calcium (Ca), carbonates (CO_3), nitrates (NO_3) and sodium (Na). This means that there is a relationship between these two variables because the concentrations of the EC can provide the TDS (or vice versa) in the formula that follows (DWAF, 1996a and b):

EC (mS/m at 25^{0}C) x 6.5 = TDS (mg/l)

"*The TDSalts concentration is directly proportional to the electrical conductivity (EC) of Water*" (DWAF, 1996a). This simply means that when the TDS increases, the EC will also increase. The WWTWs must be able to treat these variables to the required limits because they also play a role in polluting our rivers (van Blommestein, 2012). The TWQR for the EC were noted to be 70 mS/m and the RQOs require 30 mS/m, and the limits for the discharge must be ≤75 mS/m (DWAF, 1996b; RSA, 2016). The EC in Table 4.1.4 indicated that all the monitoring points during high and low flow seasons complied with the RQOs, TWQR and discharge standards. The required TWQR for the TDS were calculated using the above formula and the TWQR for the TDS were found to be 455 mg/l, 195 mg/l in terms of the RQOs and ≤1200 mg/l in terms of the drinking water standards (SANS 241) (SABS, 2015). The limits did not exceed the drinking water quality standards and therefore both the EC and TDS complied with the SANS 241 (SABS, 2015).

4.1.3.4 Dissolved oxygen

The dissolved oxygen (DO) saturation and concentrations were measured *in situ* for four sites during respective dry and wet seasons. The DO is a measure of the amount of oxygen dissolved in water, which is required for aerobic respiration (Wepener, 2016). This variable can be decreased by discharging poorly treated or untreated effluent into a water resource (van Blommestein, 2012) and that will lead to an increase in Chemical Oxygen Demand (COD). According to DWAF (1996a), "*the maintenance of adequate dissolved oxygen (DO) concentrations is critical for the survival and functioning of the aquatic biota because it is required for the respiration of all aerobic organisms*".

The discharge limits for the WWTWs must be less or equal to 10 mg/l and all the sites were less than 10 mg/l, including the discharge point (DWAF, 1984). The DO was also compared against the TWQR in terms of the saturation and the limits must range between 80 to 120 % (Table 4.1.4). The recorded DO concentrations for all the sites were less than 120 mg/l and all above 100 mg/l. In terms of the DO concentrations, the water quality was compliant with the TWQR for both the dry and wet seasons measured in the present study (DWAF, 1996a).

4.1.3.5 Ammonium, nitrites and nitrates

The Sabie River water was sampled and taken to the laboratory for the analysis of parameters such as ammonium (NH_4), nitrites (NO_2) and nitrates (NO_3). The main relationship between these variables is that they are all the nitrogen based nutrients and nitrogen is one of the essential nutrients for growth. A study done by Litav and Lehrer (1978) on *Potamogeton lucen* investigated the impact of ammonium indicated a damage to the roots due too very high NH_4 concentrations of 10 to 15 ppm of nitrogen or ammonium. A study was conducted by Okelsrud (2004) to determine the effects of nitrogen related nutrient in rivers of the Northern Queensland which included the Mitchell River, Burdekin River, Herbert River and Tully River. The results indicated high toxicity of these nitrogen nutrients on fish at nutrient concentrations between 1.31 mg/l and 1.99 mg/l (Okelsrud, 2004). Williams *et al*. (1986) indicated that ammonia is most toxic to fish and macroinvertebrate species when it is at high concentrations of 6.5 mg/l. The reality is that the ammonium, ammonia, nitrites and nitrates, all need to be managed within the required limits.

The TWQR for NH_4 is 0.007 mg/l (water resources) and ≤1 mg/l for the discharge while the NO_2^- + NO_3^- must not exceed 0.05 mg/l (DWAF, 1996a and b). All the sites exceeded the TWQR for both the wet and the dry seasons in terms of the NO_2^-, NO_3^- and NH_4. The concentrations of NO_2^- and NO_3^- for the discharge point were the highest at 18 mg/l which very high compared with the

TWQR and a study by Okelsrud (2004). This means that all the monitoring points failed to comply with the TWQR during the low and high flow seasons in the present study.

4.1.3.6 Phosphates

According to DWAF (1996a), high levels of algae may occur because of increased natural concentrations of PO_4 which reduces oxygen availability. Algae were noted in most of the monitored sites which include SMP, SSW and SLB in the present study. In this case, the presence of algae indicated a high nutrient loading into the Sabie River. Increased PO_4 concentrations in a waterbody is an indication of eutrophication (van Blommestein, 2012). In Table 4.1.4, the TWQR (<0.075 mg/l) and the RQOs (0.015 mg/l) with the discharge limits are indicated for PO_4. The monitoring sites (SMP, SSW and SLB) did not comply with the RQOs limits (RSA, 2016). The results also indicated that the sites (SMP, SSW and SLB) complied with the TQWR during the dry season while all sites (SMP, SDP, SSW and SLB) did not comply with the TWQR during the wet season (DWAF, 1996a).

Phosphorus (P) is naturally rare in waterbodies, many freshwater systems have been influenced by excessive loads of P, because of human activities (Peterson and Wasley, 2007). A study by Hester (2011) in the Ohio River (USA), concluded that blue-green algae was as a result of excessive loading of PO_4. According to Hester (2011), this type of algae is produced by harmful algal blooms (HABs) and is not really algae, but it is bacteria that is scientifically called Cyanobacteria. These bacteria, fuelled by P, tend to eat the algae using up oxygen in the waterbody causing fish, shellfish and the macroinvertebrates to suffocate (Peterson and Wasley, 2007; Hester, 2011). Sunlight struggles too adequately penetrate algal blooms to the waterbed eliminating essential aquatic plant growth. The results also indicated the decline in fish species that prefer less polluted systems and these fish species include the largemouth bass (*Micropterus salmoides*) such as bass (Hester, 2011). Hesters study, however, could not determine the concentration of PO_4 that resulted cyanobacteria blooms in the river system. Peterson and Wasley (2007) conducted a similar study in three rivers (St. Croix, Upper Mississippi, and the Minnesota rivers) within the USA. The study indicated that the low concentrations of PO_4 reduced the algal growth and the waterbodies be considered nutrient poor systems, not promoting the excessive growth of algae and aquatic plants (Peterson and Wasley, 2007). This was noted to occur at PO_4 concentration of about 10 ppb, which relates to 0.01 mg/l. On the other hand, the study has indicated the eutrophic situations in Minnesota River at extremely high PO_4 concentrations of 100 ppb (0.1 mg/l) or more. This is where the large amounts of algae were noted (Peterson and Wasley, 2007).

The PO_4 concentrations at the discharge point (SDP) were extremely high during the dry and wet seasons (1.99 mg/l and 2.73 mg/l, respectively) which is more than the concentrations of 0.1 mg/l that were found in Minnesota River. The Sabie WWTWs discharge effluent that results in eutrophication in Sabie River. The site (SDP) did not comply with the TWQR during both dry and wet seasons with high concentrations of PO_4 being 1.99 mg/l during dry season and 2.73 mg/l during wet season (DWAF, 1996a and b). This means that the Sabie WWTWs discharged poorly treated or untreated effluent during the study period.

4.1.3.7 Calcium and calcium carbonate, magnesium and potassium

Water was sampled and analysed for calcium (Ca) and magnesium (Mg). The main source of these two minerals include the geological material of the catchment, kind of soil and class, climatic conditions, type of vegetation cover, land relief, intensity of water supply and detergents such as washing soap for clothes and dishes (Potasznik and Szymczyk, 2015).

When detergents dissolve in water, they result in a hard water, which reduces flow of water in a pipeline due to mineral deposits (Goel and Kaur, 2012). The highest concentrations of Ca were recorded in site SDP as 20.86 mg/l during the dry season and 21.89 mg/l during the wet season (Table 4.1.4), while the highest concentrations for Mg were also recorded in site SDP of 11.42 mg/l during dry season and 17.65 mg/l during the wet season in the present study. There are no TWQR discharge limits or drinking water standards for these two minerals and no conclusion could be made as to whether the concentrations of Ca and Mg at site SDP complied or not (DWAF, 1996b; DWAF, 1984; SABS, 2015). A study by Kannan *et al*. (2005) in Amaravati River on water characteristics and effects of the discharged effluent around the Karur District, in the Indian state of Tamil Nadu indicated elevated levels of Ca and Mg more than 75 mg/l (Ca) and more than 30 mg/l (Mg) (BIS, 2012). According to Kannan *et al.* (2005), "*the concentrations of these elements exceeded the limits prescribed by Bureau of Indian Standards (BIS)*". When this happen, water becomes hard, brackish and not ideal for drinking purposes. The chemical contamination of the water resource by a detergent from the washing powder can be more detrimental to the aquatic life, resulting in mortality of fish and macroinvertebrates (Goel and Kaur, 2012). The concentrations of Ca and Mg can cause death to aquatic biota such as fish and macroinvertebrates when they exceed 75 mg/l for Ca and 30 mg/l for Mg because these concentrations are more than those that were set by the Bureau of Indian Standards (BIS, 2012). The Ca and Mg concentrations for the Sabie River and the Sabie WWTWs complied BIS limits of 75 mg/l for Ca and 30 mg/l for Mg.

Water was sampled and analysed for total alkalinity or calcium carbonate ($CaCO_3$) and potassium (K). The $CaCO_3$ is the form of carbonate salt, which is the main constituent of the limestone and can be found as a major component of mollusc shells (Kemper *et al*., 2001). A study was conducted by Pourkhabbaz *et al.* (2011) in Ebne Hesam River, eastern Iran, to assess the effects of water hardness and $CaCO_3$ on freshwater mosquitofish (*Gambusia holbrooki*). The influence of the Cu and Zn at in relation to water hardness was assessed. The findings were that that Cu at the soft water was more toxic to the fish. It was also indicated that increase in water hardness (between 25 to 350 mg/l of $CaCO_3$) significantly minimise the toxicity of Cu and Zn to the aquatic biota such as the fish (Pourkhabbaz *et al*., 2011). According to Lenntech (2018), $CaCO_3$ increases the pH to be highly alkaline and once the pH of the waterbody reaches a high alkaline state (e.g. 9.6 mg/l), severe impacts on fish species such as mortality, damage to the gills, eyes, and skin and interference with the disposing of metabolic wastes may occur. In Table 4.1.4, the concentrations of $CaCO_3$ for sites SMP, SSW, SDP and SLB were not complying with the TWQR of 0.07 – 0.1 mg/l (DWAF, 1996a). The $CaCO_3$ concentrations were generally above 25 mg/l and less than 350 mg/l during dry and wet seasons, meaning that the $CaCO_3$ does not result to toxicity of Cu and Zn in aquatic life of the Sabie River (Pourkhabbaz *et al*., 2011). Potassium (K) is one of the essential elements found in drinking water. This element can be problematic if found in the human body at very low or high concentrations. According to WHO (2009), the exposure to high K concentrations could lead to health risks such as kidney problems in people with kidney disease. Infants may also be vulnerable. There were no TWQR or drinking water guideline that were noted for K and therefore it was assumed to be complying in sites SMP, SDP, SSW and SLB for the dry and wet seasons (DWAF, 1996a).

4.1.3.8 Chloride and Fluoride

Water was sampled and analysed for chlorides (Cl) and Fluorides (F). Chloride is one of the required elements and is normally found in freshwater and marine systems (Schutte, 2002), while

F is derivative of Fluorine (Main, 2015). The Cl is used in WWTWs for the final treatment of the effluent and process is called chlorination (Schutte, 2002). The F is used in public water supplies for the reduction of cavities in teeth. The process of adding F to water is called Fluoridation (Main, 2015). It is added to water in small amounts for the development of strong teeth (Schutte, 2002; Spellman, 2013). A study was conducted by Hunt *et al*. (2012) in lower Woonasquatucket River, USA. The study indicated that the increase of Cl concentrations in waterbodies results from human activities such as salting of roads, water softeners and sewage contamination. This study has suggested that increases of Cl in waterbodies caused severe damage to aquatic biota (e.g. fish) by affecting osmoregulation, impaired growth and reproduction, and may eventually lead to mortality. As a result, the Department of Environmental Management (DEM) in Pretoria has set compliance limits of 230 – 860 mg/l (for freshwater biota) and 250 mg/l for drinking water (Hunt *et al*., 2012). According to Main (2015) and Mondal and Nath (2015), F can lead to dental fluorosis to fish species when in high concentrations.

In Table 4.1.4, the Cl for the discharge point (site at SDP) did not comply with the discharge limits of ≤ 0.1 mg/l (DWAF, 1984) during the dry and wet seasons because its concentrations ranged between 19 and 32 mg/l. The non-compliance could have resulted from failure of the WWTWs team to inject required doses of Cl during final treatment. The monitoring sites (SMP, SSW and SLB) were compared against the drinking water quality standards, SANS 241. All the sites complied with the drinking water quality standards of ≤ 5 mg/l (SABS, 2015), except for site SLB that did not comply with drinking water quality standards during the wet season. This may be attributed to the adequate mixing of the riverine water in the furthest site with the Sabie WWTWs discharges, which contained Cl concentrations of 32 mg/l. Table 4.1.4 also indicated that the F concentrations complied with discharge limits of ≤ 1 mg/l (DWAF, 1984) at the discharge point (site at SDP) during the monitored seasons. The F concentrations for the other sites (SMP, SSW and SLB) also complied with the TWQR of 0.75 mg/l (DWAF, 1996a) during the dry and wet seasons in the present study.

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4.1.3.9 Escherichia coli

Water was sampled and analysed for faecal coliform bacteria, *Escherichia coli* (*E. coli*). The *E. coli* is a very dangerous bacterial pathogen that results in waterborne diseases in humans. It occurs naturally in the intestines of humans and warm-blooded animals (Ishii and Sadowsky, 2008). No harmful effects of the *E. coli* on the aquatic organisms such as fish have been reported, except that fish can act as a host and the pathogen enters the human body by consuming the fish (van Elsas *et al*., 2011). A study by Rock and Rivera (2014) in the Colorado River, USA, and surrounding areas has indicated that "*most E. coli do not cause illness but if a person becomes sick from E. coli, the primary site of infection is the gastrointestinal tract and symptoms can include nausea, vomiting, diarrhoea, and fever*". The *E. coli* may be harmless when it remains in the digestive tract, but may result in sicknesses if it gets into the wrong body part such as the kidneys or blood (Rock and Rivera, 2014).

In Table 4.1.4, the *E. coli* levels for the discharge point (site SDP) did not comply with the discharge limit of ≤ 0 cfu/100ml (DWAF, 1984) and all the other monitoring sites did not comply with the limits of 0-130 cfu/100ml as per the RQOs (RSA, 2016) during dry and wet seasons in the present study. Only one site (SLB) complied with the limits as set by the RQOs (RSA, 2016) during the dry season, with 39 cfu/100ml. The reason for site SLB's compliance could be as a result of the mixing with unpolluted water from the small tributaries further downstream of the Sabie WWTWs. During the respective dry and wet seasons, the discharge point (SDP) had very high *E. coli* levels with 8164 cfu/100 ml for dry season and more than 484000 cfu/100ml for the wet season. The site below the WWTWs (SSW) is the second most contaminated site with 4333 cfu/100ml in terms of *E. coli* levels caused by poorly treated discharges from the WWTWs. It is also a concern that the monitoring point upstream of the WWTWs (SMP) was found with high *E. coli* levels of 225 cfu/100ml during the dry season and 2350 cfu/100ml during the wet season. The origin is suspected from the trout (*Oncorhynchus mykiss*) farm in the upstream and polluted storm water run-offs, especially during the high flows as the highest *E. coli* levels in this site were found during the high flow season. Studies by Soibe (1982) in the United Kingdom (Humber River) and Niemi (1985) in Finland (Kiiminkijoki River) have reported the negative impacts of fish *Oncorhynchus mykiss* farms on freshwater quality, which included the addition of faecal coliforms into a water resource.

Table 4.1.4: Water quality data for the Sabie River assessed during the dry season in 2016 and the wet season in 2017.

