A bio-indicator assessment towards the rehabilitation of the Stiebeuel River, Franschhoek, South Africa

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DECLARATION

1. I have read and understood the university's plagiarism policy. I have not plagiarized the work of others, and all work herein is my own, except where acknowledged otherwise.

2. The referencing style follows a modified version of the *Harvard Style* that is used in the South African Geographical Journal.

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CHAPTER ONE: INTRODUCTION

1.1 Streams in the urban landscape

Rivers throughout the world have had a long history of being degraded through human influences (Maddock, 1999). Human activities, coupled with increased urbanization, economic development and the consequent rise of informal settlements are the dominant causal factors responsible for changing the world's water resources (Rockstrom *et al*., 2014). These land transformations have further been identified as the primary driving force of water quality deterioration, decreased biodiversity and habitat degradation of rivers worldwide (Vitousek *et al*., 1997).

Today, the world's population is increasingly becoming more concentrated in urban areas, which has resulted in there being clear land-use changes (Paul & Meyer, 2001). As urbanization draws more people toward the city, the poor are forced to live on the periphery of the city, and occupy marginal land in the peri-urban area. Peri-urban catchments in developing countries are rapidly expanding and are becoming more prone to informal settlements (Paterson *et al*., 2007). Land-use of these catchments is being changed from natural vegetation or agricultural land, to urban impervious areas, and more specifically into urban informal settlements (Tucci, 2001). Urbanization introduces a wide range of well established hydrological challenges, which are primarily associated with an increase in impervious surfaces; altering the form, increasing the flow and decreasing the functionality of urban streams; a phenomenon known as the 'urban stream syndrome' (Walsh *et al*., 2005). The predictable changes associated with the "urban stream syndrome" include; increased flows, flashier hydrographs, and elevated loading of nutrients and contaminants in urban rivers (Walsh *et al*., 2005). The cumulative effect of these alterations to the catchment landscape typically leads to changes in urban rivers along three axes, namely; geomorphic simplification; diminished societal value; and ecological simplification (Bernhardt & Palmer, 2007). These changes combined have multiple adverse effects and turn the urban river from a functioning ecosystem into an efficient gutter draining the landscape (Bernhardt & Palmer, 2007).

In a recent study by Braud *et a*l. (2013), it is suggested that the typical hydrological alterations and impacts caused by urbanization on the natural environment also exist in peri-urban catchments. However, peri-urban areas show a high degree of heterogeneity comprising of a 'patchwork of urban, underdeveloped and agricultural lands' that makes it more difficult to quantify and predict the hydrological pattern of these areas (Andrieu & Chocat, 2004). Further more, as informal settlements in peri-urban catchments are constructed on marginal land on the outskirts of a city, they typically lack a wide range of basic services. The characteristic bare compacted land with limited, dysfunctional and/or absent drainage and sanitation services of these areas collectively produce an even more complex and varying unknown effects on the surrounding environment and receiving rivers (Parkinson *et al*., 2007).

Informal settlements has been defined by the United Nations Human Settlements Programme, as an area with inadequate access to potable water, drainage, sanitation and other formal infrastructure, with sub standard living and insecure land tenures (UN-Habitat, 2003). The combined interaction of these factors and informal settlements characteristic high density living, typically results in extensive and serious contamination of surface water (Olaseha & Sridhar, 2003; Borges *et al*., 2015). Surface water from informal settlements has been described by Armitage (2011) as a toxic cocktail of stormwater mixed with sewage, grey water and urban refuse. Surface water runoff from informal settlements is thus highly contaminated and is a vector for transferring and spreading diseases as well as for the degradation of the natural environment (Winter, 2017). In a study by Jamwal *et al*. (2008), a slum dominated watershed in India was responsible for discharging point and non-point microbial pollution from wastewater and sewage effluent into the Yamuna River, which critically polluted the water quality and modified the river's ecological condition.

In 2001, 924 million people were recorded to live in informal settlements, while, by 2030, this number is projected to be 2 billion people (UN-Habitat, 2003). It is predicted that the majority of these people will live in peri-urban informal settlements in close proximity to megacities (Niemczynowicz, 1999). The conversion of natural land to urban areas and specifically to urban informal settlements will increase the population density of the area and consequently result in a higher consumption of water. It is highly probable that this demand will not be matched with an adequate provision of basic services, and the surrounding environment will be degraded from contaminated surface water runoff (Reed, 2013; Capps *et al*., 2016). The land transformations will therefore cause further pollution to receiving rivers. It is evident that urbanization coupled with the effects of urban informal settlements, are polluting rivers and causing a decline in ecosystem functionality. Poor water quality in urban rivers has become a global concern and river restoration interventions have since been invested in to enrich river ecosystems and return biodiversity and river functionality (Maddock, 1999).

Water quality guidelines

Water quality is a term used to describe the physical, chemical and biological characteristics of water, in relation to its suitability for an intended purpose (SANS, 2015). Water quality standards are not fixed and change in accordance to usage, e.g. for drinking water, domestic use or irrigation. The most common standards used to measure and assess water quality relate to ecosystem health and habitat integrity, safety for human contact and drinking water requirements. Through this, the level of pollution in the water can be determined based on how modified the water source is from a natural condition, see table 5 and table 6 for specific river health and corresponding ecological health parameters. Water quality guidelines are based on the determinants that characterize water quality, such as physical, microbiological and chemical determinates (DWAF, 1996a), which are set at the maximum discharge level of a substance to not cause any adverse effects or harm when the water is consumed and or used continuously for a particular purpose (DWAF, 1996a). Dissolved Oxygen however, is set at a minimum acceptable concentration to protect and maintain the survival of biological communities and their functionality in river ecosystems (DWAF, 1996d). In South Africa, the Department of Water and Sanitation (DWS) formulated the South African Water Quality Guidelines, to safeguard water quality and prevent pollution for human consumption and other water uses (DWAF, 1996). These guidelines are divided into four broad categories namely; domestic, industrial, agricultural, and aquatic ecosystems and recreational guidelines (DWAF, 1996). Table 1 shows the DWS guidelines for wastewater discharge limits into a water source (SANS, 2015). The table provides relevant reference data for water quality comparisons to be made in this research. It is important to have an understanding of water quality, for it is interlinked to the distribution, abundance and biological diversity of species and habitat structure of a river system.

Table 1: Wastewater limit values applicable to discharge of wastewater into a water resource (SANS, 2015).

SUBSTANCE/PARAMETER	GENERAL LIMIT	SPECIAL LIMIT
Faecal Coliforms (per 100ml)	1000	0
Chemical Oxygen Demand (mg/l)	75*	30*
pH	5.5-9.5	5.5-7.5
Ammonia (ionized and un-ionized) as Nitrogen (mg/l)	3	2
Nitrate/Nitrite as Nitrogen (mg/l)	15	1.5
Chlorine as Free Chlorine (mg/l)	0.25	0
Suspended Solids (mg/l)	25	10
Electrical Conductivity (mS/m)	70 mS/m above intake to a maximum of 150 mS/m	50 mS/m above background receiving water, to a maximum of 1000 mS/m
Ortho-Phosphate as phosphorous (mg/l)	10	1 (median) and 2.5 (maximum)
Fluoride (mg/l)	1	1
Soap, oil or grease (mg/l)	2.5	0
Dissolved Arsenic (mg/l)	0.02	0.01
Dissolved Cadmium (mg/l)	0.005	0.001
Dissolved Copper (mg/l)	0.01	0.002
Dissolved Cyanide (mg/l)	0.02	0.01
Dissolved Iron (mg/l)	0.3	0.3
Dissolved Lead (mg/l)	0.01	0.006
Dissolved Manganese (mg/l)	0.1	0.1
Mercury and its compounds (mg/l)	0.005	0.001
Dissolved Oxygen (%)	80-122	*
Dissolved Selenium (mg/l)	0.02	0.02
Dissolved Zinc (mg/l)	0.1	0.04
Boron (mg/l)	1	0.5

1.2 The role of habitat in maintaining river health

The health and ecological condition of rivers is influenced by numerous inter-dependent factors of which habitat integrity forms a critical component (Thomson *et al*., 2001). Kleynhans *et al*. (2008) refers to habitat integrity as “the maintenance of a balanced composition of physico-chemical and habitat characteristics on a temporal and spatial scale that are comparable to the characteristics of natural habitats of the region". The main elements of habitat are thus flow, water quality and physical structure. Flow alteration (magnitude and pattern), water quality (physico-chemical characteristics) and physical structure directly influence habitat (Belletti *et al*., 2017). A variety of habitats exist in a river system which are linked to the hydrology, geomorphology and chemical parameters of a river (Beechie *et al*., 2005). Examples of different biotopes include; sand, gravel, rocks, cobbles, roots, macrophage, moss, floating, marginal plants and submerged fine leaved habitats (Demars *et al*., 2012). Biota responses to habitat related changes are indicative of habitat integrity and health of the river system. Habitat structure therefore has an affect on the abundance and diversity of organisms and species in many systems (Beck, 2000). Rivers physical forms and process have been noted as important components in analysing and managing river systems (Belletti *et al*., 2017). Poole (2010) notes that through understanding physical structures and their dynamics, this information can be integrated and the links between rivers physical and biological conditions can be established.

Habitat integrity has an important role in maintaining river health because it supports the diversity of aquatic species community structure and affects the water quality and overall functionality of the river system (Stasna, 2017). The availability and diversity of habitat is a major factor in determining the aquatic community structure (Stansa, 2017). Thus, the suite of fauna and flora within an ecosystem will directly influence the distribution and diversity of aquatic species and effect the overall functionality of the stream (Stansa, 2017). Today, the structure and function of riparian habitats is becoming altered through multiple factors associated with land use change such as the removal of vegetation, erosion, sedimentation and the invasion of alien invasive plants (DWS, 2016). These disturbances can in turn cause changes to the hydrology of the river and result in excessive sedimentation or scouring of the river bottom and altered water quality from contaminated surface water runoff and additional pollution sources. Maintaining habitat integrity is therefore important because of its influence on, the biodiversity, structure, organization and composition of the biological communities in a river (Hynes, 1970; Southwood, 1975; Meffe & Sheldon, 1988; Maddock, 1999). Such that, impaired habitat, will cause a decrease in species diversity, aquatic richness and overall health of a river (Hynes, 1970; Southwood, 1975; Meffe & Sheldon, 1988;

Maddock, 1999). Habitat integrity is thus imperative to support species diversity and sustain river health.