			Dry Season in 2016				Wet Season in 2017			
WQ Parameter	TWQR (site 1,3,4)	Discharge Limits (for site 2)	SITE ID				SITE ID			
	RQOs (site 1,3,4)		SMP	SDP	SSW	SLB	SMP	SDP	SSW	SLB
Temperature (°C)	TWQR = 5 to 30	≤ 35	16.2	15.8	17.2	14.1	14.7	15	14.9	12.3
pH (Units)	TWQR = 6 - 9	5.5 - 9.5	8.38	7.91	8.44	8.32	7.87	7.46	7.78	7.64
EC (mS/m)	RQO = 30; TWQR = 70	≤ 75	19.49	3.99	24.1	21	1.24	5.48	1.13	1.81
DO (mg/l)	N/A	≤ 10	9.06	9.3	9.05	9.42	9.57	9.02	9.11	9.41
DO (%)	TWQR = 80 -120	N/A	102.7	105	105.2	101.1	101.4	103.1	107.5	100.05
TDS (mg/l)	≤ 1200 (SANS 241)	N/A	62	230.96	72	72	8.7	38.4	7.91	12.7
NO_2^- & NO_3^- (mg/l)	TWQR=0.05; ≤ 1 (SANS 241)	N/A	0.16	13.6	0.48	0.51	5.63	18.07	8.98	0.58
NH_4 (mg/l)	0.007	≤ 1	<0.2	15	<0.2	<0.2	0.1	4.1	0.1	0.1
PO_4 (mg/l)	RQO = 0.015; TWQR = < 0.075	≤ 1	<0.1	1.99	<0.1	<0.1	>0.1	2.73	>0.1	>0.1
Potassium (K)	N/A	N/A	0.3	4.088	0.53	0.59	1.18	3.53	1.823	1.387
Chlorides (Cl) (mg/l)	≤ 5 (SANS 241)	≤ 0.1	1.56	19	2.11	2.2	2.5	32	2.5	21.3
$CaC0_3$ (mg/l)	TWQR = 0.07 – 0.1	N/A	54	56.836	58	55	38.421	66.489	27.722	24.614
Calcium (Ca)	N/A	N/A	11.8	20.861	13.7	12.5	8.874	21.887	8.132	6.387
Fluoride (F) (mg/l)	TWQR = 0.75	≤ 1	<0.2	0.025	<0.2	<0.2	0.271	0.173	0.143	0.168
Magnesium (Mg)	N/A	N/A	7.1	11.419	8.38	7.76	6.67	17.654	6.431	3.703
E.coli (cfu/100ml)	RQO = 0-130	≤ 0	225	8164	770	39	2350	>484000	4333	165

4.2 MACROINVERTEBRATES

4.2.1 THE SOUTH AFRICAN SCORING SYSTEM VERSION 5

A total number of 45 aquatic macroinvertebrate taxa were recorded from the Sabie River during the dry season and 37 were recorded during the wet season from all three monitoring points (Appendix D). In the present study, the highest number of taxa (No. of Taxa) was recorded at site SLB that was selected furthest downstream of the Sabie WWTWs. From this point, 36 taxa were recorded during the dry season assessment in July 2016 (Figure 4.2 and Appendix C). The lowest number of taxa was recorded at SSW that was located immediately downstream of the WWTWs, where only 21 taxa were recorded during the wet season in May 2017 (Figure 4.2 and Appendix C).

The highest SASS5 scores of 222 were recorded at sites SSW and SLB during the dry season in July 2016 while the lowest SASS5 score of 202 was recorded at site SSW during the wet season in May 2017 (Figure 4.2 and Appendix C). The ASPT was the highest at the site upstream of the Sabie WWTWs (SMP) with an ASPT of 7.2 during dry season in July 2016, and the lowest ASPT was recorded at the site below the WWTWs (SSW) with an ASPT of 5.3 during the wet season in May 2017.

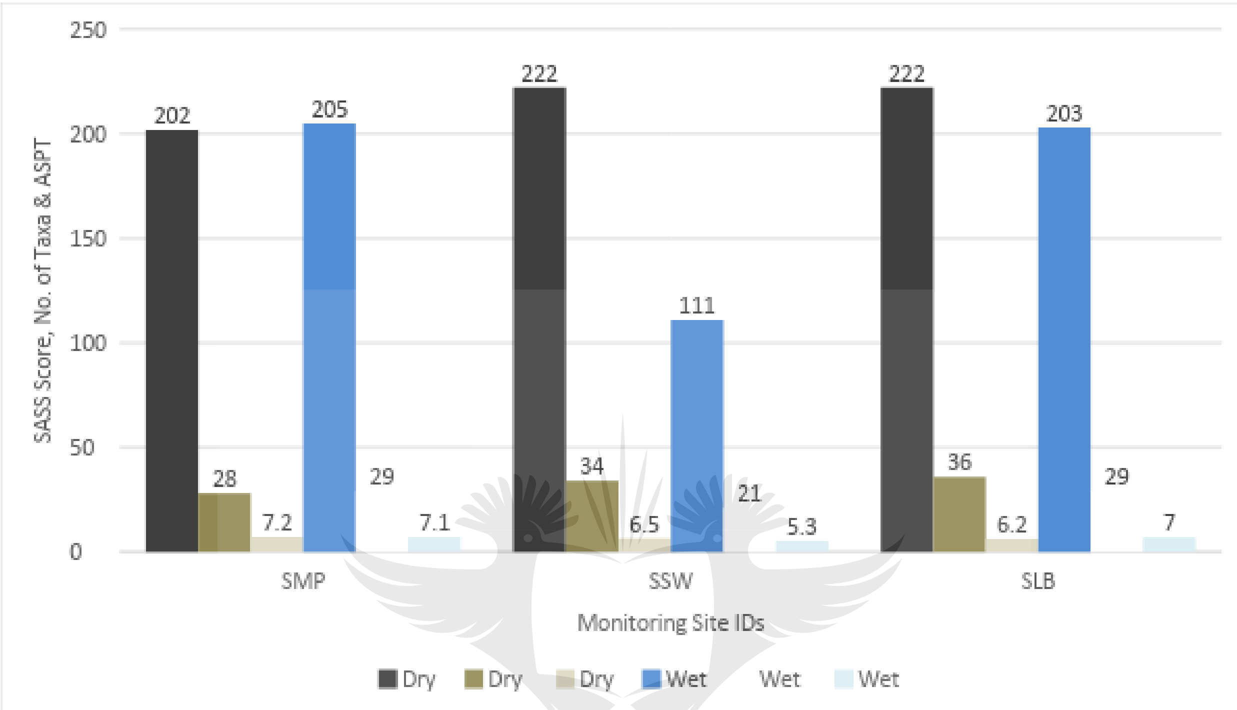

Figure 4.2: A summary of SASS5 data for sites SMP, SSW and SLB in the Sabie River that was assessed during dry season in 2016 and wet season in 2017 during the present study.

4.2.2 THE MACROINVERTEBRATES RESPONSE ASSESSMENT INDEX

The Resource Quality Objectives (RQOs) that have been published in 2016 provided the Target or Recommended Ecological Categories (REC) of a B/C class for sites within the sub-quaternary reach (SQ-Reach: X31A-00778), and B Class for those within SQ-Reach: X31B-00757. The site ID (SMP) is within the quaternary reach X31A-00778, meaning that this monitoring point must obtain an Ecological Category (EC) of a B/C to comply with the Resource Quality Objectives of the Sabie sub-catchment (RSA, 2016). The Site IDs SSW and SLB falls within the sub-quaternary reach X31B-00757, meaning an EC of a B Class in terms of the aquatic biota must be obtained to comply with the recommendations as per the RQOs (RSA, 2016).

The site at the upstream of the Sabie WWTWs (SMP) did not comply with the RQOs during the dry season assessment but did comply during the wet season as it was expected to obtain an EC of B or B/C to comply with the RQOs (Table 4.2). The two sites below the WWTWs failed to comply with the RQOs EC of a B and during both the dry and wet seasons (Table 4.2).

Table 4.2: Summary of SASS5 data for the Sabie River that was assessed during the dry season in 2016 and wet season in 2017 with MIRAI EC.

Site ID	Recommended RQO EC	EC for Dry Season	SASS SCORE	No. of Taxa	ASPT	EC for Wet Season	SASS Score	No. of Taxa	ASPT
SMP	B/C	C	202	28	7.2	B/C	205	29	7.1
SSW	B	B/C	222	34	6.5	C	111	21	5.3
SLB	B	B/C	222	36	6.2	B/C	203	29	7

4.3 STATISTICAL ANALYSES

4.3.1 THE PRINCIPAL COMPONENT ANALYSIS

Principal Component Analysis (PCA) can be defined as “*variable-reduction technique that shares many similarities to exploratory factor analysis*” (Laerd, 2013). It is also a “*mathematical procedure that transforms a number of (possibly) correlated variables into a (smaller) number of uncorrelated variables called principal components*” (Atchley, 2007). The distance between the sampling sites in the diagram indicated the similarity of sites as they were measured by their Euclidean distance. The Euclidean distance indicates that, in a PCA plot, the length of the arrow is related to the strength of the correlation. In general, the longer the arrow, the more highly related that variable is to macroinvertebrate family composition and the approximation correlation is positive when the angle is acute (<90º) and negative when the angle is large that 90 degrees (90º).

4.3.1.1 PCA Tri-plot for the sites, taxa and water quality

When the environmental variables were superimposed on the PCA plot (Figure 4.3.1), a positive correlation between macroinvertebrate taxa such as Lymnaedae, Sphaeridae, Hydropcychidea, Chlorocyphidae, Philopotamidae, Caenidea and Planorbinae with TDS, EC, Ca, Mg and $CaCO_3$ was observed at sites SLB Tot Dry (i.e. the total number of macroinvertebrate taxa with water quality during the dry season for site SLB) and SSW Tot Dry (i.e. the total number of macroinvertebrate taxa with water quality during the dry season for site SSW). In the present study, families such as Simullidae and Hydropsychidae>2 spp. correlated positively to environmental variables such as K, F, NO_2- and NO_3- at site SSW Tot Wet (i.e. the total number of macroinvertebrate taxa with water quality during the wet season for site SSW).

There was another positive correlation of macroinvertebrate taxa such as Gomphidea, Chironomidea, Ceratopogonidae, Libellulidae, Naucoridea, Hydrophilidae, Elmidea, Dytiscidae, Corixidae, Hydracarina and Calamoceratidae with environmental variables such as Chloride (Cl) and O_2 at site SLB Tot Wet. In Figure 4.3.1, the correlation of macroinvertebrates with environmental variables during different seasons at different sites indicated that the distribution of macroinvertebrates within the sites may be attributed to their environmental variable and season preferences in the Sabie River.

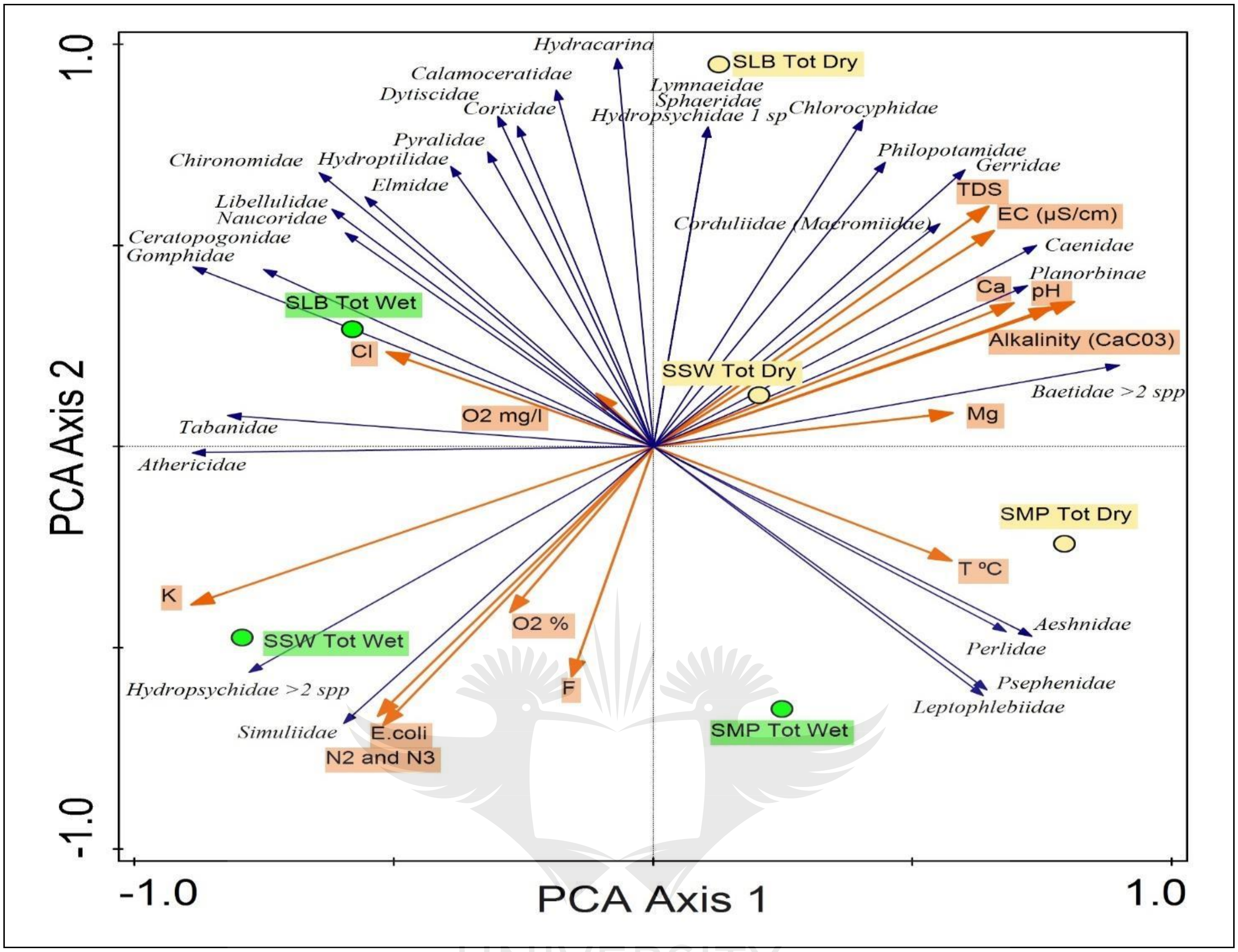

Figure 4.3.1: A tri-plot of the sites in Sabie River, macro-invertebrate, and water quality during the present study.

4.3.1.2 PCA tri-plot for the sites, No. of taxa, SASS score, ASPT and water quality

A PCA was used to assess the environmental variables at different sites during different seasons based on the physico-chemical characteristics of water with the physico-chemical variables, No. of Taxa, SASS Score and ASPT superimposed (Figure 4.3.2). This showed that environmental variables such as Mg, Ca, TDS, EC, $CaCO_3$ and pH were dominant at sites SLB Tot Dry and SSW Tot Dry with *No. of Taxa* correlating positively with these environmental variables. Sites SMP Tot Dry, SLB Tot Wet and SMP Tot Wet were dominated by environmental variables such as Oxygen (O_2), and Chloride (Cl) with the ASPT correlating positively with these environmental variables.

Sites SSW Tot Wet was separated from the rest of the sites. The separation of SSW Tot Wet can be attributed to the presence of different environmental variables such as *E. coli*, NO_{2-} and NO_{3-}, and K dominating the site. The PCA indicated that different variables dominate at different sites during respective dry and wet seasons.

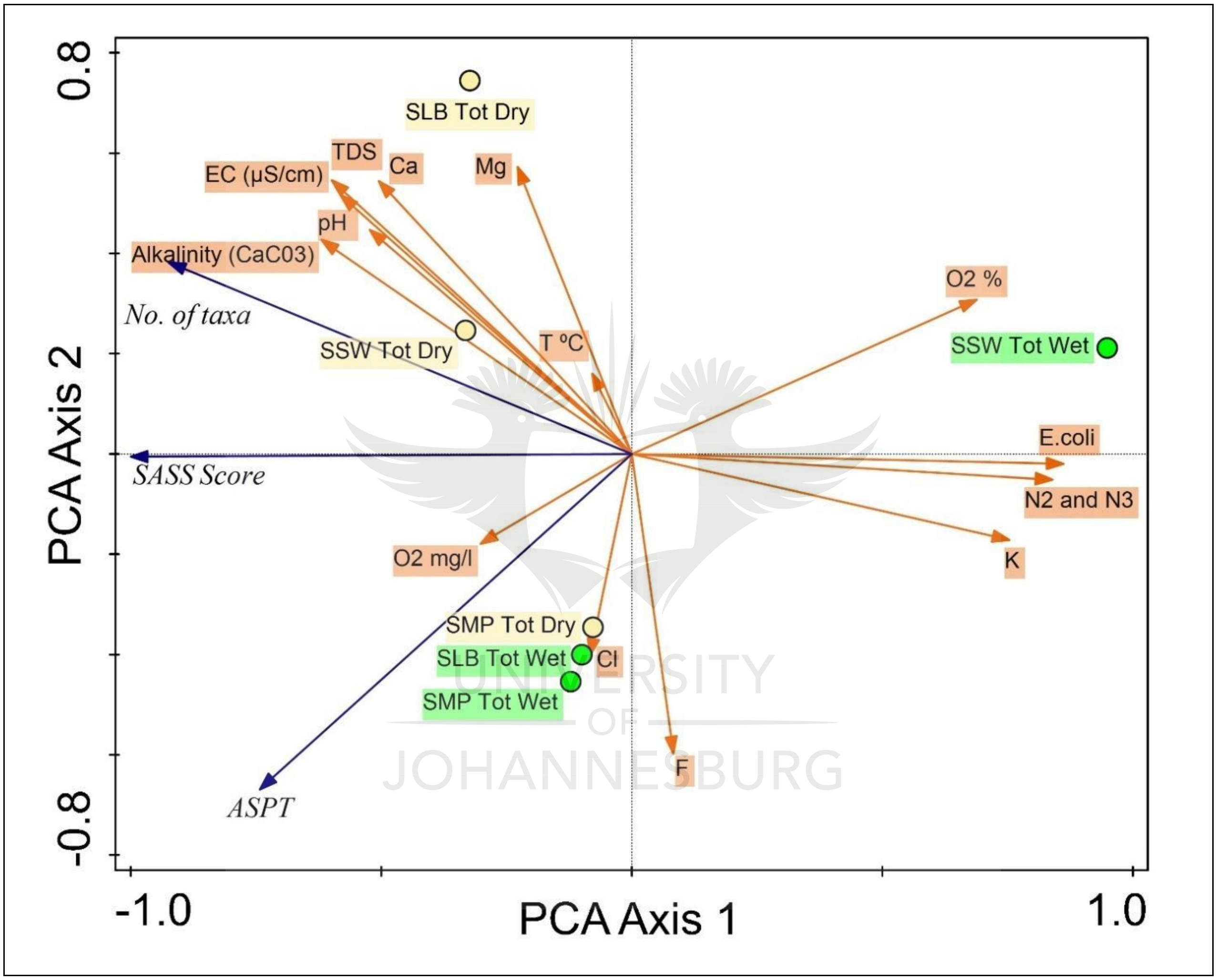

Figure 4.3.2: A tri-plot of the sites in Sabie River, SASS5 scores and water quality parameters for the present study.

4.3.1.3 PCA Bi-plot between the sites and macro-invertebrate taxa

The PCA bi-plot was further used to assess the similarities between various sites during different seasons based on macroinvertebrate assemblage superimposed (Figure 4.3.3). The distance between the sampling sites in the diagram indicated the similarity of sites. The PCA indicated there were no similarities between sites SMP Tot Dry and SSW Tot Wet because they were far apart from each other. This can be attributed to the different kind of macroinvertebrates occurring at the sites. Similarities were observed at sites SSW Tot Dry and SLB Tot Wet. These sites were situated at the sewage works (SSW To Dry) and below the sewage works (SLB Tot Wet).

The PCA analysis further showed that there was a seasonal variation amongst the sites as there was no similarities between sites sampled during wet or dry season in the present study.

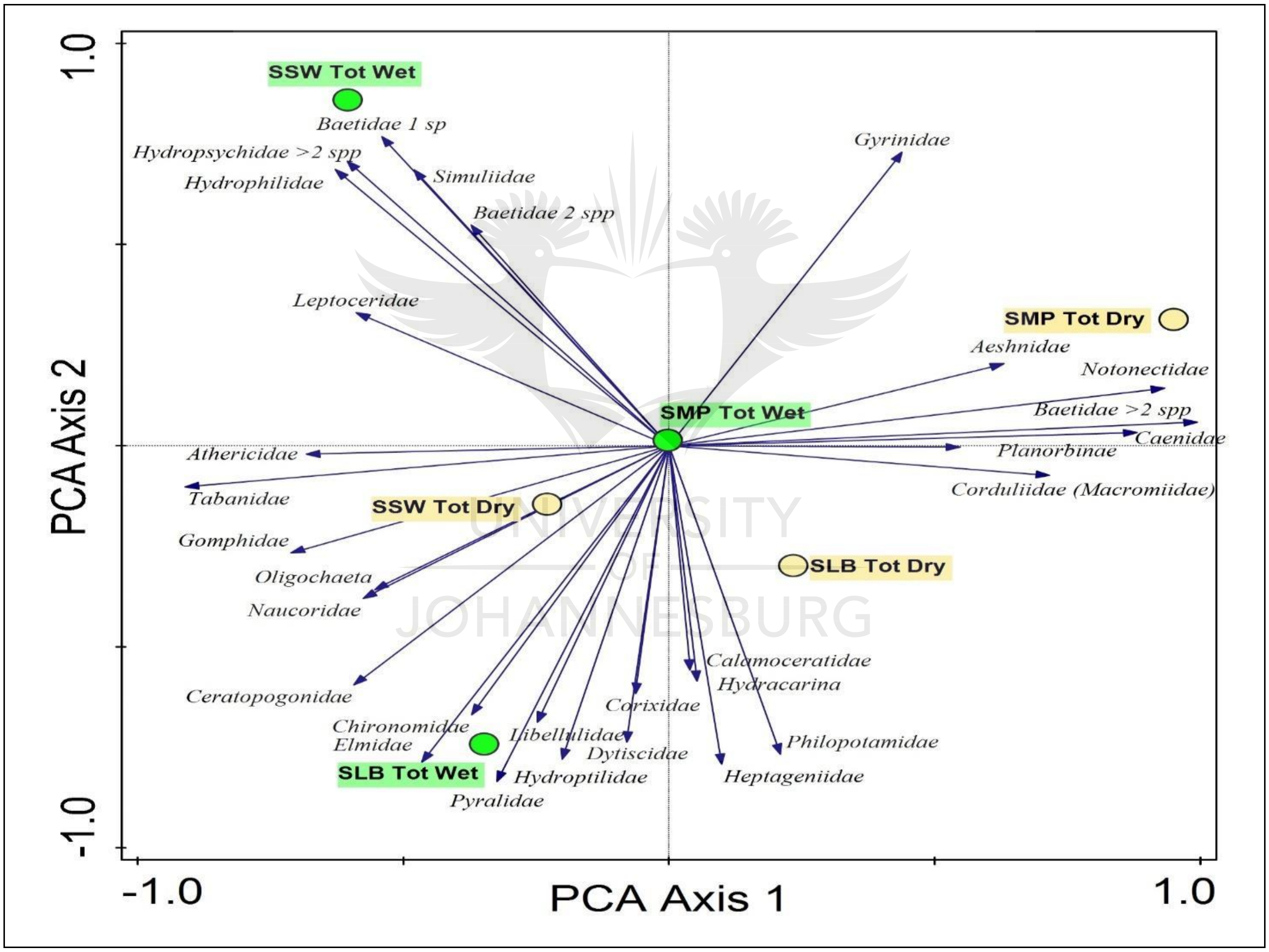

Figure 4.3.3: A bi-plot of the sites in Sabie River and the macro-invertebrate families found at the present study.

4.4 RAPID HABITAT ASSESSMENT

The Rapid Habitat Assessment Method (RHAM) was used for the study to determine the habitat availability for the aquatic biota. Habitat is required for existence of the macroinvertebrate and fish species. The quality and quantity of suitable habitat are important because limited and degraded habitat provides a lack of support to a limited species diversity and abundance of aquatic macroinvertebrates. It is important to note that the biological diversity and the habitat relates to one another because the structural disturbances of habitat have been noted as one of the major stressors to the aquatic environment (EPA, 2007; Barker *et al*., 2016). This means that habitat integrity and disturbances need to be considered during the interpretation of the macroinvertebrate data (Barker *et al*., 2016). The focus of the RHAM is a simplified procedure that measures and estimates the conditions of the habitat based on selected cross sections of the specific Geohydromophic Habitat Units (GHUs).

4.4.1 THE RHAMM FOR SITE 1 (SMP)

The monitoring site 1 (SMP) upstream of the Sabie WWTW's in the Sabie River was classified as a run-riffle in terms of the GHU type. The length of the site stretched up to 65 m with the width of 9 m and the average discharge was 0.513 m^3s^{-1}. The cross-sectional input data for this site are indicated in Appendix F. The colour of water was very clear during the field assessment. The water flow in this site was normally medium and become stronger just below the low bridge.

This site (SMP) was classified as an upper foothill system and is associated with mountain streams with riffles, runs and pools. The substrate was characterised by gravel, sand, mud, pebbles, cobbles and a few boulders, some in-stream and marginal vegetation. The elevation for this site is about 1000 m a.s.l. The anthropogenic impacts include pine plantations, stands of alien invasive vegetation species, sawmills and a trout farm further upstream (MTPA, 2012).

In Figure 4.4.1 on site 1 (SMP), the RHAM model indicated that the GHU was dominated by very fast (25%) and fast (21%) flow velocity classes. The velocity classes were classified using the RHAM manual for the Department of Water Affairs and Forestry (Louw and Kleynhans, 2009). The model has shown embeddedness as the dominating substrate with the roots, boulder, bedrock, algae and woody debris being less dominant. Aquatic vegetation assigned scores was only 2 out of 5 and the marginal vegetation 4 out of 5 with stone rated 4 out of 5, indicating that the aquatic biota prefers stones and vegetation biotopes (Thirion, 2007). All the velocity classes and the substrates were represented, and this therefore means that the macroinvertebrates taxa were expected to be abundant due to the availability of sufficient and suitable habitat. This is supported Barker *et al*. (2016), who indicated that a diverse availability of the habitat supports diverse macroinvertebrate communities.

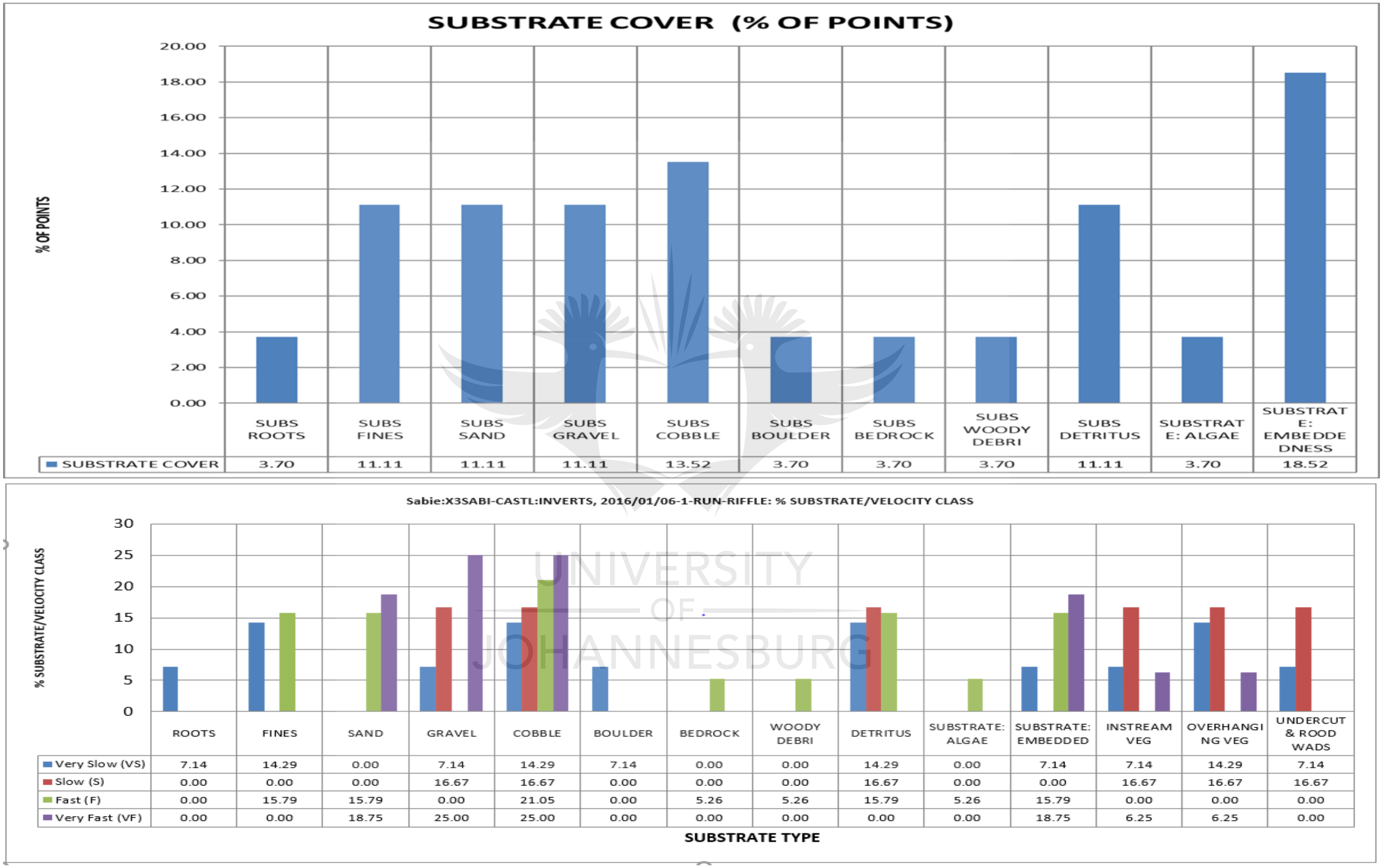

Figure 4.4.1: RHAMM substrate cover and percentage substrate-velocity classes of site SMP for the Sabie River in the present study.

4.4.2 THE RHAMM FOR SITE 2 (SSW)

The RHAM assessment was undertaken at site 2 (SSW) downstream of the Sabie WWTWs in the Sabie River during the dry season in 2016. The site was classified as a run-rapid in terms of the GHU type. The length of the site stretched up to 20 m with the width of 10 m and the average discharge was 0.644 m^3s^{-1} (MTPA, 2012). The cross-sectional input data for this site is indicated in Appendix F. The water clarity was medium to clear during the field assessment. The flow velocities were medium to strong. This site is also a biomonitoring site that falls within the upper foothills with an elevation of 953 m. It is a mountain stream with dominance of in-stream boulders, strong flows, diversity of habitat or biotope such as runs, riffles, pools and cascades. The site has been highly altered by forestry or plantations of *Eucalyptus* and *Pinus* species, developed riparian area, which caters for overhanging vegetation with undercut banks and dense stands of alien invasive vegetation species (MTPA, 2012).

In Figure 4.4.2, the RHAM model indicated that the GHU was represented by the velocity classes with fast flows (30%) being dominant and the lowest was the very slow velocity classes (4%). The RHAM model showed the dominant substratum as sand and cobbles (with 16.93 of substrate cover) and the lowest being bedrock, woody debris and detritus (both with 3.23 of substrate cover). Other substrates were roots, fine gravel, boulders, embeddedness and algae. The habitat such as stones, aquatic vegetation in and out of current, gravel, which was followed by bedrock, sand and mud were available for the macroinvertebrate assemblage (Thirion, 2007). All the velocity classes and the substrates were all represented. This means that habitat for this site was not the problem. A poor aquatic biota representation may be as a result of poor water quality (Barker *et al*., 2016). According to Barker *et al*. (2016), habitat is very important for the aquatic biota such as the macroinvertebrates, good indicators of water quality disturbances.