As river ecosystems are becoming increasingly threatened by an array of ecologically unsustainable land-use practices and development activities, awareness of their inherent importance as life-support systems has grown together with the realization of the serious need to conserve, assess and protect their ecological integrity (Ollis *et al*., 2006). Biological organisms are considered to be good indicators of a river's ecological integrity, or of the degree of water quality deterioration in an aquatic ecosystem (Holmes & Taylor, 2015). Their ability to reflect and integrate the cumulative effects of the impacts that physical or chemical disturbances within a catchment have on river ecosystems overtime makes them suitable indicators to investigate degraded rivers and/or successful river rehabilitation interventions (Holmes & Taylor, 2015).

Benthic communities in rivers are influenced by multiple factors which are typically shown by a species specific response to different ecological tolerances (Blanco & Becares, 2010). Up to date a wide range of benthic groups have been used around the world that reflect varying degrees of success, however, diatoms and macro-invertebrate species are used throughout the world (Blanco & Becares, 2010). Due to their wide range of species sensitivity to contaminates, both have been considered excellent indicator species of stream pollution and/or of clean water quality (Blanco & Becares, 2010). Comparative studies, show that macro-invertebrate based indices are more sensitive to changes influencing and affecting structural parameters in a river, such as habitat, while diatom indices are more dependent on chemical variables, in particular nutrients affecting water quality (Soininen & Kononen, 2004; Hering *et al*., 2006; Blanco *et al*., 2007). Through diatom and macro-invertebrate analysis, the water quality condition and habitat integrity of a river can be determined (Blanco & Becares, 2010).

Returning habitat integrity to a river is an effective river restoration intervention, for it will help to return biodiversity, enrich aquatic ecosystems and improve water quality in a river. According to Jackson *et al*. (1995), the aim of ecological restoration is to repair human mediated changes that have altered the diversity and dynamics of ecosystems. As complete ecological restoration is generally impossible due to urban stream channels being highly constrained in the urban setting, it is unrealistic to expect restoration efforts to return the streams condition back to its pre-urbanized state (Bernhardt & Palmer, 2007). The goal of effective restoration should instead be to return the stream as far back along the 'three axes' (returning; geomorphic functionality; societal value; and ecological biodiversity) as possible, considering the existing urban landscape constraints (Bernhardt & Palmer, 2007). Repairing segments of the riparian zone to re-introduce biotic richness and improve water quality is thus a more realistic approach (Richardson *et al*., 2007).

A critical component of effective river restoration, is to have a detailed understanding of the catchment characteristics. It is vital that the complex interactions between, the physical environment and its biotic factors, are fully understood so that thresholds that delineate certain options for effective restoration can be defined at multiple scales (Richardson *et al*., 2007). Ehrenfeld (2000) notes that in landscapes where physical energy such as water or wind movement are dominating factors in structuring an ecosystem, manipulations of abiotic components of the landscape must be a fundamental consideration in effective ecosystem and riparian corridor repair. Effective river restoration thus demands careful consideration of alternative states and positive feedbacks within the river system (Sunding *et al*., 2004).

In this turbulent era of the Anthropocene, humans are controlling and have critically modified natural landscape such that they can no longer be considered as an external force in the hydrological cycle (Rockstrom *et al*., 2014). Appropriate river restoration interventions thus need a focus on coupled human-water systems that consider feedbacks, interactions and emergent patterns (Sivapalan *et al*., 2012). The growth of informal settlements in peri-urban catchments of the developing world poses a serious threat to successful river restoration because the interactions between humans and surface water runoff is poorly understood. Understanding the highly contaminated surface water runoff of these environments thus requires research of the catchment dynamics, river water quality, and the surrounding ecological environment, so that realistic restoration interventions can be implemented. River restoration interventions in these highly polluted and diverse environments remains extremely challenging.

1.3 Research Question, Aim, Objectives

Research Question

How does the distribution of diatom and macro-invertebrate species respond to improved water quality and habitat?

Aim

To assess biodiversity recovery in a contaminated urban stream following rehabilitation.

Objectives

Objective 1: To identify and map the current status of aquatic species and organisms in the Stiebeuel River, Franschhoek.

Objective 2: To determine the species distribution and biodiversity of diatoms and macro-invertebrates during the recovery phase.

Objective 3: To assess how rehabilitating and recovering a river's habitat will enrich the biodiversity of species in urban river systems.

The focus and aim of the thesis is to understand the value of three methods, namely diatoms, miniSASS and water quality sampling, which are capable of informing rehabilitation of a river system. The research attempts to determine how these methods are interlinked and are able to assess water quality and support for potential habitat in a highly polluted river. The emphasis is on integrating a combination of well-known methods and to determine how one or more of these methods are capable of providing a stable indicator for habitat support and water quality. The assumption is that diatoms are the stable signatures of water quality as species distribute themselves according to their pollution tolerances.

1.4 Problem identification and study site

Problem Statement

The riparian zone of the Stiebeuel River and its ecological processes have been altered by urbanization in multiple ways. In particular, the informal settlement, Langrug, has caused severe modifications to the water quality, habitat and natural functioning of the Stiebeuel River. The continuous daily discharge of contaminated, untreated surface water runoff from Langrug, has resulted in the Stiebeuel River being highly polluted, critically modified, and in an extremely poor ecological condition. River management as well as river rehabilitation is fundamental in such circumstances to restore river health

Table 2, shows the water quality concentrations of different parameters measured from four sampling sites in the Stiebeuel River catchment. Fell (2017) findings show Site 1, to have the best water quality condition over the catchment, for it has the lowest nutrient concentrations (NO_2^--N, NO_3^--N, NH_3-N and PO_4^{3-}) , EC and TSS values. This good condition of the river is expected as site 1 exclusively flows through a natural area, and is not directly influenced by human activities. It must be noted that site 1 is both upstream and close to Langrug, informal settlement. Comparably, site 2 water quality is in the poorest condition within the catchment. At this site the Stiebeuel River flows through Langrug, informal settlement, and is heavily polluted by point and diffuse source contaminates being discharged into the river from the informal settlement. The water quality at site 2, has the highest NH_3-N, PO_4^{3-}, TSS and EC values, and the lowest DO concentrations (Fell, 2017). The elevated concentrations of NH_3-N (8.4mg/L) and PO_4^{3-} (5.94mg/L) at site 2 are because of the wastewater (sewage and greywater) runoff from Langrug into the Stiebeuel River. The limited sanitation and drainage systems in Langrug, suggest that household wastewater is discharged outside of peoples homes and/or into informal drainage channels, and finally into the Stiebeuel River (Fell, 2017). Fell (2017) further notes that the TSS of 135.15mg/L at site 2, aided in the transport of these nutrients through sediments to the Stiebeuel River. This is because Langrug has limited paved roads and mainly consists of easily eroded surfaces such as stone and hard gravel surfaces (Fell, 2017). These surfaces are therefore easily eroded by rainfall and excessive wastewater runoff, resulting in sediment discharge into the Stiebeuel River (Fell, 2017). Site 2, also has the lowest average DO level of 3.49mg/L in the catchment. This is an important result to note as Chapman and Kimstach (1996) state, DO levels below the value of 5mg/L have an adverse affect on the functioning and survival of aquatic communities. Through Fell (2017) findings, it is evident that the water quality of the Stiebeuel River is highly contaminated from the discharge of wastewater from Langrug, informal settlement.

Table 2: Water quality parameter concentrations from the four sampling sites in the Stiebeuel River catchment (Fell, 2017).

		NO_2^--N (mg/L)	NO_3^-N (mg/L)	NH_3^-N (mg/L)	PO_4^{3-} (mg/L)	pH	DO (mg/L)	EC (µs/cm)	TSS (mg/L)
Site 1 (Natural vegetation)	Average	0.005	0.30	0.01	0.34	6.62	6.49	36.38	9.46
	Standard deviation	0.004	0.11	0.02	0.52	0.77	2.08	4.98	8.34
Site 2 (Informal settlement)	Average	0.050	1.05	8.40	5.94	6.69	3.49	362.92	135.15
	Standard deviation	0.059	1.13	5.18	7.36	0.71	2.36	312.68	124.28
Site 3 (Built up)	Average	0.072	1.78	3.74	1.80	6.33	4.72	194.08	26.77
	Standard deviation	0.097	1.38	3.11	1.24	0.82	2.34	68.64	14.68
Site 4 (Agriculture)	Average	0.058	2.52	2.16	0.85	6.63	5.76	185.54	26.08
	Standard deviation	0.088	1.41	2.88	0.48	0.60	1.84	57.34	26.89

Nedeau *et al*. (2003) study also notes that water quality in urban watersheds is typically modified and in a poor condition due to eutrophication, environmental contamination from numerous point and non-point sources of pollution, wetland loss and warmer water temperatures. Furthermore, they note habitat quality in urban watersheds to be deteriorated and in a poor condition due to increased sedimentation from construction sites, bank erosion and loss of riparian habitat. These factors as well as many more negatively affect biological communities, and make it difficult to assess the impact and effect of a single pollutant on an urban stream (Nedeau *et al*., 2003).

Informal Settlements

Informal settlements, known as slums elsewhere, are particularly common in developing countries especially in Sub-Saharan Africa where 62% of the urban population has been recorded to live in slum conditions (UN Habitat, 2013). In South Africa, informal settlements are a distinctive part of urban areas, where a total of 1.25 million 'households' were recorded to occupy these marginal areas in 2011 (StatsSA, 2012). Informal settlements are generally located on the periphery of cities and are easily recognized by the distinct geographical lines that separate these marginal lands from high income areas (Armitage, 2011). This is a reflection of the old Apartheid Group Areas Act that implemented forced segregation between different racial groups and relocated coloured and black South Africans to underdeveloped and marginal land outside of the city. The legacy of Apartheid is still apparent today and can be visualized by the multiple poverty stricken, informal settlements, in peri-urban catchments (Bouchard *et al*., 2007).