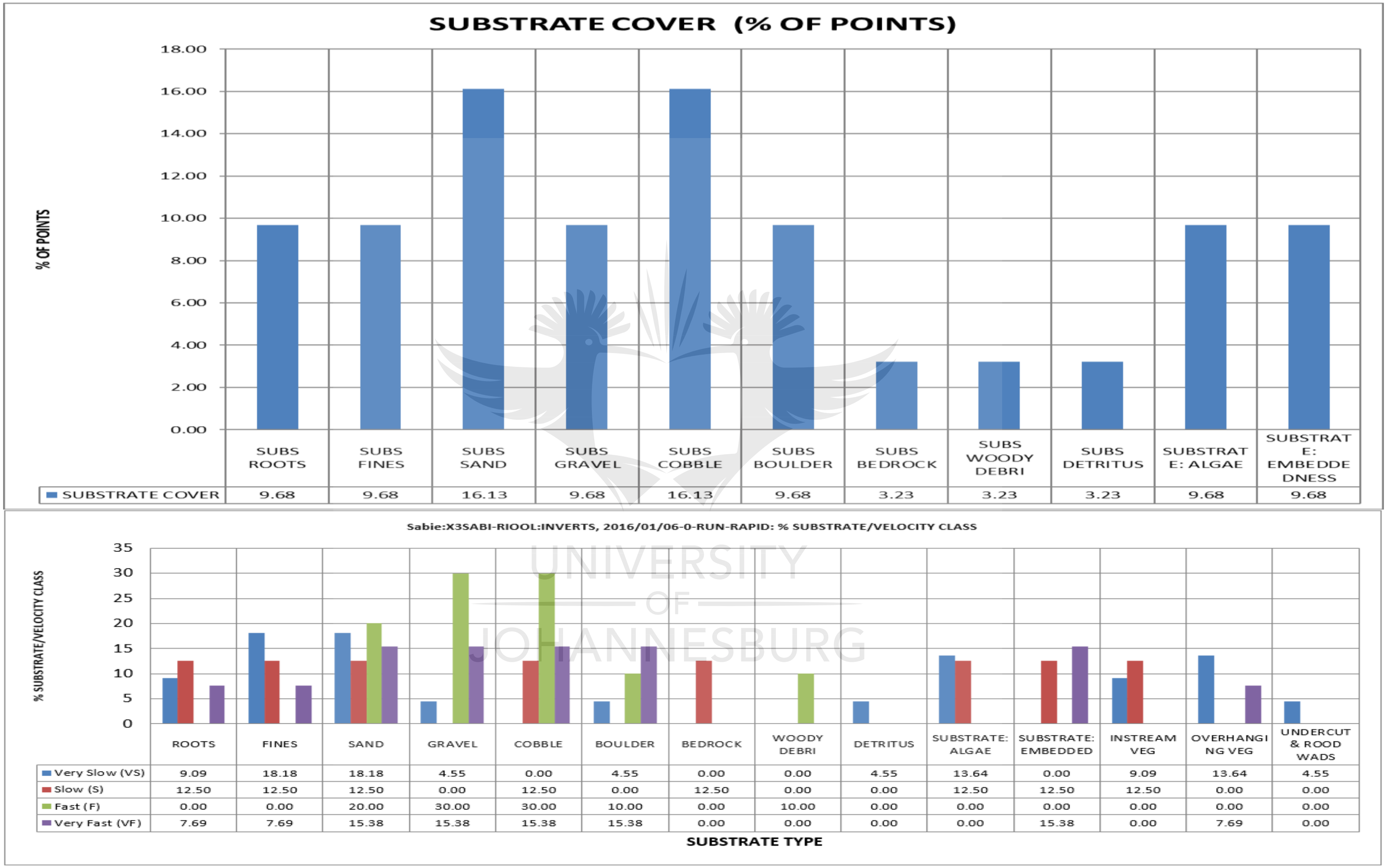

Figure 4.4.2: RHAMM substrate cover and percentage substrate-velocity classes of site SSW for the Sabie River in the present study.

4.4.3 THE RHAMM FOR SITE 3 (SLB)

The site was monitored further downstream of the Sabie WWTWs in the Sabie River during the dry season in 2016. It was categorised as a run-rapid in terms of the GHU type. The length of the site stretched up to 80 m with the width of 13.7 m and the average discharge was 0.645 m^3s^{-1} (MTPA, 2012). The cross-sectional input data for this site is indicated in Appendix F. The water clarity was medium to clear during the field assessment. The flow velocities were medium to strong flows. This is one of the biomonitoring points that falls within the upper foothills with an elevation of 870 m. It is a mountain stream with dominance of in-stream boulders, strong flows, a diversity of habitat types comprising of runs, riffles, pools and cascades. The site has been highly altered due to forestry or plantation of *Eucalyptus* and *Pinus* species (pers. Obs.), developed riparian area which provide additional area for overhanging vegetation with undercut banks and dense stands of alien invasive vegetation species (MTPA, 2012).

In Figure 4.4.3, the RHAM model indicated that the GHU type was dominated by fast flows (23%), followed by slow and very fast flow (20%) velocity classes, which were classified using the RHAM manual (Louw and Kleynhans, 2009). The model also indicated the dominant substratum as cobbles and boulders (with 13.52% of substrate cover) with the lowest being fines, bedrock, woody debris and algae (both with 3.7% of substrate cover). The presence of habitats with stones, aquatic vegetation in and out of current, gravel, bedrock, sand and mud, indicate a site that is suitable for sustaining macroinvertebrate communities (Thirion, 2007). Doke *et al*. (1995) and Barker *et al*. (2016) indicated that a good habitat availability plays the most important role in the presence of the macroinvertebrates.

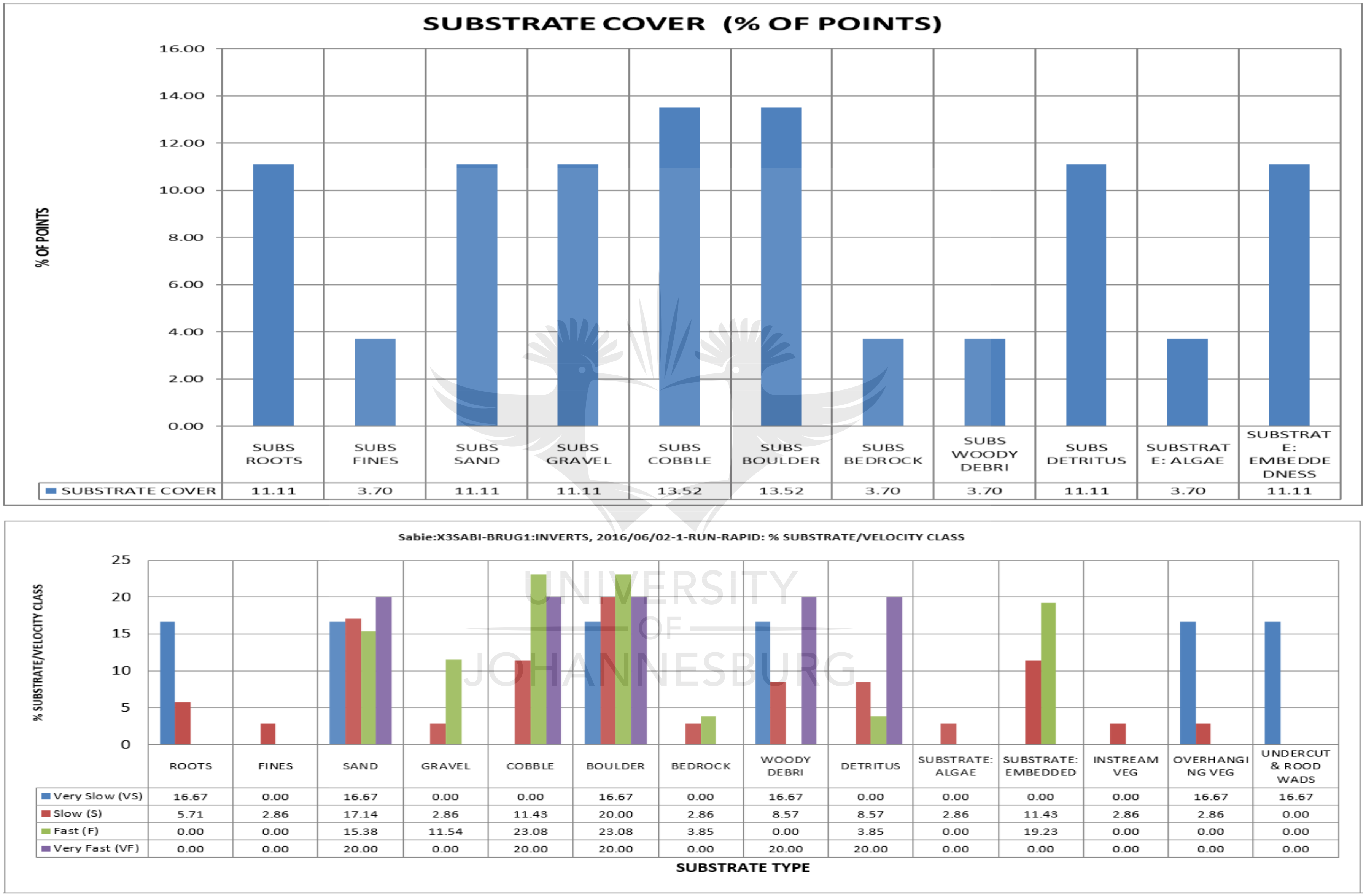

Figure 4.4.3: RHAMM substrate cover and percentage substrate-velocity classes of site SLB for the Sabie River in the present study.

CHAPTER 5: CONCLUSION REMARKS AND RECOMMENDATIONS

Water is a scarce and the most essential requirement for sustaining life (Nkosi and Odeku, 2014). The environmental factors that results from human activities have resulted in the scarcity of available and usable water for specific purposes (van Veelen and Dhemba, 2011). The legislative tools for both SA national Departments (such as DWS) and provincial or local Departments (such as Municipalities), were developed for the management, protection and provision of usable water. These include the established SA National Water Act (Act No. 36 of 1998) and Water Services Act (Act No. 108 of 1997). It is the responsibility of the DWS to ensure that the water resources are protected through the implementation of the National Water Act while the municipalities have a duty to ensure that well-treated water, that meets specific standards for specific uses, is provided to the public.

It is unfortunate that the WWTWs do not perform as expected worldwide, especially in South Africa. The Sabie WWTWs indicated a better performance compared to other facilities (WWTWs) within the same province (Mpumalanga) and the country. South Africa has embarked on several journeys in an endeavour to resolve the matter of water scarcity and environmental degradation in the country. This includes the establishment of different stand-alone monitoring programmes, water transfer schemes within South Africa and other countries, such as Lesotho, creation of impoundments or water barriers for water storage, water use authorisations, directives and opening of court cases.

This study was undertaken as part of water resource monitoring and impact assessment of WWTWs as guided by Chapter 3 of the National Water Act, Act No. 36 of 1998, due to the importance of the Sabie River system. Reasons include the fact that the Sabie River, as a water resource, provides water to the surrounding communities of the Sabie area and it falls within the Inkomati River basin, which is very important as an international basin that houses three countries (i.e. South Africa, Swaziland and Mozambique).

The monitoring methods applied in this study such as the water quality, Rapid Habitat Assessment Method and the South African Scoring System 5 were relevant to the study and provided data related to the performance of the Sabie WWTWs and the water quality of the Sabie River. The WWTWs have been shown to be major sources of pollution in urban lotic streams. The amount of effluent and its quality, extent of discharge, the area of the water resource where the effluent is being discharged, the general river condition, size and its sensitivity are the factors that determine the severity of the disturbance in a receiving aquatic ecosystem (Luger and Brown, 2003). The socio-economic disturbance that is associated with the discharge of poorly treated effluent has a way of disadvantaging the country's economy and that matter is either overlooked or not being realised (Luger and Brown, 2003)

The aim of this study was to determine the impacts that the WWTWs has on the Sabie River. This included the selection of sampling or assessment methodologies to achieve this aim. This involved the use of the biological indicators (macroinvertebrates) where the SASS5 method by (Dickens and Graham, 2002), RHAM was used to assess the habitat availability for the aquatic biota (Louw and Kleynhans, 2009) and water quality variables were analysed at the DWS laboratories.

To achieve the aims of the project, the following objectives were set. The first objective for this study was to determine the present ecological state (PES) of the Sabie River by monitoring the macroinvertebrate taxa, abundance and diversity. The assessment of the Sabie River and the Sabie WWTWs was undertaken at site 1 (SMP) upstream of the WWTWs, two sites (SSW and SLB) downstream of the WWTWs with and a fourth site at the discharge point (SDP) to assess water quality. Based on the findings of this assessment, a high diversity of macroinvertebrates was observed at the two sites downstream of the WWTWs during the low flow season. This was attributed to the availability of adequate quality habitat for the biota. The lowest site comprised of the highest abundance of macroinvertebrate taxa, which may be due to better water quality and habitat availability. The ASPT for the upper site was the highest at 7.2 and sensitive species such as Perlidae and Heptagenidae were found during the dry season. The SSW and SLB downstream were dominated by species that are tolerant to water pollution, which was an indication of water quality degradation. During the wet season, the number of taxa declined below the WWTWs and slightly increased upstream site of the WWTWs, which may be attributed to improved water quality at site SMP upstream of the Sabie WWTWs. This situation once occurred in three rivers in Bangladesh (i.e. Buriganga, Turag, and Shitalakkhya Rivers) where the rivers were more polluted during the dry season, and the water quality improved during the rainy season as a result of contaminated water being diluted by the rain water (Islam *et al*., 2015). In Sabie River, the ASPT was good upstream (SMP) and furthest downstream (SLB) of the WWTWs. A decline in SASS5 score, number of taxa and the ASPT was observed at the site that was monitored immediately downstream of the WWTWs. This was attributed to nutrient loading into the Sabie River such as ammonia, nitrites and nitrates and *E. coli.* It can be concluded that the *E. coli* was a big issue in the Sabie River, especially below the WWTWs, which is seemingly not always working optimally. The present ecological state (PES) is good and fair as the EC for all the sites during the two monitoring seasons was between the B and C Class. The upstream site complied with the RQOs during the wet season and not during the dry season, while the two sites downstream of WWTWs did not comply during both seasons, which indicates a serious problem.

The second objective was to assess the impacts of WWTWs on water quality and the sites were selected upstream and downstream of the Sabie WWTWs with the additional point being selected at the discharge point. The discharge point (SDP) was analysed separately from the other sites and the results of this site were compared against the discharge limits as approved by the Department of Water Affairs and Sanitation (DWAF, 1984). The results for sites SMP, SSW and SLB, were compared against the TWQR or RQOs or SANS 241 (DWAF, 1996a and b; RSA, 2016; SABS, 2015). The water quality for all the sites in the upstream and downstream of WWTWs did not comply with the RQOs and TWQR in terms of the NO_2^- and NO_3^- (during wet season), NH_4 (during dry and wet seasons), PO_4 (during wet season), chloride (at lowest point during wet season) and the *E. coli* (especially during wet season at SSW). The discharge point has the highest concentrations of ammonium, nitrites, nitrates, and phosphates for both seasons and very high *E. coli* counts. According to the CRR of the risk profile of the WWTWs, the Sabie WWTWs was found to have a risk percentage of 24%, which is classified a low risk (DWS, 2014). This is contradictory when looking at the increase in concentrations of the *E. coli* because *E. coli* concentrations exceeded the discharge limits of ≤ 0 cfu/100 ml (DWAF, 1984) at the discharge point (SDP) which also affected the downstream site (SSW).

The third objective was to assess the in-stream habitat availability for the aquatic biota using RHAM. The conclusion in terms of the method is that the habitat was generally good and ideal for most of the macroinvertebrate assemblages. The study found that adequate habitat availability resulted in an increased abundance of macroinvertebrates (Doke *et al*., 1995; Barker *et al*., 2016). It has been noted that the habitat is adequately available, but its good quality also plays a role in the presence of macroinvertebrate communities (Doke *et al*., 1995). Habitat disturbances were noted in the Sabie River during the assessment.

The fourth and last objective was to assess the spatial and temporal trends of water quality and ecological state of macroinvertebrates. In terms of the trends, trend lines were mostly fluctuating, which makes it difficult to conclude whether the water quality is declining or improving. The line graphs were mostly positive, showing an increase in specific variables (such as PO_4 in site SDP and NO_2^- + NO_3^- in SSW and SLB). According to the statistical analysis, the data for macroinvertebrate community and water quality indicated the special and temporal trends based on the two surveys. The analysis indicated positive correlation between macroinvertebrate taxa such as Lymnaedae, Sphaeridae, Hydropcychidea, Chlorocyphidae, Philopotamidae, Caenidea and Planorbinae with TDS, EC, Ca, Mg and $CaCO_3$ at sites SLB Tot Dry and SSW Tot Dry. Families such as Simullidae and Hydropsychidae>2 correlated positively to environmental variables such as K, F, NO_2^- and NO_3^- at site SSW To Wet. The correlation of macroinvertebrates with environmental variables during different seasons at different sites indicated that the distribution of macroinvertebrates within the sites could be attributed to environmental variables and seasonal preferences.