Despite there being great variability within and between informal settlements they typically are places with; high density living, are limited and/or inadequately resourced, poorly managed and lack a wide range of basic services. They are places, that are typically unplanned, and best visualized as a conglomeration of 'shacks', where housing structures have been built from locally available makeshift materials, such as pieces of corrugated iron or wood (Winter, 2017). The basic urban services which are generally provided in informal settlements include; a small and inadequate number of communal toilets and taps to supply potable water, a basic and often unreliable solid waste collection service, as well as no formalized drainage system (Armitage, 2011). In South Africa, formal waste water drainage is not classified as a basic service, and, is often only a feature in formal, higher income urban areas. Formal drainage systems in unplanned, informal settlements are typically not a priority, as emphasis is rather placed on the provision of safe drinking water and functioning sanitation systems (Armitage *et al*., 2010). Surface water runoff is therefore generated daily from dysfunctional communal sanitation facilities, public tap stands, washing facilities, and other household grey water (Winter, 2017). Without adequate formal drainage services, this surface water plagues informal settlements as it flows past the homes and accumulates in filthy ponds within the settlement. The surface water runoff from urban informal settlements ultimately discharges highly contaminated water into receiving rivers, which in turn, severely degrades the surrounding habitat, pollutes the water quality, and decreases species biodiversity within the river.

Study Site

The study was carried out in the Stiebeuel River catchment, in the peri-urban area of Franschhoek, 75km outside of Cape Town CBD, Western Cape, South Africa (Figure 1). Water quality in the Stiebeuel River has deteriorated as a result of the river's close proximity to the urban informal settlement of Langrug. Water quality in the Stiebeuel River is polluted from surface water runoff from litter, and domestic wastewater, as well as from, dysfunctional or inadequate drainage systems causing the river to receive a daily discharge of highly contaminated water. The low cost housing area Groendal, to some extent also pollutes surface water runoff, as well as the agricultural practices adjacent to the river add to the deterioration of the Stiebeuel River.

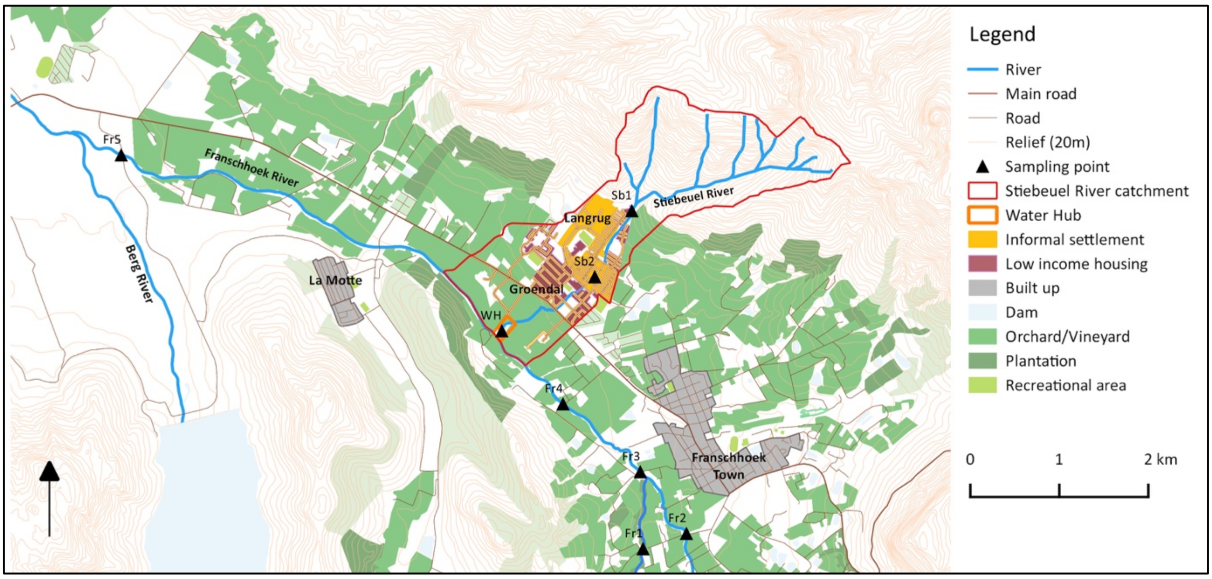

Figure 1: The sub-catchment of the Stiebeuel River.

1.5 Research design and methods

As habitat integrity encourages a diversity of species, this project will investigate how nature in the form of biodiversity of diatoms and macro-invertebrates, are observed in a river when a range of habitats are created and restored through the replanting of indigenous vegetation within the river channel. Bio-assessment will be used to determine how does rehabilitating a river change the distribution of diatom and macro-invertebrate species overtime?

The evaluation of the health of the Stiebeuel River will be ascertained through the use of three monitoring methods; diatoms and macro-invertebrates as bio-indicators, and physical water parameters, to monitor water quality. It will attempt to determine how these methods are capable of assessing water quality, and support potential habitat in a highly polluted river. Diatoms will be the main focus of the study, for diatoms are stable signatures in reflecting water quality changes (Taylor, 2006). However, it is useful to use diatoms in conjunction with miniSASS (South African Scoring System), for the indictor systems when used together will provide a more comprehensive data set of the Stiebeuel River ecosystem health (de la Rey *et al*., 2008). The water quality monitoring data will further assist in confirming the condition of the Stiebeuel River. The emphasis is on integrating a combination of well-known methods, and to determine how one or more of these methods are capable of providing a stable indicator for habitat support and water quality. The three monitoring methods when used together will also provide high confidence results of the health of the Stiebeuel River.

Diatoms have been chosen as they are stable signatures of water quality and their pollution tolerances are valuable in measuring a critically modified river. mini-SASS is a useful method as the macro-invertebrate sensitivity scores will provide valuable information on habitat integrity and health class of the river, while the inclusion of water quality parameters was used to show and confirm the physio-chemical condition of the river.

miniSASS

As reliable indicators of river health conditions and water quality are typically expensive and difficult to determine, miniSASS was developed as a simplified method of bio-monitoring based on the well tested SASS (South African Scoring) technique (Graham *et al*., 2004). The taxonomic complexity of SASS was reduced to a few aquatic invertebrate 'groupings', which act as surrogates for the comprehensive and complete suite of SASS taxa (Graham *et al*., 2004). The following requirements were identified to make miniSASS efficient; "minimise the number of aquatic invertebrate groupings necessary to perform miniSASS; aquatic invertebrate groups should be easily identifiable; the method should be robust and produce results comparable to the full SASS technique; and be geographically widely applicable (Graham *et al*., 2004:25). As SASS requires the identification of up to 90 different aquatic invertebrate families, it is difficult for non-invertebrate taxonomists to accurately achieve this without training. The method is thus limited to a small number of specialists, who are able identify the taxa (Graham *et al*., 2004). An important aspect of the development of miniSASS was centered on the increased opportunity for public participation in being able to use a scientifically valid bio-monitoring tool to measure the health of river systems (Graham *et al*., 2004). Through this the availability of reliable data sets on river health will also be increased (Graham et al., 2004).

1.5.1 Research Methods (data collection and data analysis)

The baseline reference data was collected in September 2016, site preparation was in October 2017, planting of vegetation was done in early November 2017, and the final data collection was taken in mid- December 2017/early January 2018. The study examined the response of a river rehabilitation intervention over a short 1-2-month period.

Sampling method:

Twenty-seven sampling sites were chosen strategically to provide a representative sample set. A reference site at the head of the Stiebeuel River catchment, above Langrug informal settlement, was used for comparison to monitor the effects of the pollutants downstream. The Franschhoek River, was also used as a reference condition of a naturally functioning river in the catchment. This allowed for comparison to be made, and the deterioration caused to the Stiebeuel River from the in flow of highly polluted water from Langrug, informal settlement to be quantified.

Diatoms were collected using Taylor (2007a), well-established methods. Five to ten cobbles from within the river bed were collected at 30m intervals downstream along the river. The diatom water samples were analysed at The University of Cape Town's 'Water Analysis Laboratory'. The standard methods of a miniSASS assessment were used to sample for macro-invertebrates (Graham *et al*., 2004). The species were collected and scored according to their sensitivities to the water quality. The species sensitivity scores were then extrapolated to determine the ecological condition of the river which range from natural to very poor. It must be noted that macro-invertebrates are strongly affected by land-use patterns, and often show the highest sensitivity to urbanization thus making them useful indicators of water quality changes (Violin *et al*., 2011). Water quality monitoring was used to measure the pH, EC (electrical conductivity), DO (dissolved oxygen), and temperature of the river. pH was measured using a hand-held Martini pH55 meter, EC was measured using a hand-held Martini EC59 meter and DO was measured using a Milwaukee MW600 Smart DO Meter. The temperature reading was taken from the DO meter.

The rehabilitation involved removing all alien invasive vegetation along the river banks and re-planting indigenous plants and flowers that support the habitat of the organisms living along the river corridor. Through this, it is predicted that the biodiversity of the river will increase, and in turn, the overall structure of the river system will be improved. Changes in the distribution of diatoms along the river was the primary indicator of the river's water quality and the successfulness of the river rehabilitation. The results obtained from the miniSASS monitoring and water quality monitoring, should correlate with the distribution of diatoms in the river, giving a more comprehensive analysis of the river's ecosystem health.
Through these results the research question can be answered, based on, whether the diatom and macro-invertebrate diversity elevated following the rehabilitation of the Stiebeuel River's habitat.

1.5.2 Project within the Water Hub context

The Water Hub is located in Franschhoek, South Africa on an abandoned wastewater treatment works site. The Water Hub is an innovative project that aims to connect multiple elements of the urban water cycle, and investigates novel options for the treatment of highly polluted water and river restoration (Winter, 2017). The site focuses on the use of natural processes in accordance to the principles of biomimicry to treat contaminated water. A primary goal of the Water Hub is to treat the water to support biodiversity and ecosystem services in the wetlands and rivers surrounding the site.

The Water Hub aims to develop and showcase innovative tools, techniques and management solutions to improve water quality, as well as offer education and training that will contribute to a water secure future for South Africa. The project will advance knowledge in the field of green technologies in water resource management, by learning from nature, as well as encourages the active participation of local people. This project is involved in Water Treatment Technology, specifically focusing on the principles of bio-mimicry to rehabilitate the river's water quality.

1.6 Scope of the study

This study will examine the response of a river rehabilitation intervention over a short 1-2 to month period. The selected short time frame is designed to understand the rapid response of biodiversity, to return or to enrich the river system, through identifying and gaining an understanding on which species are first to recolonise the improved ecological and environmental conditions. A small rehabilitation intervention in improving the riparian vegetation of a river system can therefore start to show an increase in biodiversity. In turn, this will demonstrate the significant value of rehabilitating the riparian zone of a river to return habitat integrity, biological diversity and improve water quality.

1.6.1 Limitations

The main limiting factor of this project is the critical time it takes for the growth of the plants used to rehabilitate the banks of the river, and reintroduce habitat to increase the biodiversity of the river ecosystem. It may be that the timeframe of this project is too short to witness a clear improvement of the habitat diversity and water quality of the Stiebeuel River. However, it is predicted that within this time period, the Stiebeuel River will show a response to the intervention, and progress toward improving the ecological corridor will be evident.

CHAPTER TWO: LITERATURE REVIEW

2.1 Rivers in the Anthropocene

It is argued that the Earth in now entering the Anthropocene indicates a shift away from the stable environmental conditions of the Holocene, to a new era driven by human interferences that are controlling and altering the forces of nature (Rockstrom *et al*., 2014). The impact of the human population on the global hydrological cycle is posed to be one of the greatest challenges of this epoch (Montanari *et al*., 2013). Human activities coupled with increased urbanization and economic development are the dominant causal factors that are changing the worlds' water resources (Rockstrom *et al*., 2014). Anthropogenically induced changes to surface water quality and quantity, flow regimes and the physical structure of rivers have resulted in widespread modification of riverine habitats, biotic communities and the ecological functioning of ecosystems worldwide (Thomson *et al*., 2001).

Land transformations represent the primary driving force of biodiversity degradation and consequent deterioration of water quality worldwide (Vitousek *et al*., 1997). As less than 17% of the land surface remains untouched, without a human footprint, the natural functioning of the environment has since been altered (Sanderson *et al*., 2002). The direct human induced stressors include urbanization, land cover change, industrialization and engineering schemes. Such land transformations dominated by hard surfaces and concrete infrastructure are causing multiple impairments and alterations to ecological environments.

Widespread evidence shows rivers as being low lying, uni-directional and confined features draining the landscape, are particularly susceptible to being polluted by surface water runoff (Dallas, 2000). Human activities have changed the natural hydrological response of catchments which has severely impacted the ecological integrity of rivers in multiple ways (Savenije *et al*., 2014). For example, chronic pollution, from diffuse and point sources, are contaminating streams, the optimal functioning of rivers is modified from disturbances to the natural flow and sediment supply, groundwater sources are polluted and/or overexploited and natural lakes in closing basins are disappearing (Meybeck, 2003; & Gupta *et al*., 2013). These impacts reveal that 'nature talks back' when humans over-step the environmental threshold and cross certain boundaries (Savenije *et al*., 2014).

Urban rivers have been identified as being more prone to pollution, because of their close proximity to multiple urban pollution sources such as; waste water discharge points, industrial effluent discharge points, on site sanitation systems for institutional and domestic sources and solid waste disposal sites (Mbuligwe & Kaseva, 2005). Informal settlements, common in developing countries, are also a critical source of pollution, as they discharge highly contaminated, untreated water into rivers. In areas where urban agriculture is practiced, surface water runoff from agricultural lands contribute an additional source of pollution to urban rivers.

Tong & Chen (2002), note a correlation between land use activities and the quantity and quality of the available water in a system. Such that changes in land cover are associated with, urban activities polluting surface water runoff, increasing the natural hydrology and altering the geomorphology of rivers draining urban areas. Cumulatively, these changes decrease the in-stream biota and habitat integrity, such that, there will be a collapse in the overall biodiversity and functionality of the urban river system, as well as, a loss of water use opportunities e.g. for recreational purposes, such as fishing, swimming and eco-tourism, as well as irrigation for agricultural practices (Francis, 2012). Urban developments have thus been identified as one of the leading causes contributing to the deterioration of surface water quality and consequent degradation of urban rivers as seen in Figure 2 (Tong & Chen 2002; Angela *et al*., 2015; Patenaude *et al*., 2015; Yang *et al*., 2015).

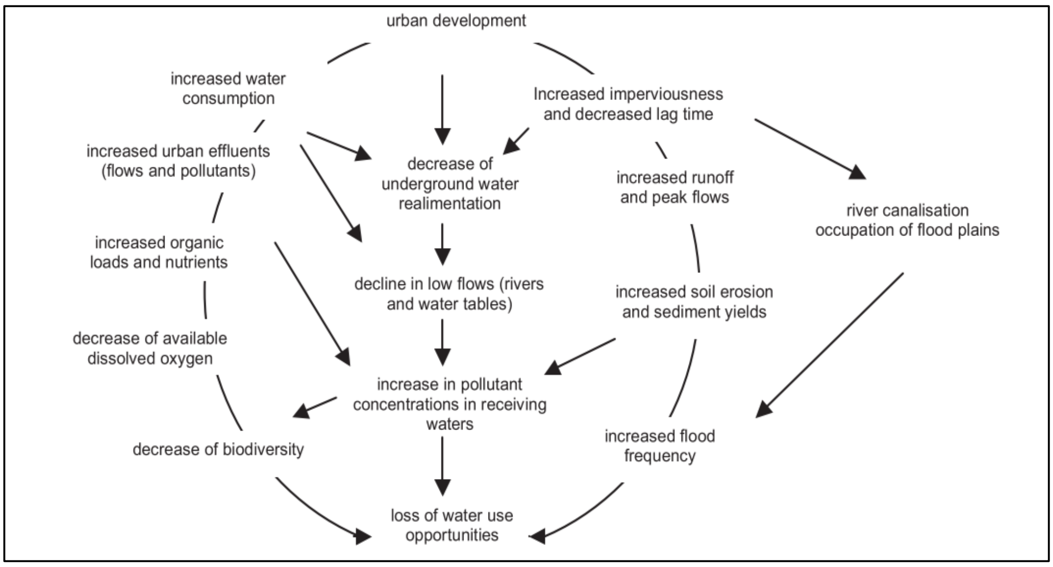

Figure 2: Impacts caused by urbanization on the hydrological cycle (Chocat *et al*., 2007).

2.2 Urban drainage from informal settlements

Urban informal settlements are typically unplanned areas characterized by, high density living with the prevalence of poverty (Parkinson *et al*., 2007). The lack of infrastructure and absent basic services, contribute to the desperate living conditions of these areas. There is typically no running water, functioning toilets, safe sewage disposal, rubbish nor waste removal facilities as well as no formal drainage networks, providing ideal conditions for highly contaminated surface water runoff (Winter, 2017). The inadequate or absent drainage systems of informal settlements in particular, is indirectly the causal factor responsible for spreading diseases, contaminating surface water runoff, deteriorating the physical environment and degrading the biodiversity and habitat integrity of urban streams (Winter, 2017). The management of surface water runoff from informal settlements is extremely challenging to control because of its complexity and presence of diverse living conditions. It is thus difficult to implement an effective general strategy, and as a result informal settlements often remain unstudied and marginalized.

Urban Informal settlements of the developing world are thus dynamic environments that are poorly understood, with a vague perception on the most basic hydrological principles (Reed, 2013; Jiusto & Kenney, 2016; Capps *et al*., 2016). At best, there is very patchy and incomplete information on water quality and flow conditions which has primarily been gained through isolated spot measurements and grab samples (Tucci, 2001; Goldenfum *et al*., 2007). Informal settlements are thus largely unexamined areas, with an inadequate understanding of the versatile catchment characteristics and unique behavioral differences which shape and drive the hydrology of these areas (Parkinson, 2002). The impacts, interactions and combined effect of land use practices adjacent to informal settlements, on the hydrology is also poorly understood (Mokaya *et al*., 2004; Rodriguez *et al*., 2013). Furthermore, Schoeman *et al*. (2001) also recognized the limitations of hydrologic studies within the context of South African informal settlements. These authors note, that there are only a handful of studies that are capable of providing meaningful data on simultaneous water quality and flow measurements that could enable the derivation of semi-quantitative relationships within informal settlements. However, Parkinson *et al*. (2007) emphasizes that, informal settlements severely degrade surface water quality and acknowledges the impact of heavily polluted surface water runoff to be acute and needs to be treated. Thus, with a lack of knowledge on varied water quality and associated flow patterns from different slum settlements, it is increasingly difficult to effectively control the use of water for other purposes (Parkinson *et al*., 2007).

In South Africa, the quality of urban water runoff is connected to development types (formal vs informal), development density (number of dwelling units or people per unit area), standard of living or cost of development (low cost- high density living vs high cost-low density of living) as well as the level of services provided and the degree of maintenance of the area (Carden, 2013). The absence of formal urban services, in particular, dysfunctional and/or absent drainage systems within informal settlements causes surface water to be a mixture of, surface water runoff, greywater and solid waste (Armitage, 2011). Consequently, the surface water pollutants in these areas are diverse, and include a wide range of nutrients, sediments, viruses, faecal bacteria, organic matter, sediments, pharmaceuticals and personal care products (Subbarman *et al*., 2013; Katukiza *et al*., 2015, Kimani-Murage & Ngindu, 2007).