The PCA has shown that environmental variables such as TDS, EC, and pH were dominant at sites SLB Tot Dry and SSW Tot Dry with No. of Taxa correlating positively with these environmental variables. Sites SMP Tot Dry, SLB Tot Wet and SMP Tot Wet were dominated by environmental variables such as Oxygen (O_2), and Chloride (Cl) with the ASPT correlating positively with these environmental variables. The separation of SSW Tot Wet can be attributed to the presence of different environmental variables such as *E. coli* dominating the site. The PCA indicated that different variables dominate at different sites during the dry and wet seasons.

In conclusion, the prediction that the Sabie WWTWs has a negative impact on the water quality and aquatic health of the Sabie River system is therefore accepted. The results have shown the impacts of the WWTWs in terms of the water quality at the discharge point (SDP). This has negatively affected the site downstream, especially with *E. coli* concentrations. Seasonal variations in terms of water quality and macroinvertebrate community structure were observed.

The recommendations were drawn in an endeavour to remediate the current situation in the Sabie River. The ecological disturbances are as a result of poor and/or unsuccessful management practices (Nkosi, 2015). It is recommended that the public be educated on the importance or benefits of pollution prevention as well as the dangers associated with pollution. According to Nkosi (2015), it is better to prevent than to cure the effects of pollution. The higher authorities (such as municipal authorities) are therefore required to be stringent in terms of compliance with permits and ensure that pollution does not occur. It would also be advisable that more studies be conducted that combine vegetation, macroinvertebrates, habitat, water quality, fish and diatoms, looking at the impacts of the Sabie WWTWs. This study compared seasonal changes and the field assessment were undertaken once per season. It is therefore recommended that future studies be undertaken where the assessment will be done monthly or quarterly to make informed decisions concerning the impacts and the present ecological state of the river system. The wastewater discharges must be regularly monitored, and the authorities must ensure that the facility is always in a good working condition. Any failure that is associated with the working condition of the WWTWs must be fixed immediately. The sites below the Sabie WWTWs have been selected as the Environmental Water Requirements (EWR) sites and it is therefore recommended that the water quality assessment be strengthened to ensure compliance with the Resource Quality Objectives (RQOs). The Thaba Chweu Local Municipality must improve their compliance monitoring to ensure that the discharge effluent complies with the water use license conditions. The municipality must monitor specific variables such as *E. coli*, nitrogen, phosphates, chloride and fluoride dosages.

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LIST OF APPENDICES

APPENDIX A: EXAMPLE OF THE INKOMATI-USUTHU CATCHMENT MANAGEMENT AGENCY DIRECTIVE

APPENDIX A: EXAMPLE OF THE IUCMA DIRECTIVE for 2015

Suite 801, 8th Floor
The MAXSA Building
13 Streak Street
Mbombela

Private Bag X11214
Mbombela
1200

Tel 013 753 9000
Fax 013 753 2786

INKOMATI-USUTHU
CATCHMENT MANAGEMENT AGENCY

Enquiries: Mr G.W Mthembi
Reference: 14/1/6/2/1/3/15/X100/X05/4
E-mail : mthembig@iucma.co.za
Date : 30 June 2015

The Municipal Manager
Nkomazi Local Municipality
Private bag X101
Malelane
1320

ATTENTION: MR. M.D Ngwenya

Dear Sir

NOTICE OF INTENTION TO ISSUE A DIRECTIVE IN TERMS OF SECTION 19(3) OF THE NATIONAL WATER ACT, 1998 (ACT NO. 36 OF 1998) FOR FAILING TO TAKE REASONABLE MEASURES TO PREVENT POLLUTION FROM OCCURRING, CONTINUING OR RECCURING: TONGA PONDS.

I, Thomas Gyedu-Ababio in my capacity as the Acting Chief Executive Officer of Inkomati-Usuthu Catchment Management Agency (IUCMA) and duly authorized in terms of powers delegated to me by the Governing Board of the Inkomati-Usuthu Catchment Management Agency, hereby give a written notice of my intention to issue you , in your capacity as the Municipal Manager for Nkomazi Local Municipality with a directive in terms of section 19(3) of the National Water Act, 1998 (Act No. 36 of 1998), hereinafter referred to as "NWA".

The directive that I intend to issue relates to contravention of the following section of the NWA:

- *Section 19(1) of the NWA states that a person in control of land or a person who occupies or uses land on which any activity or process is or was performed or undertaken or any other situation exists, which causes, has caused or is likely to cause pollution of a water resources, must take all reasonable measures to prevent any such pollution from occurring, continuing or recurring.*

I have reached this conclusion based on the following:

On the 25 June 2015 the Inkomati-Usuthu Catchment Management Agency (IUCMA) official Mr Golden Mthembi together with a representative from Nkomazi Local Municipality Mr Dan Nkuna conducted a site investigation at Tonga Ponds to ensure that all best environmental practices are being implemented in order to protect the environment and the water resources

The following observation were made;

- The inlet was not well maintained, there was no bar screen to trap solid material, the screenings were not well disposed and they were easily washed away by storm water during rain events.
- The site was not fully fenced, plants and grass have over grown and the primary settling ponds were not accessible.
- The maturation ponds were well fenced and kept clean by cutting the grass and any plan growing onsite.
- No Chlorination of the final effluent is taking place.

Directive:

In accordance with Section 3 of the Promotion of Administrative Justice Act, Act no 3 of 2000, I hereby afford you an opportunity to make representations in writing to me within fourteen (14) working days from the date of receipt of this Notice, if you believe there are any compelling reasons for me not to exercise my powers in terms of section 19(3) of the NWA and issue a directive. Which will require Nkomazi Local Municipality to:

- Clear all the overgrown grass, plants which makes it difficult to access the primary settling ponds
- Ensure that there is disinfection of the final effluent.
- Install a bar screen on the inlet.
- Use a proper disposal method for the screenings where they will not be easily washed away into the nearby canal or Komati River.

- Provide an action plan with specified time frames within fourteen (14) working days from the receipt of the direction. the action plan must include measures to:
  - Cease, modify or control any act or process causing the pollution;
  - Comply with any prescribed waste standard or management practice;
  - Contain or prevent the movements of pollutants;
  - Eliminate any source of the pollution; and
  - Remedy the effects of the pollution.
  -

I would also like to bring to your attention that failure to make representations within fourteen (14) working days of receipt of the notice will leave the IUCMA with no option but to issue you with a directive in terms of sections 19(3) of the NWA to which failure to comply with constitutes an offence in terms of section 151 of the NWA.

It must be noted that in terms of Section 151 (1), subsection (i) of the National Water Act, 1998 (Act 36 of 1998) states that, no person may unlawfully and intentionally or negligently commit any act or omission which pollutes or is likely to pollute a water resource

Furthermore, Section 151(2) of the National Water Act, 1998 (Act 36 of 1998) states that any person who contravenes any provision of subsection (1) is guilty of an offence and liable, on the first conviction, to a fine or imprisonment for a period not exceeding five years or to both a fine and such imprisonment and in case of second or subsequent conviction to a fine or imprisonment for a period not exceeding ten years or both a fine and such imprisonment.

Please do not hesitate to contact the IUCMA office on the contact details provided above should you have any queries.

Yours faithfully

ACTING CHIEF EXECUTIVE OFFICER

Date :

APPENDIX B: DETERMINATION OF CUMULATIVE RISK RATIOS (CRR)

APPENDIX B: DETERMINATION OF CUMULATIVE RISK RATIOS (CRR)

TABLE A: DESIGN CAPACITY OF THE WWTP WHICH ALSO REPRESENT THE HYDRAULIC LOADING ONTO THE RECEIVING WATER RESOURCE

A: Design Capacity (Ml/d)		WF
Design Capacity Rating	> 400	7
	201 to 400	6
	101 to 200	5
	51 to 100	4
	21 to 50	3
	20 to 5	2
	<5	1

TABLE B: OPERATIONAL FLOW EXCEEDING THE CAPACITY OF WWTP OR NOT

B: Capacity Exceedance (%)		WF
Capacity Exceedance Rating	> 151 %	5
	101 - 150 %	4
	51 - 100 %	3
	1 - 50 %	2
	0 - 10 %	1
	< 0 %	0

TABLE C: A NUMBER OF NON-COMPLIANT PARAMETERS FOR THE WWTP IN TERM OF THE QUALITY OF EFFLUENT

C: No of Non-Compliant Parameter Failures	WF
Effluent Failure Rating	8
	7
	6
	5
	4
	3
	2
	1
	0

TABLE D: COMPLIANCE OR NON-COMPLIANCE IN TERMS OF THE TECHNICAL SKILLS

D: Weighting Factor (WF) for the Technical Skills		WF
Technical Skills Rating	Superintendent + Process Controllers + Maintenance Team	1
	Superintendent + Maintenance Team but no Process Controllers	2
	Process Controllers + Maintenance Team but no Superintendent	
	Process Controllers + Superintendent but no Maintenance Team	
	Superintendent but no Maintenance Team & no Process Controllers	3
	Process Controllers but no Maintenance Team & no Superintendent	
	Maintenance Team but no Superintendent & no Process Controllers	
	No Superintendent + No Process Controllers + No Maintenance Team	4

APPENDIX C: SOUTH AFRICAN SCORING SYSTEM – DATA SHEETS

APPENDIX C: SOUTH AFRICAN SCORING SYSTEM – DATA SHEETS

Date:	1/6/2016																
Site ID	SMP																
Collector/Sampler	B. Cele																
River Name	Sabie																
Taxon	**QV**	**S**	**Veg**	**GSM**	**Total**	**Taxon**	**QV**	**S**	**Veg**	**GSM**	**Total**	**Taxon**	**QV**	**S**	**Veg**	**GSM**	**Total**
PORIFERA (Sponge)	5					**HEMIPTERA (Bugs)**						**DIPTERA (Flies)**					
COELENTERATA (Cnidaria)	1					Belostomatidae* (Giant water bugs)	3					Athericidae (Snipe flies)	10	A			A
TURBELLARIA (Flatworms)	3	A			A	Corixidae* (Water boatmen)	3					Blepharoceridae (Mountain midges)	15				
ANNELIDA						Gerridae* (Pond skaters/Water striders)	5	1	A		A	Ceratopogonidae (Biting midges)	5				
Oligochaeta (Earthworms)	1					Hydrometridae* (Water measurers)	6					Chironomidae (Midges)	2	A			A
Hirudinea (Leeches)	3					Naucoridae* (Creeping water bugs)	7		A		A	Culicidae* (Mosquitoes)	1				
CRUSTACEA						Nepidae* (Water scorpions)	3					Dixidae* (Dixid midge)	10				
Amphipoda (Scuds)	13					Notonectidae* (Backswimmers)	3		A		A	Empididae (Dance flies)	6				
Potamonautidae* (Crabs)	3	A	1		A	Pleidae* (Pygmy backswimmers)	4					Ephydridae (Shore flies)	3				
Atyidae (Freshwater Shrimps)	8					Veliidae/M...veliidae* (Ripple bugs)	5		1		1	Muscidae (House flies, Stable flies)	1				
Palaemonidae (Freshwater Prawns)	10					**MEGALOPTERA (Fishflies, Dobsonflies & Alderflies)**						Psychodidae (Moth flies)	1				
HYDRACARINA (Mites)	8					Corydalidae (Fishflies & Dobsonflies)	8					Simuliidae (Blackflies)	5	A	1		A
PLECOPTERA (Stoneflies)						Sialidae (Alderflies)	6					Syrphidae* (Rat tailed maggots)	1				
Notonemouridae	14					**TRICHOPTERA (Caddisflies)**						Tabanidae (Horse flies)	5				
Perlidae	12	A			A	Dipseudopsidae	10					Tipulidae (Crane flies)	5	1			1
EPHEMEROPTERA (Mayflies)						Ecnomidae	8					**GASTROPODA (Snails)**					
Baetidae 1sp	4					Hydropsychidae 1 sp	4					Ancylidae (Limpets)	6	A	1		A
Baetidae 2 sp	6					Hydropsychidae 2 sp	6	A			A	Bulininae*	3				
Baetidae > 2 sp	12	B	C	B	C	Hydropsychidae > 2 sp	12					Hydrobiidae*	3				
Caenidae (Squaregills/Cainfles)	6	A	1	A	B	Philopotamidae	10	A			A	Lymnaeidae* (Pond snails)	3				
Ephemeridae	15					Polycentropodidae	12					Physidae* (Pouch snails)	3				
Heptageniidae (Flatheaded mayflies)	13	A	A	1	B	Psychomyiidae/Xiphocentronidae	8					Planorbinae* (Orb snails)	3		B	1	B
Leptophlebiidae (Prongills)	9		A		A	**Cased caddis:**						Thiaridae* (=Melanidae)	3				
Oligoneuridae (Brushlegged mayflies)	15					Barbarochthonidae SWC	13					Viviparidae* ST	5				
Polymitarcyidae (Pale Burrowers)	10					Calamoceratidae ST	11					**PELECYPODA (Bivalves)**					
Prosopistomatidae (Water specs)	15					Glossosomatidae SWC	11					Corbiculidae (Clams)	5				
Teloganodidae SWC (Spiny Crawlers)	12					Hydroptilidae	6					Sphaeriidae (Pill clams)	3				
Tricorythidae (Stout Crawlers)	9	B	1		B	Hydrosalpingidae SWC	15					Unionidae (Perly mussels)	6				
ODONATA (Dragonflies & Damselflies)						Lepidostomatidae	10					**SASS Score**					202
Calopterygidae ST,T (Demoiselles)	10					Leptoceridae	6		A		A	**No. of Taxa**					28
Chlorocyphidae (Jewels)	10	1	A		A	Petrothrincidae SWC	11					**ASPT**					7.2
Synlestidae (Chlorolestidae)(Sylphs)	8					Pisuliidae	10										
Coenagrionidae (Sprites and blues)	4		B		B	Sericostomatidae SWC	13										
Lestidae (Emerald Damselflies)	8					**COLEOPTERA (Beetles)**											
Platycnemidae (Stream Damselflies)	10					Dytiscidae/Noteridae* (Diving beetles)	5										
Protoneuridae (Threadwings)	8					Elmidae/Dryopidae* (Riffle beetles)	8										
Aeshnidae (Hawkers & Emperors)	8	B	A	1	B	Gyrinidae* (Whirligig beetles)	5	A	A		B						
Corduliidae (Cruisers)	8			A	A	Haliplidae* (Crawling water beetles)	5										
Gomphidae (Clubtails)	6			A	A	Helodidae (Marsh beetles)	12										
Libellulidae (Darters/Skimmers)	4					Hydraenidae* (Minute moss beetles)	8										
LEPIDOPTERA (Aquatic Caterpillars/Moths)						Hydrophilidae* (Water scavenger beetles)	5										
Crambidae (Pyralidae)	12					Limnichidae (Marsh-Loving Beetles)	10										
						Psephenidae (Water Pennies)	10	A		1	A						