Gangoo (2003) case study on the influence of the Umlazi informal community on the water quality of the Umlaas River, Kwa-Zulu Natal, South Africa demonstrates the detrimental impact that informal communities have on downstream water quality. Ten water samples were collected both upstream and downstream of the informal settlement, to establish the degree of water quality deterioration caused to the river from the inflow of highly polluted runoff from the informal settlement. Gangoo, (2003) additionally notes that informal settlements, are typically established on the banks of rivers, for easy access and use of the water source adding increased pressure on the water course. The study aimed to assess the following water quality parameters*; E-coli*, chemical oxygen demand (COD), turbidity, electrical conductivity (EC), nitrate and phosphorous concentrations, up-and-down stream of the informal settlement.

Table 3: The ranges of water quality parameters taken in the Umlaas River (Gangoo, 2003).

Water Quality Parameter	Upstream of Umlazi informal settlement	Downstream of Umlazi informal settlement
E-coli	2500 – 110 000 cfu/100ml	120 000- 230 000 cfu/100ml
COD	4.5 – 8.2 mg/l	184 -197 mg.l
Turbidity	4.7 – 6.8 NTU	164 - 197 NTU
EC	9 – 29 mS.m	171 -197 mS.m
Nitrate	3.3 – 3.12 mg/IN	9.5 – 15.8 mg/IN
Phosphorous	0.13 – 1.8 mg/IP	156 – 196 mg/IP

Table 3 shows the negative impact that surface water runoff from the informal settlement has on the Umlaas River. The high levels of *E.coli*, COD, turbidity, EC, nitrate and phosphorous concentrations compared to upstream readings, can be linked to the 'open' sewer effect of the informal settlement discharging untreated faecal pollution and other domestic effluents into the river. In particular, Gangoo (2003), notes that the lack of sanitation facilities in informal settlements is a major problem responsible for contributing increased microbiological content and pollution into rivers. The study shows that the condition of the Umlaas River has been severely altered and its functionality drastically impaired, as a consequence of the continuous discharge of highly polluted water from the Umlazi informal settlement.

Similarly, in a case study on Delhi, Jamwal *et a*l. (2008), notes that due to changes in the land-use pattern, growth of slums and an increase imperviousness, the runoff from Delhi is of extremely poor quality and is discharging a continuous flow of highly polluted water into the Yamuna River. The Yamuna River, is the main watercourse through Delhi, and is the source of water supply for the downstream population. The River is highly polluted and poses a serious health threat to the downstream users. Jamwal *et al*. (2008), further notes that the biological quality of urban runoff produced from sub-catchments within the Delhi watershed correlate with the impervious cover and population density of its drainage area.

The continuous discharge of diffuse effluents laden with pollutants has negative implications for aquatic ecosystems, which in turn has created new challenges for water research managers. As many of these pollutants are non-bio-degradable, the river is unable to trap toxic chemicals and nutrients in their sediments and the chemicals remain in the water (Sibanda *et al*., 2015). This results in an accumulation of contaminates that persist in the environment and significantly alter the water quality (Sibanda *et al*., 2015). Such surface water runoff conditions result in a heavily degraded ecological corridor that has little biodiversity and is unable to provide valuable eco-system services (Parkinson, 2003). With the overload of pollutants, a river's habitat is destroyed, species biodiversity is diminished and functionality to treat the incoming contaminates is impaired. This observed ecological degradation of urban streams has been termed the 'urban stream syndrome' (Kominkova, 2012). Through urban stream syndrome altering the form, flow and function of a river, its overall health and ecological condition declines.

2.3 The role of habitat in maintaining river health

The health and ecological condition of rivers is influenced by numerous inter-dependent factors of which habitat integrity forms a critical component (Thomson *et al*., 2001). The availability and diversity of habitat is a major determinate of the aquatic community structure, such that, the suite of flora and fauna within a specific ecosystem will directly influence the diversity of aquatic species and overall functionality of a stream (Stansa, 2017). Local habitat, thus has an influence on the biodiversity, organization, structure and composition of the biological communities, such that through improving habitat, species diversity and aquatic richness will increase and the condition of the river will be improved (Hynes, 1970; Southwood, 1975; Meffe & Sheldon, 1988; Maddock, 1999).

In theory, the riparian zone plays a role in providing habitat for terrestrial and aquatic species in maintaining the form of a river channel, and in filtering nutrients, sediments and light (DWS, 2016). The structure and function of riparian vegetation is altered through a range of factors including the removal of vegetation, erosion, sedimentation, and the invasion of alien vegetation (DWS, 2016). In-stream habitat however varies with substrate and typically houses a wide diversity of aquatic organisms. Habitat integrity of these areas are affected by a range of disturbances which can include, excessive sedimentation or scouring of the river bottom, alteration of the water quality from contaminates and additional pollution sources, as well as changes to the hydrology of the river (DWS, 2016). Habitat integrity thus has an important role in maintaining river health, for it supports the diversity of aquatic species community structure and affects the water quality and overall functionality of the river system (Stansa, 2017).

2.4 Bio-monitoring as an option for water quality assessments

As river ecosystems are becoming increasingly threatened by an array of ecologically unsustainable land-use practices and development activities, awareness of their inherent importance as life-support systems has grown, together with the realization of the serious need to conserve, assess and protect their ecological integrity (Ollis *et al*., 2006). Conserving ecological integrity is also especially important in semi-arid or arid regions that have existing or impeding water shortages, such as in a large part of South Africa (Ollis *et al*., 2006). Since the 1990s, there has been a global trend towards including and integrating in-stream biological monitoring, as a means to determine ecological integrity to assist water resources management (Roux, 2003). For instance, The European Union implemented the *Water Framework Directive,* an integrated river basin management strategy for Europe that requires the integration of bio-monitoring techniques to be used in the water quality monitoring procedures (Chave, 2002). Water quality monitoring in South Africa also recognized various shortcomings in standard chemical and physical monitoring methods, such that bio-monitoring techniques were introduced into the routine monitoring programmes (DWAF, 1996). Through this, there has been a noticeable shift in scientific literature focus towards integrating bio-monitoring techniques with chemical and physical parameters (Bere & Tundisi, 2011).

In South Africa, the National Water Act No. 36 of 1998 stipulates a legal mandate for the ecological assessment of water resources (Ollis *et al*., 2006). It states that every significant water resource within the country must be classified and appropriate verifiable resource quality objectives must be set according to the assigned class of the water resource (Roux, 2003). The Department of Water Affairs and Forestry initiated the formal design of the River Health Programme in 1994, to provide information regarding the overall ecological status of river ecosystems within the country (DWA, 2013).

Water resource assessment in South Africa has become more complex over the last 60 years (Pitman, 2011). The complexity is attributable to the increased growth in land-use, decline in natural habitats, deterioration in water quality, and the need to examine the interaction between groundwater and surface water (Pitman, 2011). Exponential growth in computing power and the advancements in related software and tools, has helped the handling of these complexities (Pitman, 2011). However, a major concern, is the alarming decline in both rainfall and river flow measurements (Pitman, 2011). Rainfall data in particular is worrying, as the network has declined as far back as the network of the 1920s (Pitman, 2011). The growth in land-use has increased the problem, and contributed towards the poor or non-existent monitoring (Pitman, 2011). With the possibility of climate change and climate cycles, these should be considered, but it is important that it does not distract from the main goal of water resource monitoring (Pitman, 2011). The River Eco-status Monitoring Programme (REMP) evolved from the River Health Programme (RHP), and replaced the River Health Programme in 2016. It is a component of the National Aquatic Ecosystem Health Monitoring Programme (NAEHMP), and focuses on monitoring ecological conditions, that are reflected by system drivers and biological responses in a river.

The River Health Programme, is used to assess habitat and biological integrity of rivers in South Africa (DWA, 2013). It rests on the foundations of biological monitoring and the use of standardized indicators such as aquatic macro-invertebrates and riparian vegetation to characterize the response of the aquatic environment to different environmental disturbances and determine the ecological integrity (DWA, 2013). Ollis *et al*. (2006) notes, it is globally accepted that, the health or integrity of a river system can best be established through the identification of biota inhabiting the river ecosystem. A river's biological diversity can thus be used to provide a direct and integrated measure of the health of a river system (DWA, 2013). The limited application of biological monitoring in the past has been a major factor responsible for the degradation and deterioration of the ecological integrity and water quality of rivers (Ollis *et al*., 2006). Given this, bio-assessments are now included as a key element of environmental and water resource management policies in numerous countries worldwide (Chessman,1995; Norris & Norris, 1995; Moog & Chovanec, 2000).

Biological organisms are considered to be good indicators of a river's ecological integrity or of the degree of water quality deterioration in an aquatic ecosystem because of their ability to reflect and integrate the cumulative effects of the factors negatively impacting on a river ecosystem overtime as shown in Figure 3 (Ollis *et al*., 2006). Bio-assessments and bio-monitoring have been created on the assumption that measurements of the condition, responses and/or community integrity of biota can be used to assess the ecological integrity of an ecosystem (Hawkes, 1975,1982; Herricks & Cairns, 1982; Dallas, 1995). The ecological integrity of an ecosystem can be derived using various attributes as biological indicators for example, the growth rate of individual species, the species composition of biotic communities or through the rate of nutrient cycling from natural processes (Dallas & Day, 1993; Roux *et al*., 1993; Dallas, 1995). Dallas *et al*. (1995) notes that the use of biotic communities in bio-assessment is relatively well established in the aquatic sciences.