Date:	1/6/2016																
Site ID	SSW																
Collector/Sampler	B. Cele																
River Name	Sabie																
Taxon	**QV**	**S**	**Veg**	**GSM**	**Total**	**Taxon**	**QV**	**S**	**Veg**	**GSM**	**Total**	**Taxon**	**QV**	**S**	**Veg**	**GSM**	**Total**
PORIFERA (Sponge)	5					**HEMIPTERA (Bugs)**						**DIPTERA (Flies)**					
COELENTERATA (Cnidaria)	1					Belostomatidae* (Giant water bugs)	3					Athericidae (Snipe flies)	10	A			A
TURBELLARIA (Flatworms)	3	A		A	B	Corixidae* (Water boatmen)	3		A		A	Blepharoceridae (Mountain midges)	15				
ANNELIDA						Gerridae* (Pond skaters/Water striders)	5		A		A	Ceratopogonidae (Biting midges)	5		1	A	A
Oligochaeta (Earthworms)	1	1			1	Hydrometridae* (Water measurers)	6					Chironomidae (Midges)	2			B	B
Hirudinea (Leeches)	3					Naucoridae* (Creeping water bugs)	7		B	B	B	Culicidae* (Mosquitoes)	1				
CRUSTACEA						Nepidae* (Water scorpions)	3					Dixidae* (Dixid midge)	10		1		1
Amphipoda (Scuds)	13					Notonectidae* (Backswimmers)	3					Empididae (Dance flies)	6				
Potamonautidae* (Crabs)	3	1		1	A	Pleidae* (Pygmy backswimmers)	4					Ephydridae (Shore flies)	3				
Atyidae (Freshwater Shrimps)	8					Veliidae/M...veliidae* (Ripple bugs)	5		1		1	Muscidae (House flies, Stable flies)	1				
Palaemonidae (Freshwater Prawns)	10					**MEGALOPTERA (Fishflies, Dobsonflies & Alderflies)**						Psychodidae (Moth flies)	1				
HYDRACARINA (Mites)	8		1	1	A	Corydalidae (Fishflies & Dobsonflies)	8					Simuliidae (Blackflies)	5		A		A
PLECOPTERA (Stoneflies)						Sialidae (Alderflies)	6					Syrphidae* (Rat tailed maggots)	1				
Notonemouridae	14					**TRICHOPTERA (Caddisflies)**						Tabanidae (Horse flies)	5	A			A
Perlidae	12	B			B	Dipseudopsidae	10					Tipulidae (Crane flies)	5	A		1	A
EPHEMEROPTERA (Mayflies)						Ecnomidae	8					**GASTROPODA (Snails)**					
Baetidae 1sp	4					Hydropsychidae 1 sp	4					Ancylidae (Limpets)	6			1	1
Baetidae 2 sp	6					Hydropsychidae 2 sp	6	B			B	Bulininae*	3				
Baetidae > 2 sp	12	B	B	B	C	Hydropsychidae > 2 sp	12					Hydrobiidae*	3				
Caenidae (Squaregills/Cainflies)	6	1		A	A	Philopotamidae	10	A	A		B	Lymnaeidae* (Pond snails)	3				
Ephemeridae	15					Polycentropodidae	12					Physidae* (Pouch snails)	3		A		A
Heptageniidae (Flatheaded mayflies)	13	A			A	Psychomyiidae/Xiphocentronidae	8					Planorbinae* (Orb snails)	3		B	1	B
Leptophlebiidae (Prongills)	9		A		A	**Cased caddis:**						Thiaridae* (=Melanidae)	3				
Oligoneuridae (Brushlegged mayflies)	15					Barbarochthonidae SWC	13					Viviparidae* ST	5				
Polymitarcyidae (Pale Burrowers)	10					Calamoceratidae ST	11					**PELECYPODA (Bivalves)**					
Prosopistomatidae (Water specs)	15					Glossosomatidae SWC	11					Corbiculidae (Clams)	5				
Teloganodidae SWC (Spiny Crawlers)	12					Hydroptilidae	6					Sphaeriidae (Pill clams)	3				
Tricorythidae (Stout Crawlers)	9	A			A	Hydrosalpingidae SWC	15					Unionidae (Perly mussels)	6				
ODONATA (Dragonflies & Damselflies)						Lepidostomatidae	10					**SASS Score**					222
Calopterygidae ST,T (Demoiselles)	10					Leptoceridae	6	1	A	1	A	**No. of Taxa**					34
Chlorocyphidae (Jewels)	10		1		1	Petrothrincidae SWC	11					**ASPT**					6.5
Synlestidae (Chlorolestidae)(Sylphs)	8					Pisuliidae	10										
Coenagrionidae (Sprites and blues)	4		B	A	B	Sericostomatidae SWC	13										
Lestidae (Emerald Damselflies)	8					**COLEOPTERA (Beetles)**											
Platycnemidae (Stream Damselflies)	10					Dytiscidae/Noteridae* (Diving beetles)	5										
Protoneuridae (Threadwings)	8					Elmidae/Dryopidae* (Riffle beetles)	8	A	1	A	A						
Aeshnidae (Hawkers & Emperors)	8					Gyrinidae* (Whirligig beetles)	5		A		A						
Corduliidae (Cruisers)	8					Haliplidae* (Crawling water beetles)	5										
Gomphidae (Clubtails)	6			B	B	Helodidae (Marsh beetles)	12										
Libellulidae (Darters/Skimmers)	4					Hydraenidae* (Minute moss beetles)	8										
LEPIDOPTERA (Aquatic Caterpillars/Moths)						Hydrophilidae* (Water scavenger beetles)	5		A		A						
Crambidae (Pyralidae)	12	A			B	Limnichidae (Marsh-Loving Beetles)	10										
						Psephenidae (Water Pennies)	10										

Date:	2/6/2016																
Site ID	SLB																
Collector/Sampler	B. Cele																
River Name	Sabie																
Taxon	**QV**	**S**	**Veg**	**GSM**	**Total**	**Taxon**	**QV**	**S**	**Veg**	**GSM**	**Total**	**Taxon**	**QV**	**S**	**Veg**	**GSM**	**Total**
PORIFERA (Sponge)	5					**HEMIPTERA (Bugs)**						**DIPTERA (Flies)**					
COELENTERATA (Cnidaria)	1					Belostomatidae* (Giant water bugs)	3					Athericidae (Snipe flies)	10	A		1	A
TURBELLARIA (Flatworms)	3	A	A		A	Corixidae* (Water boatmen)	3		B		B	Blepharoceridae (Mountain midges)	15				
ANNELIDA						Gerridae* (Pond skaters/Water striders)	5	A	A		B	Ceratopogonidae (Biting midges)	5		B		B
Oligochaeta (Earthworms)	1	1	A		A	Hydrometridae* (Water measurers)	6					Chironomidae (Midges)	2	B	A	B	B
Hirudinea (Leeches)	3					Naucoridae* (Creeping water bugs)	7	A	A	B	B	Culicidae* (Mosquitoes)	1				
CRUSTACEA						Nepidae* (Water scorpions)	3					Dixidae* (Dixid midge)	10				
Amphipoda (Scuds)	13					Notonectidae* (Backswimmers)	3		A		A	Empididae (Dance flies)	6				
Potamonautidae* (Crabs)	3	A			A	Pleidae* (Pygmy backswimmers)	4					Ephydridae (Shore flies)	3				
Atyidae (Freshwater Shrimps)	8					Veliidae/M...veliidae* (Ripple bugs)	5					Muscidae (House flies, Stable flies)	1				
Palaemonidae (Freshwater Prawns)	10					**MEGALOPTERA (Fishflies, Dobsonflies & Alderflies)**						Psychodidae (Moth flies)	1				
HYDRACARINA (Mites)	8	1	1	A	A	Corydalidae (Fishflies & Dobsonflies)	8					Simuliidae (Blackflies)	5	A			A
PLECOPTERA (Stoneflies)						Sialidae (Alderflies)	6					Syrphidae* (Rat tailed maggots)	1				
Notonemouridae	14					**TRICHOPTERA (Caddisflies)**						Tabanidae (Horse flies)	5	1			1
Perlidae	12					Dipseudopsidae	10					Tipulidae (Crane flies)	5				
EPHEMEROPTERA (Mayflies)						Ecnomidae	8					**GASTROPODA (Snails)**					
Baetidae 1sp	4					Hydropsychidae 1 sp	4	B	A		B	Ancylidae (Limpets)	6		1		1
Baetidae 2 sp	6			A		Hydropsychidae 2 sp	6					Bulininae*	3				
Baetidae > 2 sp	12	B	B		A	Hydropsychidae > 2 sp	12					Hydrobiidae*	3				
Caenidae (Squaregills/Cainflies)	6	A	A	A	B	Philopotamidae	10	B			B	Lymnaeidae* (Pond snails)	3	1	A		A
Ephemeridae	15					Polycentropodidae	12					Physidae* (Pouch snails)	3				
Heptageniidae (Flatheaded mayflies)	13	B	B	1	B	Psychomyiidae/Xiphocentronidae	8					Planorbinae* (Orb snails)	3	1	1	A	A
Leptophlebiidae (Prongills)	9					**Cased caddis:**						Thiaridae* (=Melanidae)	3				
Oligoneuridae (Brushlegged mayflies)	15					Barbarochthonidae SWC	13					Viviparidae* ST	5				
Polymitarcyidae (Pale Burrowers)	10					Calamoceratidae ST	11		A		A	**PELECYPODA (Bivalves)**					
Prosopistomatidae (Water specs)	15					Glossosomatidae SWC	11					Corbiculidae (Clams)	5				
Teloganodidae SWC (Spiny Crawlers)	12					Hydroptilidae	6	1			1	Sphaeriidae (Pill clams)	3		A		A
Tricorythidae (Stout Crawlers)	9	B	A		B	Hydrosalpingidae SWC	15					Unionidae (Perly mussels)	6				
ODONATA (Dragonflies & Damselflies)						Lepidostomatidae	10					**SASS Score**					222
Calopterygidae ST,T (Demoiselles)	10					Leptoceridae	6		B	A	B	**No. of Taxa**					36
Chlorocyphidae (Jewels)	10	A	B		B	Petrothrincidae SWC	11					**ASPT**					6.2
Synlestidae (Chlorolestidae)(Sylphs)	8					Pisuliidae	10										
Coenagrionidae (Sprites and blues)	4		A	A	A	Sericostomatidae SWC	13										
Lestidae (Emerald Damselflies)	8					**COLEOPTERA (Beetles)**											
Platycnemidae (Stream Damselflies)	10					Dytiscidae/Noteridae* (Diving beetles)	5		1		1						
Protoneuridae (Threadwings)	8					Elmidae/Dryopidae* (Riffle beetles)	8	A		1	A						
Aeshnidae (Hawkers & Emperors)	8		1		1	Gyrinidae* (Whirligig beetles)	5	1	A		A						
Corduliidae (Cruisers)	8			A	A	Haliplidae* (Crawling water beetles)	5										
Gomphidae (Clubtails)	6	A	A	B	B	Helodidae (Marsh beetles)	12										
Libellulidae (Darters/Skimmers)	4	A	A	A	B	Hydraenidae* (Minute moss beetles)	8										
LEPIDOPTERA (Aquatic Caterpillars/Moths)						Hydrophilidae* (Water scavenger beetles)	5										
Crambidae (Pyralidae)	12	A			A	Limnichidae (Marsh-Loving Beetles)	10										
						Psephenidae (Water Pennies)	10										

Date:	5/5/2017																
Site ID	SMP																
Collector/Sampler	B. Cele																
River Name	Sabie																
Taxon	**QV**	**S**	**Veg**	**GSM**	**Total**	**Taxon**	**QV**	**S**	**Veg**	**GSM**	**Total**	**Taxon**	**QV**	**S**	**Veg**	**GSM**	**Total**
PORIFERA (Sponge)	5					**HEMIPTERA (Bugs)**						**DIPTERA (Flies)**					
COELENTERATA (Cnidaria)	1					Belostomatidae* (Giant water bugs)	3					Athericidae (Snipe flies)	10		A	A	A
TURBELLARIA (Flatworms)	3	A	A	A	B	Corixidae* (Water boatmen)	3	1	1		A	Blepharoceridae (Mountain midges)	15				
ANNELIDA						Gerridae* (Pond skaters/Water striders)	5					Ceratopogonidae (Biting midges)	5	A		A	A
Oligochaeta (Earthworms)	1		1	A	A	Hydrometridae* (Water measurers)	6					Chironomidae (Midges)	2	1			1
Hirudinea (Leeches)	3	A			A	Naucoridae* (Creeping water bugs)	7	A	A	1	A	Culicidae* (Mosquitoes)	1				
CRUSTACEA						Nepidae* (Water scorpions)	3					Dixidae* (Dixid midge)	10				
Amphipoda (Scuds)	13					Notonectidae* (Backswimmers)	3					Empididae (Dance flies)	6				
Potamonautidae* (Crabs)	3	A	1	1	A	Pleidae* (Pygmy backswimmers)	4					Ephydridae (Shore flies)	3				
Atyidae (Freshwater Shrimps)	8					Veliidae/M...veliidae* (Ripple bugs)	5					Muscidae (House flies, Stable flies)	1				
Palaemonidae (Freshwater Prawns)	10					**MEGALOPTERA (Fishflies, Dobsonflies & Alderflies)**						Psychodidae (Moth flies)	1				
HYDRACARINA (Mites)	8					Corydalidae (Fishflies & Dobsonflies)	8					Simuliidae (Blackflies)	5	A	A		A
PLECOPTERA (Stoneflies)						Sialidae (Alderflies)	6					Syrphidae* (Rat tailed maggots)	1				
Notonemouridae	14					**TRICHOPTERA (Caddisflies)**						Tabanidae (Horse flies)	5		1		1
Perlidae	12	A	A	A	B	Dipseudopsidae	10					Tipulidae (Crane flies)	5				
EPHEMEROPTERA (Mayflies)						Ecnomidae	8					**GASTROPODA (Snails)**					
Baetidae 1sp	4					Hydropsychidae 1 sp	4		A	1		Ancylidae (Limpets)	6				
Baetidae 2 sp	6			B		Hydropsychidae 2 sp	6	B				Bulininae*	3				
Baetidae > 2 sp	12	B	B		C	Hydropsychidae > 2 sp	12				B	Hydrobiidae*	3				
Caenidae (Squaregills/Cainfles)	6					Philopotamidae	10	A	A		A	Lymnaeidae* (Pond snails)	3				
Ephemeridae	15					Polycentropodidae	12					Physidae* (Pouch snails)	3				
Heptageniidae (Flatheaded mayflies)	13	B	1	A	B	Psychomyiidae/Xiphocentronidae	8					Planorbinae* (Orb snails)	3				
Leptophlebiidae (Prongills)	9	A	A	A	B	**Cased caddis:**						Thiaridae* (=Melanidae)	3				
Oligoneuridae (Brushlegged mayflies)	15					Barbarochthonidae SWC	13					Viviparidae* ST	5				
Polymitarcyidae (Pale Burrowers)	10					Calamoceratidae ST	11					**PELECYPODA (Bivalvles)**					
Prosopistomatidae (Water specs)	15			1	1	Glossosomatidae SWC	11					Corbiculidae (Clams)	5		1		1
Teloganodidae SWC (Spiny Crawlers)	12					Hydroptilidae	6					Sphaeriidae (Pill clams)	3				
Tricorythidae (Stout Crawlers)	9	B	A	A	B	Hydrosalpingidae SWC	15					Unionidae (Perly mussels)	6				
ODONATA (Dragonflies & Damselflies)						Lepidostomatidae	10					**SASS Score**					205
Calopterygidae ST,T (Demoiselles)	10					Leptoceridae	6	1	A	A	A	**No. of Taxa**					29
Chlorocyphidae (Jewels)	10	1			1	Petrothrincidae SWC	11					**ASPT**					7.1
Synlestidae (Chlorolestidae)(Sylphs)	8					Pisuliidae	10										
Coenagrionidae (Sprites and blues)	4	1	B	A	B	Sericostomatidae SWC	13										
Lestidae (Emerald Damselflies)	8					**COLEOPTERA (Beetles)**											
Platycnemidae (Stream Damselflies)	10					Dytiscidae/Noteridae* (Diving beetles)	5										
Protoneuridae (Threadwings)	8					Elmidae/Dryopidae* (Riffle beetles)	8	1			1						
Aeshnidae (Hawkers & Emperors)	8	B	A	1	B	Gyrinidae* (Whirligig beetles)	5	A	1	1	A						
Corduliidae (Cruisers)	8					Haliplidae* (Crawling water beetles)	5										
Gomphidae (Clubtails)	6		A	A	A	Helodidae (Marsh beetles)	12										
Libellulidae (Darters/Skimmers)	4		1		1	Hydraenidae* (Minute moss beetles)	8										
LEPIDOPTERA (Aquatic Caterpillars/Moths)						Hydrophilidae* (Water scavenger beetles)	5										
Crambidae (Pyralidae)	12					Limnichidae (Marsh-Loving Beetles)	10										
						Psephenidae (Water Pennies)	10	A	1	A	A						