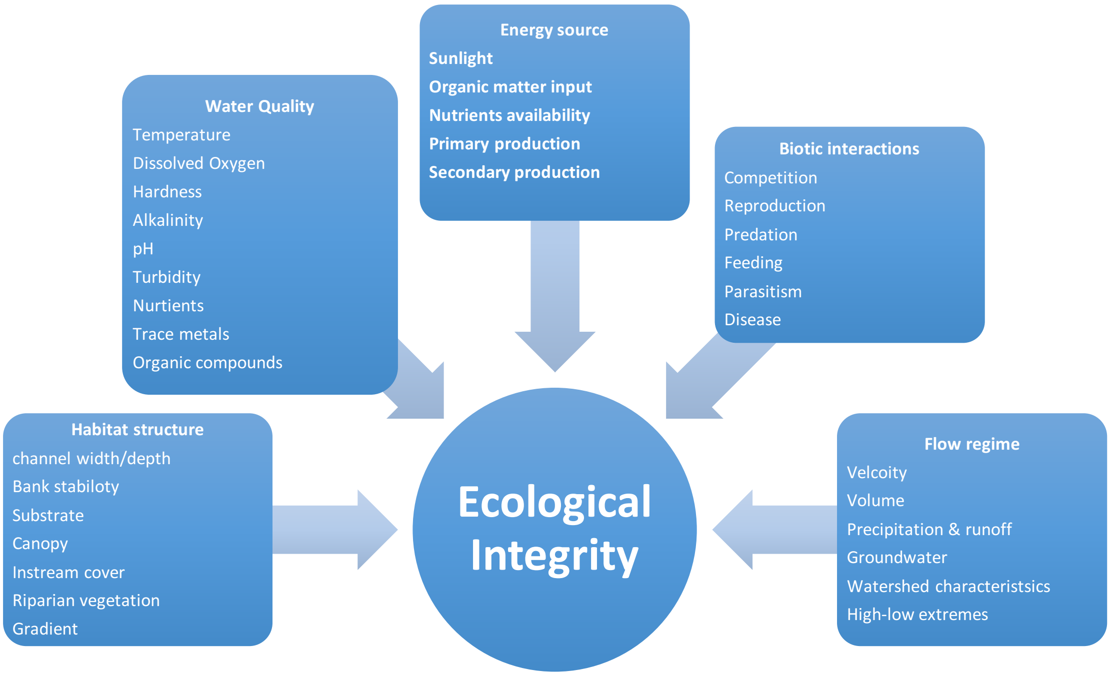

Figure 3: Factors affecting the ecological integrity of river ecosystems (modified from Dallas & Day, 1993 & Roux, 1997).

A wide range of organisms have been used in the bio-assessment of ecological integrity and water quality assessment of aquatic ecosystems which include protozoans, bacteria, algae, diatoms, macrophytes, fish and macro-invertebrates (Dallas & Day, 1993; Barbour *et al*., 1999; Brown, 2001). Of these, benthic macro-invertebrates are the most commonly used group, especially within lotic systems (Ollis *et al*., 2006). Hellawell (1986), summarizes the multiple advantages of using benthic macro-invertebrates in bio-assessments. Briefly, benthic macro-invertebrates are predominantly non-mobile, ubiquitous and abundant species of a river that occupy most habitats. Many species within a community typically have varying sensitivities to stressors that are able to react quickly resulting in a broad spectrum of graded and recognizable responses to environmental disturbances. The responses of many common species to different types of pollution have since been established. The life cycle of macro-invertebrates is also long enough for the temporal changes caused by perturbation to be detected, but is short enough to observe their recolonization patterns following perturbation. They are also fairly easy and inexpensive to collect and are well suited to experimental approaches in bio-monitoring.

Biological community data is also easily summerised and presented as a simple, numeric or catagorised index (Ollis *et al*., 2006). The indices used can communicate the ecological assessment results in an appropriate way that is understood by natural resource managers, politicians, decision makers and the general public (Beck, 1955; Hawkes, 1975; Spellerberg, 1991). Three basic types of indices can be used, comparison indices (similarity or dissimilarity), diversity indices, and biotic indices (Johnson *et al*., 1993). Of these, biotic indices are the most commonly used.

Early hydrobiological studies on macro-invertebrate communities in some major rivers of South Africa during the 1950s and 1960s laid down the foundation for river bio-assessment within the country (Ollis *et al*., 2006). The pioneer studies of particular significance were the hydrobiological surveys of the Berg River (Harrison, 1958a, 1958b, 1964; Harrison & Elsworth, 1958), the Tugela River System (Oliff, 1960a, 1960b, 1963; Oliff & King, 1964; Oliff *et al*., 1965; Brand *et al*., 1967), the Jukskei- Crocodile River System (Allanson, 1961), the Vaal River in the Vereeniging area (Chutter, 1963; Harrison *et al*., 1963), the catchment of the Vaal Dam (Chutter, 1970,1971) and the Umgeni River (Schoonbee & Kemp, 1965). The work of King (1981, 1983) on the Eerste River, although carried out almost 20 years later was also pivotal towards the formal implementation of biological monitoring in river management in South Africa (Ollis *et al*., 2006).

Over time, South Africa's Government's focus and priorities have been progressive and transformative in managing water resources. Through the implementation of evolving strategies, the South African Government's policy has now afforded protection to catchment and river ecosystems through Resource Directed Measures, Source Directed Controls and the national River Health Programme.

A classification scheme is used to rate the class of a river as excellent, good, fair or poor depending on how modified the water resource is from a pre-determined reference condition (Roux, 2003). Specific ecological indicator groups such as the South African Scoring System, better know as SASS, Habitat Integrity Index, Geomorphological Index, Fish assemblage Index and Riparian Vegetation Index are used to measure the multiple chemical, physical and biological factors influencing a river's health (DWA, 2013). This information allows for standardised measurements of ecological integrity to be determined and comparisons between river conditions to be expressed in accordance with a management or ecological perspective, as shown in table 5 (DWS,2016). Each class also incorporates a socio-economic assessment which evaluates the goods and services available by the river and determines its functionality at its present state.

Eco-status Classification concept

Water resources are classified according to the degree of modification from a 'natural' state and its level of impairment. The classes used by the South African River Health Programme are showed in table 4, which will be used as the basis for classification of rivers in this study.

Table 4: Classification of river health assessment classes in line with the RHP (DWS, 2016).

Class	Description
A	Unmodified, natural
B	Largely natural, with few modifications
C	Moderately modified
D	Largely modified
E	Extensively modified
F	Critically modified

Table 5: River health classes expressed in terms of ecological and management perspectives (DWS, 2016).

River Health Class	Ecological perspective	Management perspective
Excellent/ natural	No or negligible modification of in-stream and riparian biota and habitats.	Protected rivers; relatively untouched by human hands; no discharges or impoundments allowed
Good	Ecosystems essentially in a good state; biodiversity largely intact	Some human-related disturbance but mostly of low impact potential
Fair	Sensitive species may be lost; lower abundances of biological populations are likely to occur; or sometimes, higher abundances of tolerant or opportunistic species occur.	Multiple disturbances associated with need for socio-economic development, e.g. impoundment, habitat modification and water quality degradation
Poor	Habitat diversity and availability have declined; mostly only tolerant species present; species present are often very diseased; population dynamics have been disrupted (e.g. biota can no longer breed or alien species have invaded the ecosystem).	Often characterized by high human densities or extensive resource exploitation. Management intervention is needed to improve river health e.g. to restore flow patterns, river habitats or water quality.

In addition, the ecological category (EC) classification was implemented using the eco-status A to F continuum approach (Kleynhans *et al.*, 2007). The approach includes boundary categories denoted as A/B, C/D, E/F etc, to be used.

However, Round (1991) identified multiple reasons suggesting why animals, fish and macro-invertebrates are not always a satisfactory index system to use in bio-monitoring. The reasons are linked to the complexities of animal reproductive cycles that are often seasonal, the possibility of animals having multiple life stages and experiencing metamorphosis, the high motility of animals causing difficulty during sampling, animals having specific niches and habitats being closely linked to flow conditions that cause an uneven distribution of species from headwaters to estuaries. Deep water courses are extremely difficult if not impossible to evaluate, and studies have shown that macro-invertebrates are weak indicators of eutrophication and diffuse and point source pollution (Harding & Archibald, 2005). However, diatoms, unlike fish and macro-invertebrates, inhabit a wider variety of water conditions that can range from clean water to critically polluted water and have a cosmopolitan distribution, suggesting their inclusion as a formal bio-monitoring method of water quality monitoring (Potapova & Charles, 2007).

2.4.1 Diatoms in water quality monitoring

According to Kelly (2002), no single group of organisms is best suited for detecting the environmental changes associated with human activities. In maintaining ecosystem integrity through environmental management of a river system, it is important that the status of different taxonomic groups is monitored to gain an integrated, broad and holistic understating of the stream's health (Harding & Taylor, 2011). In South Africa the SASS bio-monitoring system is widely used after it gained support as a rapid system for evaluating water quality (de la Rey *et al*., 2008). Recently, diatom based indices such as the Biological Diatom Index (BDI) and the Specific Pollution Sensitivity Index (SPI) have come into the spotlight as being potential additions in bio-monitoring (de la Rey *et al*., 2008). Taylor *et al*.(2007c), Harding *et al*. (2005) and de la Rey *et al*. (2004) have published paper that explore the potential use of diatoms as valuable bio-indicators. Taylor's *et al*. (2005), development of a standard protocol for the assessment of diatoms used for the comparability of diatom index results, was instrumental towards the Department of Water and Sanitation including diatoms as a bio-monitoring tool to assess water quality in South Africa (Harding & Taylor, 2011).

The potential use of diatoms as bio-indicators was recognized to the point that they were first included in South Africa in the State of the River's Report for the Crocodile (West) and Marico - Water Management Area in 2005 as an indicator of water quality (Taylor *et al*., 2007d; River Health Programme, 2005). Based on their success of indicating eutrophication, organic pollution and heavy metal pollution together with the advancements in diatom based methods and tools, diatoms are now included in the EcoClassification process. This includes the River Health Programme and the Ecological Reserve to complement the physio-chemical and aquatic biota sampling and provide additional information as a response variable to changes in water quality (Harding & Taylor, 2011). The motivation for including diatoms in bio-monitoring is because they are cosmopolitan, have a rapid cell cycle and are able to respond rapidly to disturbances and pollution (Walsh & Wepener, 2009). Unlike other aquatic biota, diatoms do not have specialized habitat niches and are not predominantly controlled by streamflow (Walsh & Wepener, 2009).

de la Rey *et al*. (2008) conducted a study that aimed to evaluate the efficacy of diatom-based indices in river systems in South Africa. The paper compares the relationship of using the SASS5 invertebrate index and diatom indices responses to habitat availability and chemical water quality. The study concluded that both diatom-and invertebrate-based indices showed significant correlations to water quality variables. The diatom-based indices portrayed a clearer response to general water quality compared to macro-invertebrates, and did not react to changes in seasons. The invertebrate indices showed a stronger relationship to changes in habitat scores, compared to the diatom-based indices. Season variability also influenced macro-invertebrate indices more than diatom indices, however the total effect of seasonality on the indices was low. The study shows that diatoms are suitable indicators of short to medium changes in general water quality which may not be detected using only invertebrate indices. Conversely, as diatoms are not able to effectively indicate habitat degradation, which is an important component of the functioning of healthy rivers, invertebrates need to still be included in the bio-monitoring of rivers. Figure 4 shows a conceptual model of the positioning of SASS5 and diatoms as indicators in water resource management.