Date:	5/5/2017																
Site ID	SSW																
Collector/Sampler	B. Cele																
River Name	Sabie																
Taxon	**QV**	**S**	**Veg**	**GSM**	**Total**	**Taxon**	**QV**	**S**	**Veg**	**GSM**	**Total**	**Taxon**	**QV**	**S**	**Veg**	**GSM**	**Total**
PORIFERA (Sponge)	5					**HEMIPTERA (Bugs)**						**DIPTERA (Flies)**					
COELENTERATA (Cnidaria)	1					Belostomatidae* (Giant water bugs)	3					Athericidae (Snipe flies)	10	A	A	1	A
TURBELLARIA (Flatworms)	3	A		1	A	Corixidae* (Water boatmen)	3		1		1	Blepharoceridae (Mountain midges)	15				
ANNELIDA					A	Gerridae* (Pond skaters/Water striders)	5					Ceratopogonidae (Biting midges)	5	A	1	A	A
Oligochaeta (Earthworms)	1	1	A		A	Hydrometridae* (Water measurers)	6					Chironomidae (Midges)	2	A	A	B	B
Hirudinea (Leeches)	3					Naucoridae* (Creeping water bugs)	7	B	A	A	B	Culicidae* (Mosquitoes)	1				
CRUSTACEA						Nepidae* (Water scorpions)	3					Dixidae* (Dixid midge)	10				
Amphipoda (Scuds)	13					Notonectidae* (Backswimmers)	3					Empididae (Dance flies)	6				
Potamonautidae* (Crabs)	3	A		1	A	Pleidae* (Pygmy backswimmers)	4					Ephydridae (Shore flies)	3				
Atyidae (Freshwater Shrimps)	8					Veliidae/M...veliidae* (Ripple bugs)	5					Muscidae (House flies, Stable flies)	1				
Palaemonidae (Freshwater Prawns)	10					**MEGALOPTERA (Fishflies, Dobsonflies & Alderflies)**						Psychodidae (Moth flies)	1				
HYDRACARINA (Mites)	8					Corydalidae (Fishflies & Dobsonflies)	8					Simuliidae (Blackflies)	5	B	A	A	B
PLECOPTERA (Stoneflies)						Sialidae (Alderflies)	6					Syrphidae* (Rat tailed maggots)	1				
Notonemouridae	14					**TRICHOPTERA (Caddisflies)**						Tabanidae (Horse flies)	5	1		A	A
Perlidae	12					Dipseudopsidae	10					Tipulidae (Crane flies)	5			1	1
EPHEMEROPTERA (Mayflies)						Ecnomidae	8					**GASTROPODA (Snails)**					
Baetidae 1sp	4			A		Hydropsychidae 1 sp	4					Ancylidae (Limpets)	6	A		1	A
Baetidae 2 sp	6	A	A		B	Hydropsychidae 2 sp	6			A		Bulininae*	3				
Baetidae > 2 sp	12					Hydropsychidae > 2 sp	12	B	B		C	Hydrobiidae*	3				
Caenidae (Squaregills/Cainflies)	6					Philopotamidae	10					Lymnaeidae* (Pond snails)	3				
Ephemeridae	15					Polycentropodidae	12					Physidae* (Pouch snails)	3				
Heptageniidae (Flatheaded mayflies)	13					Psychomyiidae/Xiphocentronidae	8					Planorbinae* (Orb snails)	3				
Leptophlebiidae (Prongills)	9					**Cased caddis:**						Thiaridae* (=Melanidae)	3				
Oligoneuridae (Brushlegged mayflies)	15					Barbarochthonidae SWC	13					Viviparidae* ST	5				
Polymitarcyidae (Pale Burrowers)	10					Calamoceratidae ST	11					**PELECYPODA (Bivalves)**					
Prosopistomatidae (Water specs)	15					Glossosomatidae SWC	11					Corbiculidae (Clams)	5				
Teloganodidae SWC (Spiny Crawlers)	12					Hydroptilidae	6					Sphaeriidae (Pill clams)	3				
Tricorythidae (Stout Crawlers)	9					Hydrosalpingidae SWC	15					Unionidae (Perly mussels)	6				
ODONATA (Dragonflies & Damselflies)						Lepidostomatidae	10					**SASS Score**					111
Calopterygidae ST,T (Demoiselles)	10					Leptoceridae	6	A	B	A	B	**No. of Taxa**					21
Chlorocyphidae (Jewels)	10					Petrothrincidae SWC	11					**ASPT**					5.3
Synlestidae (Chlorolestidae)(Sylphs)	8					Pisuliidae	10										
Coenagrionidae (Sprites and blues)	4	1	B	A	B	Sericostomatidae SWC	13										
Lestidae (Emerald Damselflies)	8					**COLEOPTERA (Beetles)**											
Platycnemidae (Stream Damselflies)	10					Dytiscidae/Noteridae* (Diving beetles)	5										
Protoneuridae (Threadwings)	8					Elmidae/Dryopidae* (Riffle beetles)	8	1		1	A						
Aeshnidae (Hawkers & Emperors)	8					Gyrinidae* (Whirligig beetles)	5	A	A		A						
Corduliidae (Cruisers)	8					Haliplidae* (Crawling water beetles)	5										
Gomphidae (Clubtails)	6	A	A	B	B	Helodidae (Marsh beetles)	12										
Libellulidae (Darters/Skimmers)	4	A	1		A	Hydraenidae* (Minute moss beetles)	8										
LEPIDOPTERA (Aquatic Caterpillars/Moths)						Hydrophilidae* (Water scavenger beetles)	5	1	A		A						
Crambidae (Pyralidae)	12					Limnichidae (Marsh-Loving Beetles)	10										
						Psephenidae (Water Pennies)	10										

Date:	5/5/2017																
Site ID	SLB																
Collector/Sampler	B. Cele																
River Name	Sabie																
Taxon	**QV**	**S**	**Veg**	**GSM**	**Total**	**Taxon**	**QV**	**S**	**Veg**	**GSM**	**Total**	**Taxon**	**QV**	**S**	**Veg**	**GSM**	**Total**
PORIFERA (Sponge)	5					**HEMIPTERA (Bugs)**						**DIPTERA (Flies)**					
COELENTERATA (Cnidaria)	1					Belostomatidae* (Giant water bugs)	3					Athericidae (Snipe flies)	10	A	1	1	A
TURBELLARIA (Flatworms)	3	A	A	1	A	Corixidae* (Water boatmen)	3	1	A	1	A	Blepharoceridae (Mountain midges)	15				
ANNELIDA						Gerridae* (Pond skaters/Water striders)	5					Ceratopogonidae (Biting midges)	5		B	A	B
Oligochaeta (Earthworms)	1	1	A		A	Hydrometridae* (Water measurers)	6					Chironomidae (Midges)	2	A	A	A	B
Hirudinea (Leeches)	3					Naucoridae* (Creeping water bugs)	7	B	A	A	B	Culicidae* (Mosquitoes)	1				
CRUSTACEA						Nepidae* (Water scorpions)	3					Dixidae* (Dixid midge)	10				
Amphipoda (Scuds)	13					Notonectidae* (Backswimmers)	3					Empididae (Dance flies)	6				
Potamonautidae* (Crabs)	3	A	A		A	Pleidae* (Pygmy backswimmers)	4					Ephydridae (Shore flies)	3				
Atyidae (Freshwater Shrimps)	8					Veliidae/M...veliidae* (Ripple bugs)	5					Muscidae (House flies, Stable flies)	1				
Palaemonidae (Freshwater Prawns)	10					**MEGALOPTERA (Fishflies, Dobsonflies & Alderflies)**						Psychodidae (Moth flies)	1				
HYDRACARINA (Mites)	8	1		1	A	Corydalidae (Fishflies & Dobsonflies)	8					Simuliidae (Blackflies)	5	A	1	A	A
PLECOPTERA (Stoneflies)						Sialidae (Alderflies)	6					Syrphidae* (Rat tailed maggots)	1				
Notonemouridae	14					**TRICHOPTERA (Caddisflies)**						Tabanidae (Horse flies)	5	A		1	A
Perlidae	12	1			1	Dipseudopsidae	10					Tipulidae (Crane flies)	5				
EPHEMEROPTERA (Mayflies)						Ecnomidae	8					**GASTROPODA (Snails)**					
Baetidae 1sp	4					Hydropsychidae 1 sp	4					Ancylidae (Limpets)	6	A	1		A
Baetidae 2 sp	6					Hydropsychidae 2 sp	6		A			Bulininae*	3				
Baetidae > 2 sp	12	B	A	A	B	Hydropsychidae > 2 sp	12	B			B	Hydrobiidae*	3				
Caenidae (Squaregills/Cainfles)	6					Philopotamidae	10	A	A	1	A	Lymnaeidae* (Pond snails)	3				
Ephemeridae	15					Polycentropodidae	12					Physidae* (Pouch snails)	3				
Heptageniidae (Flatheaded mayflies)	13	B	B	A	B	Psychomyiidae/Xiphocentronidae	8					Planorbinae* (Orb snails)	3				
Leptophlebiidae (Prongills)	9					**Cased caddis:**						Thiaridae* (=Melanidae)	3				
Oligoneuridae (Brushlegged mayflies)	15					Barbarochthonidae SWC	13					Viviparidae* ST	5				
Polymitarcyidae (Pale Burrowers)	10					Calamoceratidae ST	11		1		1	**PELECYPODA (Bivalvles)**					
Prosopistomatidae (Water specs)	15					Glossosomatidae SWC	11					Corbiculidae (Clams)	5				
Teloganodidae SWC (Spiny Crawlers)	12					Hydroptilidae	6	A			A	Sphaeriidae (Pill clams)	3				
Tricorythidae (Stout Crawlers)	9	B	A	1	B	Hydrosalpingidae SWC	15					Unionidae (Perly mussels)	6				
ODONATA (Dragonflies & Damselflies)						Lepidostomatidae	10					**SASS Score**					203
Calopterygidae ST,T (Demoiselles)	10					Leptoceridae	6	1	A	A	A	**No. of Taxa**					29
Chlorocyphidae (Jewels)	10	1	A		A	Petrothrincidae SWC	11					**ASPT**					7
Synlestidae (Chlorolestidae)(Sylphs)	8					Pisuliidae	10										
Coenagrionidae (Sprites and blues)	4	1	A	A	A	Sericostomatidae SWC	13										
Lestidae (Emerald Damselflies)	8					**COLEOPTERA (Beetles)**											
Platycnemidae (Stream Damselflies)	10					Dytiscidae/Noteridae* (Diving beetles)	5		1		1						
Protoneuridae (Threadwings)	8					Elmidae/Dryopidae* (Riffle beetles)	8	A	A	A	B						
Aeshnidae (Hawkers & Emperors)	8					Gyrinidae* (Whirligig beetles)	5	1	A	A	A						
Corduliidae (Cruisers)	8					Haliplidae* (Crawling water beetles)	5										
Gomphidae (Clubtails)	6	A	A	B	B	Helodidae (Marsh beetles)	12										
Libellulidae (Darters/Skimmers)	4	A	A	A	B	Hydraenidae* (Minute moss beetles)	8										
LEPIDOPTERA (Aquatic Caterpillars/Moths)						Hydrophilidae* (Water scavenger beetles)	5										
Crambidae (Pyralidae)	12	A	1	A	A	Limnichidae (Marsh-Loving Beetles)	10										
						Psephenidae (Water Pennies)	10										

APPENDIX D: LIST OF MACRO-INVERTEBRATE TAXA

APPENDIX D: LIST OF MACRO-INVERTEBRATE TAXA

TABLE D-1: LIST OF INDIVIDUAL FAMILY TAXA SAMPLED AT THREE SITES IN SABIE RIVER DURING JUNE 2016 (DRY SEASON).

	SITE ID: SMP				SITE ID: SSW				SITE ID: SLB			
Taxon	**Stones**	**Veg.**	**GSM**	**Total**	**Stones**	**Veg.**	**GSM**	**Total**	**Stones**	**Veg.**	**GSM**	**Total**
Turbellaria	4	0	0	4	5	0	7	12	2	3	0	5
Oligochaeta	0	0	0	0	1	0	0	1	1	5	0	6
Potamonautidae	5	1	0	6	1	0	1	2	2	0	0	2
Hydracarina	0	0	0	0	0	1	1	2	1	1	4	6
Perlidae	8	0	0	8	13	0	0	13	0	0	0	0
Baetidae 2 spp	0	0	0	0	0	0	0	0	0	0	5	5
Baetidae >2 spp	82	115	45	242	13	11	12	36	69	51	0	120
Caenidae	7	1	5	13	1	0	3	4	4	3	3	10
Heptageniidae	5	7	1	13	6	0	0	6	13	11	1	25
Leptophlebiidae	0	4	0	4	0	3	0	3	0	0	0	0
Trichorythidae	11	1	0	12	4	0	0	4	16	8	0	24
Chlorocyphidae	1	3	0	4	0	1	0	1	4	11	0	15
Coenagrionidae	0	12	0	12	0	13	7	20	0	4	3	7
Aeshnidae	12	4	1	17	0	0	0	0	0	1	0	1
Corduliidae (Macromiidae	0	0	2	2	0	0	0	0	0	0	3	3
Gomphidae	0	0	6	6	0	0	11	11	3	4	7	14
Libellulidae	0	0	0	0	0	0	0	0	4	6	2	12
Pyralidae	0	0	0	0	2	0	0	2	2	0	0	2
Corixidae	0	0	0	0	0	4	0	4	0	11	0	11
Gerridae	1	3	0	4	0	3	0	3	9	2	0	11
Naucoridae	0	2	0	2	0	17	15	32	5	4	12	21
Notonectidae	0	4	0	4	0	0	0	0	0	2	0	2
Veliidae	0	1	0	1	0	1	0	1	0	0	0	0
Hydropsychidae 1 sp	0	0	0	0	0	0	0	0	13	3	0	16
Hydropsychidae 2 spp	2	0	0	2	12	0	0	12	0	0	0	0
Philopotamidae	4	0	0	4	4	3	0	7	14	0	0	14
Calamoceratidae	0	0	0	0	0	0	0	0	0	2	0	2
Hydroptilidae	0	0	0	0	0	0	0	0	1	0	0	1
Leptoceridae	0	3	0	3	1	4	1	6	0	12	2	14
Dytiscidae	0	0	0	0	0	0	0	0	0	1	0	1
Elmidae	0	0	0	0	4	1	2	7	4	0	1	5
Gyrinidae	8	3	0	11	0	2	0	2	1	3	0	4
Hydrophilidae	0	0	0	0	0	2	0	2	0	0	0	0
Psephenidae	3	0	1	4	0	0	0	0	0	0	0	0
Athericidae	3	0	0	3	3	0	0	3	3	0	1	4
Ceratopogonidae	0	0	0	0	0	1	5	6	0	12	0	12
Chironomidae	4	0	0	4	0	0	11	11	16	4	11	31
Dixidae	1	0	0	1	0	1	0	1	0	0	0	0
Simuliidae	8	1	0	9	0	6	0	6	5	0	0	5
Tabanidae	0	0	0	0	3	0	0	3	1	0	0	1
Tipulidae	1	0	0	1	3	0	0	3	0	0	0	0
Ancylidae	7	1	0	8	0	0	1	1	0	1	0	1
Lymnaeidae	0	0	0	0	0	0	0	0	1	2	0	3
Physidae	0	0	0	0	0	6	0	6	0	0	0	0
Planorbinae	0	11	1	12	0	13	1	14	1	1	4	6
Sphaeridae	0	0	0	0	0	0	0	0	0	2	0	2

TABLE D-2: LIST OF INDIVIDUAL FAMILY TAXA SAMPLED AT THREE SITES IN SABIE RIVER DURING MAY 2017 (WET SEASON).

	SITE ID: SMP				SITE ID: SSW				SITE ID: SLB			
Taxon	**Stones**	**Veg.**	**GSM**	**Total**	**Stones**	**Veg.**	**GSM**	**Total**	**Stones**	**Veg.**	**GSM**	**Total**
Turbellaria	8	2	5	15	2	0	1	3	2	3	1	6
Oligochaeta	0	1	4	5	1	4	0	5	1	6	0	7
Hirudinea	3	0	0	3	0	0	0	0	0	0	0	0
Potamonautidae	6	1	1	8	6	0	1	7	5	3	0	8
Hydracarina	0	0	0	0	0	0	0	0	1	0	1	2
Perlidae	6	3	4	13	0	0	0	0	1	0	0	1
Baetidae 1 sp	0	0	0	0	0	0	2	2	0	0	0	0
Baetidae 2 spp	0	0	11	11	8	3	0	11	0	0	0	0
Baetidae >2 spp	41	33	0	74	0	0	0	0	16	8	5	29
Heptageniidae	21	1	8	30	0	0	0	0	19	12	6	37
Leptophlebiidae	8	4	7	19	0	0	0	0	0	0	0	0
Prosopistomatidae	0	0	1	1	0	0	0	0	0	0	0	0
Trichorythidae	34	6	9	49	0	0	0	0	12	4	1	17
Chlorocyphidae	1	0	0	1	0	0	0	0	1	2	0	3
Coenagrionidae	1	13	4	18	1	12	2	15	1	5	2	8
Aeshnidae	11	8	1	20	0	0	0	0	0	0	0	0
Gomphidae	0	3	4	7	4	2	11	17	4	3	13	20
Libellulidae	0	1	0	1	2	1	0	3	6	8	3	17
Pyralidae	0	0	0	0	0	0	0	0	3	1	2	6
Corixidae	1	1	0	2	0	1	0	1	1	3	1	5
Naucoridae	3	2	1	6	11	3	2	16	12	4	4	20
Hydropsychidae 1 sp	0	0	1	1	0	0	0	0	0	0	0	0
Hydropsychidae 2 spp	2	5	0	7	0	0	4	4	0	4	0	4
Hydropsychidae >2 spp	12	0	0	12	41	63	0	104	14	0	0	14
Philopotamidae	3	2	0	5	0	0	0	0	4	3	1	8
Calamoceratidae	0	0	0	0	0	0	0	0	0	1	0	1
Hydroptilidae	0	0	0	0	0	0	0	0	2	0	0	2
Leptoceridae	1	6	2	9	4	11	2	17	1	4	3	8
Dytiscidae	0	0	0	0	0	0	0	0	0	1	0	1
Elmidae	1	0	0	1	1	0	1	2	5	6	2	13
Gyrinidae	4	1	1	6	7	2	0	9	1	2	1	4
Hydrophilidae	0	0	0	0	1	3	0	4	0	0	0	0
Psephenidae	2	1	4	7	0	0	0	0	0	0	0	0
Athericidae	0	2	2	4	2	2	1	5	3	1	1	5
Ceratopogonidae	2	0	3	5	2	1	5	8	0	12	3	15
Chironomidae	1	0	0	1	4	3	11	18	78	5	3	86
Simuliidae	6	3	0	9	12	4	2	18	6	1	3	10
Tabanidae	0	1	0	1	1	0	2	3	2	0	1	3
Tipulidae	0	0	0	0	0	0	1	1	0	0	0	0
Ancylidae	0	0	0	0	4	0	1	5	6	1	0	7
Corbiculidae	0	1	0	1	0	0	0	0	0	0	0	0

APPENDIX E: MACRO-INVERTEBRATES MODEL - MIRAI EC TABLES

APPENDIX E: MACRO-INVERTEBRATES MODEL - MIRAI EC TABLES

TABLE E-1: INVERTEBRATE EC: BASED ON WEIGHTS OF METRIC GROUPS FOR SITE 1 (SMP) THAT WAS SAMPLED DURING 2016 FIELD ASSESSMENT

INVERTEBRATE EC METRIC GROUP		METRIC GROUP CALCULATED SCORE	CALCULATED WEIGHT	WEIGHTED SCORE OF GROUP	RANK OF METRIC GROUP	%WEIGHT FOR METRIC GROUP
FLOW MODIFICATION	FM	77.0	*0.328*	25.2153	2	95
HABITAT	H	75.9	*0.345*	26.1839	1	100
WATER QUALITY	WQ	76.4	*0.328*	25.013	2	95
CONNECTIVITY & SEASONALITY	CS	90.0	*0.000*	0	3	0
						290
INVERTEBRATE EC				76.4122		
INVERTEBRATE EC CATEGORY				C		

TABLE E-2: INVERTEBRATE EC: BASED ON WEIGHTS OF METRIC GROUPS FOR SITE 2 (SSW) THAT WAS SAMPLED DURING THE 2016 FIELD ASSESSMENT

INVERTEBRATE EC METRIC GROUP		METRIC GROUP CALCULATED SCORE	CALCULATED WEIGHT	WEIGHTED SCORE OF GROUP	RANK OF METRIC GROUP	%WEIGHT FOR METRIC GROUP
FLOW MODIFICATION	FM	80.9	*0.328*	26.5035	2	95
HABITAT	H	78.0	*0.345*	26.8864	1	100
WATER QUALITY	WQ	72.3	*0.328*	23.6772	2	95
CONNECTIVITY & SEASONALITY	CS	90.0	*0.000*	0	3	0
						290
INVERTEBRATE EC				77.0671		
INVERTEBRATE EC CATEGORY				C/B		

TABLE E-3: INVERTEBRATE EC: BASED ON WEIGHTS OF METRIC GROUPS FOR SITE 3 (SLB) THAT WAS MONITORED DURING THE 2016 FIELD ASSESSMENT

INVERTEBRATE EC METRIC GROUP		METRIC GROUP CALCULATED SCORE	CALCULATED WEIGHT	WEIGHTED SCORE OF GROUP	RANK OF METRIC GROUP	%WEIGHT FOR METRIC GROUP
FLOW MODIFICATION	FM	79.4	*0.328*	25.9988	2	95
HABITAT	H	85.2	*0.345*	29.3813	1	100
WATER QUALITY	WQ	73.9	*0.328*	24.2159	2	95
CONNECTIVITY & SEASONALITY	CS	90.0	*0.000*	0	3	0
						290
INVERTEBRATE EC				79.5961		
INVERTEBRATE EC CATEGORY				C/B		

TABLE E-4: INVERTEBRATE EC: BASED ON WEIGHTS OF METRIC GROUPS FOR SITE 1 THAT WAS MONITORED DURING 2017 FIELD ASSESSMENT

INVERTEBRATE EC METRIC GROUP		METRIC GROUP CALCULATED SCORE	CALCULATED WEIGHT	WEIGHTED SCORE OF GROUP	RANK OF METRIC GROUP	%WEIGHT FOR METRIC GROUP
FLOW MODIFICATION	FM	79.2	*0.328*	25.9287	2	95
HABITAT	H	72.5	*0.345*	24.9859	1	100
WATER QUALITY	WQ	82.5	*0.328*	27.0222	2	95
CONNECTIVITY & SEASONALITY	CS	90.0	*0.000*	0	3	0
						290
INVERTEBRATE EC				77.9368		
INVERTEBRATE EC CATEGORY				C/B		

TABLE E-5: INVERTEBRATE EC: BASED ON WEIGHTS OF METRIC GROUPS FOR SITE 2 THAT WAS MONITORED DURING THE 2017 FIELD ASSESSMENT

INVERTEBRATE EC METRIC GROUP		METRIC GROUP CALCULATED SCORE	CALCULATED WEIGHT	WEIGHTED SCORE OF GROUP	RANK OF METRIC GROUP	%WEIGHT FOR METRIC GROUP
FLOW MODIFICATION	**FM**	**74.0**	***0.328***	**24.2414**	**2**	**95**
HABITAT	**H**	**73.1**	***0.345***	**25.213**	**1**	**100**
WATER QUALITY	**WQ**	**69.9**	***0.328***	**22.8874**	**2**	**95**
CONNECTIVITY & SEASONALITY	**CS**	**90.0**	***0.000***	**0**	**3**	**0**
						290
INVERTEBRATE EC				**72.3417**		
INVERTEBRATE EC CATEGORY				**C**		

TABLE E-6: INVERTEBRATE EC: BASED ON WEIGHTS OF METRIC GROUPS FOR SITE 3 THAT WAS MONITORED DURING THE 2017 FIELD ASSESSMENT

INVERTEBRATE EC METRIC GROUP		METRIC GROUP CALCULATED SCORE	CALCULATED WEIGHT	WEIGHTED SCORE OF GROUP	RANK OF METRIC GROUP	%WEIGHT FOR METRIC GROUP
FLOW MODIFICATION	**FM**	**80.4**	***0.328***	**26.3473**	2	95
HABITAT	**H**	**78.1**	***0.345***	**26.927**	1	100
WATER QUALITY	**WQ**	**75.0**	***0.328***	**24.569**	2	95
CONNECTIVITY & SEASONALITY	**CS**	**90.0**	***0.000***	**0**	3	0
						290
INVERTEBRATE EC				**77.8432**		
INVERTEBRATE EC CATEGORY				**C/B**		

APPENDIX F: RHAMM DATA

APPENDIX F: RHAMM DATA

TABLE F-1: CROSS SECTIONAL INPUTS FOR SITE 1 (SMP)

DATE (yyyy/mm/dd) (FILL IN FOR ALL CELLS)	INDICAT:WE (LE & RE)	GHU TYPEINS_XSEC INPUT_ FILL IN FOR ALL POINTS (CELLS) DONE.	X SECTION NR ((FILL IN FOR ALL CELLS- GHU NR FOLLOWED BY POINT NUMBER FOR THAT GHU)	POINT DISTANCE (m) (INCREMENTS, NOT ACCUMULATIVE)	DEPTH (m)	MAX HEAD (m)	MIN HEAD (m)	ROOTS	FINES	SAND	GRAVEL	COBBLE	BOULDER	BEDROCK	WOODY DEBRI	DETRITUS	SUBSTRATE: ALGAE	SUBSTRATE: EMBEDDED	INSTREAM VEG	OVERHANGING VEG	UNDERCUT & ROOD WADS
1/6/2016	LE	RUN-RIFFLE	1.01	0.00	0.14	0.14	0.14	1.00	1.00		1.00	1.00	1.00			1.00			1.00	1.00	1.00
1/6/2016		RUN-RIFFLE	1.01	1.00	0.70	0.15	0.60		1.00			1.00				1.00		1.00		1.00	
1/6/2016		RUN-RIFFLE	1.01	1.00	0.12	0.15	0.12		1.00			1.00			1	1.00	1.00	1.00			
1/6/2016		RUN-RIFFLE	1.01	1.00	0.11	0.12	0.10		1.00	1.00		1.00		1		1.00		1.00			
1/6/2016		RUN-RIFFLE	1.01	1.00	0.12	0.17	0.13		1.00	1.00		1.00				1.00		1.00			
1/6/2016		RUN-RIFFLE	1.01	1.00	0.14	0.16	0.12			1.00		1.00									
1/6/2016		RUN-RIFFLE	1.01	1.00	0.18	0.24	0.16				1.00	1.00						1.00			
1/6/2016		RUN-RIFFLE	1.01	1.00	0.19	0.24	0.17			1.00	1.00	1.00						1.00			
1/6/2016		RUN-RIFFLE	1.01	1.00	0.23	0.27	0.18			1.00	1.00	1.00						1.00			
1/6/2016		RUN-RIFFLE	1.01	1.00	0.20	0.26	0.18			1.00	1.00	1.00							1.00	1.00	
1/6/2016	RE	RUN-RIFFLE	1.01	1.00	0.16	0.18	0.17				1.00	1.00				1.00			1.00	1.00	1.00

TABLE F-2: CROSS SECTIONAL INPUTS FOR SITE 2 (SSW)

DATE (yyyy/mm/dd) (FILL IN FOR ALL CELLS)	INDICAT:WE (LE & RE)	GHU TYPEINS_XSEC INPUT_ FILL IN FOR ALL POINTS (CELLS) DONE.	X SECTION NR ((FILL IN FOR ALL CELLS- GHU NR FOLLOWED BY POINT NUMBER FOR THAT GHU)	POINT DISTANCE (m) (INCREMENTS, NOT ACCUMULATIVE)	DEPTH (m)	MAX HEAD (m)	MIN HEAD (m)	ROOTS	FINES	SAND	GRAVEL	COBBLE	BOULDER	BEDROCK	WOODY DEBRI	DETRITUS	SUBSTRATE: ALGAE	SUBSTRATE: EMBEDDED	INSTREAM VEG	OVERHANGING VEG	UNDERCUT & ROOD WADS
1/6/2016	RE	RUN-RAPID	0.01	0.00	0.10	0.11	0.10	1.00						1			1.00		1.00		
1/6/2016		RUN-RAPID	0.01	1.00	0.36	0.37	0.35				1.00	1.00			1.00						
1/6/2016		RUN-RAPID	0.01	1.00	0.56	0.62	0.51			1.00	1.00	1.00	1.00					1.00			
1/6/2016		RUN-RAPID	0.01	1.00	0.60	0.63	0.56			1.00	1.00	1.00	1.00					1.00			
1/6/2016		RUN-RAPID	0.01	1.00	0.41	0.43	0.39			1.00	1.00	1.00	1.00								
1/6/2016		RUN-RAPID	0.01	1.00	0.38	0.38	0.34			1.00	1.00	1.00									
1/6/2016		RUN-RAPID	0.01	1.00	0.40	0.41	0.40		1.00	1.00		1.00						1.00			
1/6/2016		RUN-RAPID	0.01	1.00	0.40	0.40	0.40		1.00	1.00											
1/6/2016		RUN-RAPID	0.01	1.00	0.28	0.28	0.28		1.00	1.00			1.00				1.00			1.00	
1/6/2016		RUN-RAPID	0.01	1.00	0.19	0.18	0.18	1.00	1.00	1.00							1.00		1.00	1.00	
1/6/2016		RUN-RAPID	0.01	1.00	0.11	0.11	0.11	1.00	1.00	1.00	1.00					1.00	1.00		1.00	1.00	1.00
1/6/2016	LE	RUN-RAPID	0.01	0.70	0.10	0.11	0.05	1.00	1.00											1.00	

TABLE F-3: CROSS SECTIONAL INPUTS FOR SITE 3 (SLB)

DATE (yyyy/mm/dd) (FILL IN FOR ALL CELLS)	INDICAT:WE (LE & RE)	GHU TYPEINS_XSEC INPUT_ FILL IN FOR ALL POINTS (CELLS) DONE.	X SECTION NR ((FILL IN FOR ALL CELLS- GHU NR FOLLOWED BY POINT NUMBER FOR THAT GHU)\	POINT DISTANCE (m) (INCREMENTS, NOT ACCUMULATIVE)	DEPTH (m)	MAX HEAD (m)	MIN HEAD (m)	ROOTS	FINES	SAND	GRAVEL	COBBLE	BOULDER	BEDROCK	WOODY DEBRI	DETRITUS	SUBSTRATE: ALGAE	SUBSTRATE: EMBEDDED	INSTREAM VEG	OVERHANGING VEG	UNDERCUT & ROOD WADS
6/2/2016	RE	RUN-RAPID	1.01	1.00	0.20	0.25	0.25	1		1			1		1					1	1
6/2/2016		RUN-RAPID	1.01	1.00	0.30	0.32	0.31			1		1	1	1	1	1					
6/2/2016		RUN-RAPID	1.01	1.00	0.36	0.39	0.35				1	1	1	1		1					
6/2/2016		RUN-RAPID	1.01	1.00	0.34	0.38	0.33			1		1	1		1	1					
6/2/2016		RUN-RAPID	1.01	1.00	0.44	0.44	0.43			1		1	1			1		1			
6/2/2016		RUN-RAPID	1.01	1.00	0.62	0.64	0.60			1		1	1					1			
6/2/2016		RUN-RAPID	1.01	1.00	0.46	0.47	0.46			1		1	1					1			
6/2/2016		RUN-RAPID	1.01	1.00	0.48	0.48	0.46			1		1	1					1			
6/2/2016		RUN-RAPID	1.01	1.00	0.40	0.45	0.41			1	1	1	1					1			
6/2/2016		RUN-RAPID	1.01	1.00	0.46	0.47	0.44					1	1					1			
6/2/2016		RUN-RAPID	1.01	1.00	0.51	0.53	0.49			1	1	1	1					1			
6/2/2016		RUN-RAPID	1.01	1.00	0.43	0.45	0.44			1		1	1				1	1			
6/2/2016		RUN-RAPID	1.01	1.00	0.32	0.32	0.31			1	1		1		1						
6/2/2016		RUN-RAPID	1.01	1.00	0.39	0.41	0.40	1		1			1		1	1		1	1		
6/2/2016	LE	RUN-RAPID	1.01	0.70	0.02	0.05	0.04	1	1				1							1	