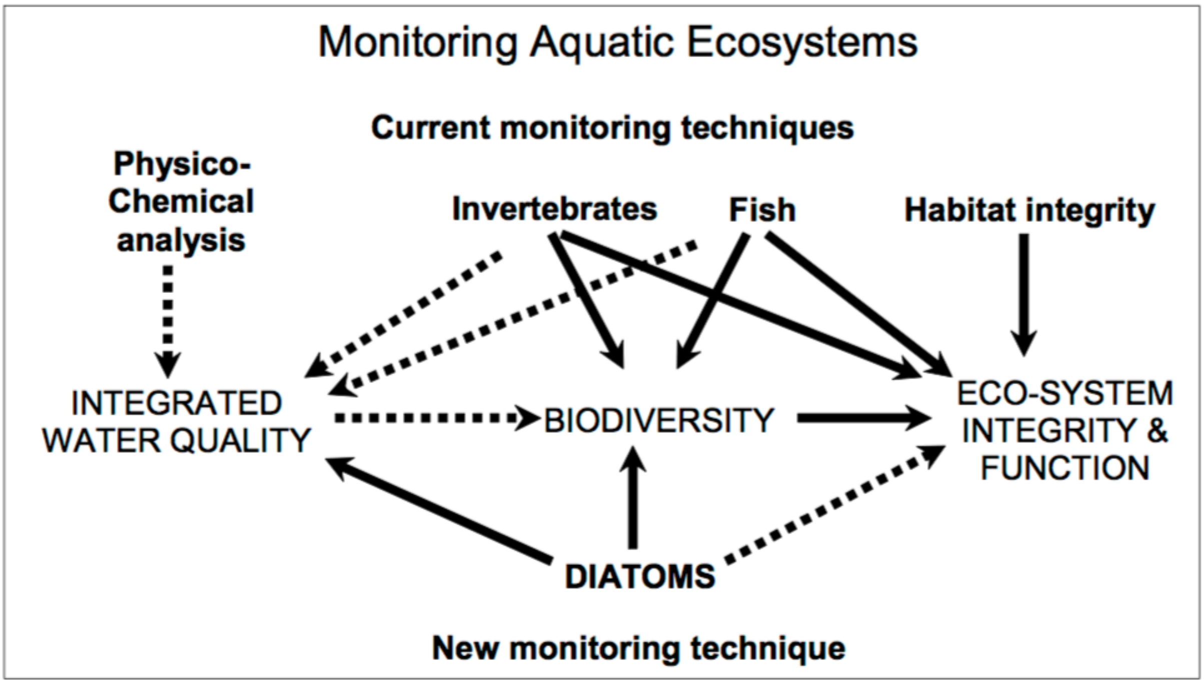

Figure 4: The relationship between parameters used to monitor aquatic ecosystems adapted from Taylor *et al*. (2006).

Figure 4, illustrates the relationship between biological indicators and environmental responses. As diatoms are directly dependent on the water chemistry of their immediate environment, as well as reliant on nutrients for their reproduction and continued growth, they are sensitive to changes in water conditions and are directly influenced by pollutants, hence the solid black lines (de la Rey *et al*., 2008). The diversity of diatoms in different population densities, overall abundance and composition, will provide considerable ecological information of a water sources condition (Harding & Taylor, 2011). Given this, diatoms provide interpretable indications of water quality changes, whereas macro-invertebrates may better reflect the impact of changes on the physical habitat and ecological integrity of their direct environment, hence the solid black lines (McCormick & Cairns, 1994). de la Rey *et al*. (2008) recommends based on the results, that diatoms and SASS5 can, and should be used as complementary techniques in the bio-monitoring of rivers. The simultaneous use of multiple bio-monitoring indicators will provide high confidence results of varying conditions which can assist in environmental water management (Harding & Taylor, 2011).

Walsh & Wepener (2009), recognized the ability of epilithic diatom communities to provide an integrated and holistic approach for assessing water quality, because these diatoms remain in a certain place for a number of months and reflect an ecological memory of water quality over time. Walsh & Wepener (2009) conducted an in-depth study with the primary objective to compare and relate changes in diatom species to land use type. Comparisons in diatom assemblages were used to differentiate between particular land types (urban, agricultural and natural reference sites) and determine the associated water quality impacts on the Crocodile and Magalies Rivers (Gauteng and North West Province, South Africa) that are linked to these adjacent land-use patterns.

The results from Walsh and Wepener (2009) study showed that the community structure of diatoms sampled from each site reflected differences attributable to the particular land use practice. Based on the species similarity analyses, the reference sites showed strong associations with *Gomphonema venusta, Achnanthes minutissima and Cocconeis placentula* var. *euglypta*., diatoms that typically inhabit clean water and are classified as 'good' in terms of water quality. Diatom indices showed that, agriculture land use sites ecological status was slightly more modified compared to urban sites. Agriculture land use could be divided into high and low intensity practices based on species composition. High intensity farming was indicated by motile diatom species of the genus *Nitzschia,* while, low-intensity farming was indicated by the presence of motile diatoms in the *Navicula* genus. The sites impacted by high intensity agriculture, diatoms were classified in a 'poor/moderate' class overall, indicating significant alterations in water quality. Whilst the urban sites sampled were associated with *Navicula tripunctata*, *Diatoma vulgaris* and *Amphora pediculus*, a combination of diatom species that were able to tolerate spikes in water quality. Overall, the urban area diatom community structure portrayed a 'moderate' class.

Bere and Mangadze (2014), further investigated the response of diatoms to changes in water quality in topical streams draining Chinhoyi Town, Zimbabwe. Eight of the sites were specifically chosen to evaluate the impact of sewage effluent on water quality, and determine the associated influence of poor water quality on diatom communities. The results showed that, as pollution increased, i.e., increase in nutrients, metal levels and conductivity, and a decrease in dissolved oxygen and pH levels; low or moderate pollution tolerant species were replaced by high pollution tolerant species. Low pollution tolerant species included Cocconeis *placentula*, *Cymbela tumida*, and *Eunotia formica* and high pollution tolerant species included *Gomphonema parvulum*, *Nitzschia palea* and *Navicula gregalis*. *Nitzschia palea*, together with *Gomphonema parvulum,* were recorded at all highly polluted sites, and are often the dominant species in streams where treated sewage, or untreated sewage, as was the case in this study, constitutes the major component of flow (Fukushima *et al*., 1994). Furthermore, *Nitzschia palea* is described as a cosmopolitan, high pollution tolerant species, in particular to eutrophication, while, *Gomphonema parvulum,* has been described as an indicator species of, high organic pollution, and low concentrations of dissolved oxygen and eutrophication (Lobo *et al*., 2002; Van Dam *et al*., 1994). Overall, the study revealed that diatom community structure and composition is closely linked to the observed changes in pollution levels and water quality. Such that, less polluted sites were associated with diatoms that were distinct and different from highly polluted sites.

Changes in the community composition of diatoms can therefore be used to determine pollution levels present in the water (Harding & Taylor, 2011). Typically, pollutants will negativity impact the viability of sensitive diatom species, while favoring the growth of tolerant species (Harding & Taylor, 2011). Through this, inter-species competition and niche habitat dynamics are affected, resulting in a change in community structure and composition in accordance to dominant and sub-dominant diatom species (Harding & Taylor, 2011). The predictable changes of diatom species, based on their ecological tolerances, makes them a suitable indicator for monitoring fluctuations in water quality (Biggs, 1989). Diatoms as stable signatures of water quality are thus ideal bio-organisms to use in rapidly changing environments, such as urban catchments (Round, 1993).

2.5 Diatoms as indictors of river recovery processes

Research has emphasized the importance of riparian ecosystems as centers of biodiversity and as the interface between terrestrial and aquatic ecosystems (Richardson *et al*., 2007). Riparian zones are key landscape features with substantial regulatory controls on environmental vitality (Naiman *et al*., 1992). Physical habitat in a river is determined by the interaction of the river's hydrology and geomorphology which has a strong influence on habitat formation and stability, the inherent attributes of riparian vegetation, on local geomorphology and the diversity of ecological functions (Naiman *et al*., 1992). As both the quantity and quality of available habitat has an affect on the composition and structure of resident biological communities, the role of habitat integrity in maintaining ecological biodiversity within a river system is emphasized (Hynes, 1968; Ward & Stanford, 1979; Meffe & Sheldon, 1988; Calow & Petts, 1994). Hood and Naiman (2000), further explain the significant role of riparian vegetation in fulfilling important ecological functions in relation to aquatic habitats, that include providing a source of food, moderating stream water temperature via shading and evapotranspiration, providing a buffer zone that controls the flow of water and nutrients from uplands to streams, filters sediments as well as stabilizes stream banks. These riparian zones also provide a corridor for the movement of biota and forms the foundation of the delivery of ecosystem services which are valuable to humans.

Biological assessments can be used to understand how the biodiversity of a river changes over time, as well as the extent of this change in response to a habitat rehabilitation intervention (Taylor, 2006). Diatoms rapid response rate to environmental changes and as stable signatures of water quality, coupled with macro-invertebrate's response to changes in physical habitat and ecological integrity, are an accurate way to determine a stream's response to a riparian restoration intervention (Taylor,2006). There is thus a strong correlation between a stream's habitat, water quality condition, and the biotic richness of species that are populating the river (Bernhardt & Palmer, 2007). Improving the habitat and biodiversity of a river system will thus increase species diversity of the aquatic environment and will ultimately improve the stream's water quality (Bernhardt & Palmer, 2007). Successful riparian restoration projects ought to result in having stream habitat and biological communities that are distinct from unrestored streams (Violin *et al*., 2011).

A successful habitat restoration intervention will result in specialised habitat niches forming, and an increase in the diversity of macro-invertebrate species. As invertebrates have a strong relationship with habitat integrity, a miniSASS or a SASS5 assessment of macro-invertebrates will indicate the condition of the available habitat and in turn, indicate the water quality and functionality of the river (de la Rey, 2008). According to Harding and Taylor (2011), the simultaneous use of multiple bio-monitoring indicators should be used to provide high confidence results of varying environmental conditions. Given this, SASS and diatoms can be used in conjunction to evaluate the progress of a habitat rehabilitation intervention.

Diatoms, similar to many other species, prefer certain physiological and ecological ranges in which to inhabit, such that the dominant diatom community present in the water source will represent the quality of water. If these favorable conditions change, and the diatom tolerance levels are exceeded, the composition of the diatom community will in turn change accordingly (Holmes & Taylor, 2015). Biggs (1989), notes that the predictable changes of diatoms, based on their ecological tolerances makes them a suitable indictor for monitoring fluctuations in water quality and consequent environmental changes. The effectiveness of a river rehabilitation intervention can be assessed through the re-introduction of diatom species that are signatures of 'cleaner' water quality.

The most realistic approaches for effective riparian restoration are to either work within the catchment limitations, below the areas threshold, focusing on reach scale interventions, or to work at a catchment scale where goals are still reachable and/or where conservation priority is high (Moerke & Lamberti, 2004). The conceptual model developed by Whisenant (1999), Figure 5, demonstrates the usefulness of abiotic (shaded areas) and biotic thresholds (unshaded areas), when riparian ecosystems are both influenced and highly prone to invasions by alien plants. Generally, the magnitude and frequency of physical disturbances in the catchment determine the patterns of succession and rate of species turnover, which often triggers the proliferation of alien plants (Nilsson *et al*., 2002). Figure 5 outlines a framework of appropriate management practices for facilitating the restoration of riparian plant communities. According to Holmes & Richardson (1999), riparian zones that are patchily invaded, or have recently become densely invaded by alien plants, have the potential to be restored to their historic catchment scale species composition through biotic manipulations in removing alien invasive species.

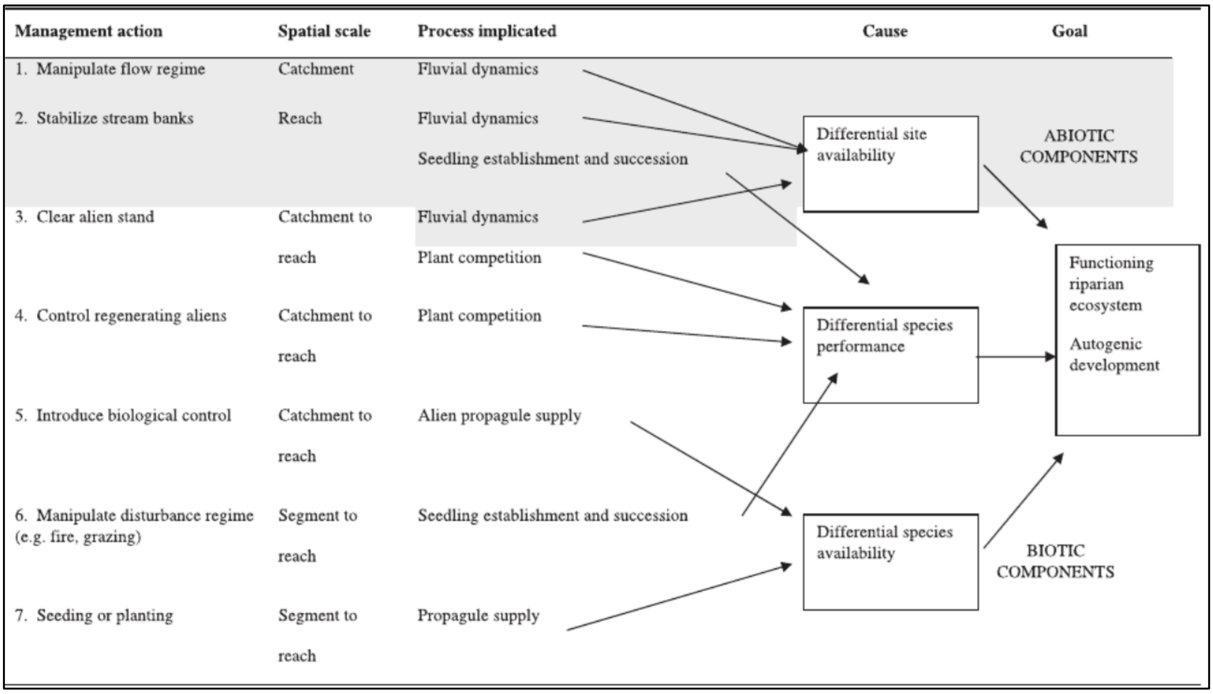

Figure 5: A framework showing main management actions available for facilitating the restoration of riparian plant communities affected by alien plant invasions, adapted from Richardson *et al*. (2007).

A study by Sweeney *et al.* (2002), shows the success of a small scale restoration project of a riparian forest via planting containerized and bare root plants. The sowing or planting of indigenous riparian species accelerated the recovery of vegetation in a highly altered riparian zone that had been cleared of dense and extensive thickets of alien invasive plants. As riparian vegetation refugia, was scarce and soil-stored seed banks depleted, the recolonization of riparian zones by dispersing suitable indigenous species was slow, and the probability of re-establishment of alien species were high (Richardson *et al*., 2007). In highly modified rivers, the creation of nodes of indigenous riparian vegetation is important towards sustaining long term restoration of riparian zones (Richardson *et al*., 2007).

In landscapes where inputs of physical energy, such as water or wind movement, are dominating forces in structuring an ecosystem, manipulations of abiotic components of the landscape must be a pivotal consideration in effective ecosystem and riparian corridor repair (Ehrenfeld, 2000). Biotic components, such as vegetation composition and structure are appropriate focus of repair targets where the geomorphological and hydrological functioning of a system can support the intended assemblage of species, or where it can or has been restored (Hobbs & Harris, 2001). It is therefore evident that there are multiple management approaches, but for river restoration to be effective, techniques must be catchment dependent, such that the dynamics of land use, land use activities and natural process that influence water quality must be considered to achieve the greatest results.

An alternative approach to river restoration and management of riparian ecosystems develops if it is accepted that riparian ecosystems are open and dynamic, and humans are identified as a crucial part of the functionality of ecosystems (Richardson *et al*., 2007). Through this approach, restoration does not aim to recreate any historic species assemblages, but rather focuses on restoring the processes that provide a desired riparian corridor structure and function (Richardson *et al*., 2007). Physical habitats, have thus been identified as fundamental units that should be used to base river conservation and restoration interventions upon (Harper *et al*., 1992).

2.6 Concluding remarks

This investigative study, concentrates on the processes of river rehabilitation. The focus of the study is to understand the value of three different types of bio-assessment methodologies, namely, diatoms, miniSASS and water quality parameters, which are capable of informing rehabilitation of a river system, through assessing water quality and support for potential habitat in a highly polluted river. The emphasis is on integrating a combination of well-known methods, and to determine how one or more of these methods are capable of providing a stable indicator for habitat support and water quality. The assumption is that diatoms are the stable signatures of water quality as species distribute themselves according to their pollution tolerances.

CHAPTER THREE: RESEARCH METHODS

3.1 Study Design

This project aims to determine the ability of a contaminated urban stream towards enriching the biodiversity of species and organisms, following a rehabilitation intervention, in a small informally settled catchment in Franschhoek, South Africa. The study design incorporates three water monitoring methods that include; diatoms, miniSASS and water quality monitoring, to define the condition of the Stiebeuel Rivers water quality and habitat integrity before and after rehabilitation.

Diatoms have been chosen as the main bio-indicator in monitoring the pollution gradients along the Stiebeuel River, for diatoms are stable signatures in reflecting water quality changes particularly in urban areas. The study method follows Taylor (2007a), well-established methods for diatom collection. Macro-invertebrate sampling was included because of their ability to reflect changes to the physical habitat and ecological integrity of their direct environment. Macro-invertebrates were collected in accordance with the guidelines for a miniSASS assessment. Lastly, water quality parameters (pH, temp, DO, EC) were used to test and monitor the physical parameters of the Stiebeuel River. Readings were taken using hand-held Martini probe meters.

3.1.1 Sampling sites

A total of twenty-seven sampling sites were selected for diatom, macro-invertebrate and water quality monitoring in the catchment. Twenty- two sites were strategically chosen to determine the effect of Langrug, surface water runoff, on the Stiebeuel River. Of these twenty-two sampling sites, two sites were situated above the R45 main road which included, at the top of the Stiebeuel River Catchment, Sb1 (reference site), and in the middle of Langrug informal settlement, site Sb2. The additional twenty sites were located in the Water Hub, of which, seventeen sites were sampled along the Stiebeuel River, and three in the Franschhoek River. These sites were chosen, to isolate the effect of the informal settlement, on the Stiebeuel River.

The study will examine the response of a river rehabilitation intervention over a short 1-2 to month period. The selected short time frame is designed to understand the rapid response of biodiversity, to return or to enrich the river system, through identifying and gaining an understanding on which species are first to recolonise the improved ecological and environmental conditions. This was achieved through comparisons of diatoms, miniSASS and water quality parameters pre and post the rehabilitation intervention.

Figure 6: The condition of the Stiebeuel River.

Two important sampling points to note are site Fr20, and site Fr22, in the Franschhoek River, within the Water Hub boundary. Site Fr20, is 5m above the confluence with the Stiebeuel River and site Fr22, is 5m below the confluence with the Stiebeuel River. These sites were chosen to provide valuable information on the extent of deterioration caused to the Franschhoek River, by the in-flow of highly polluted water from the Stiebeuel River. Figure 6 shows pictures of the current condition of the Stiebeuel River.

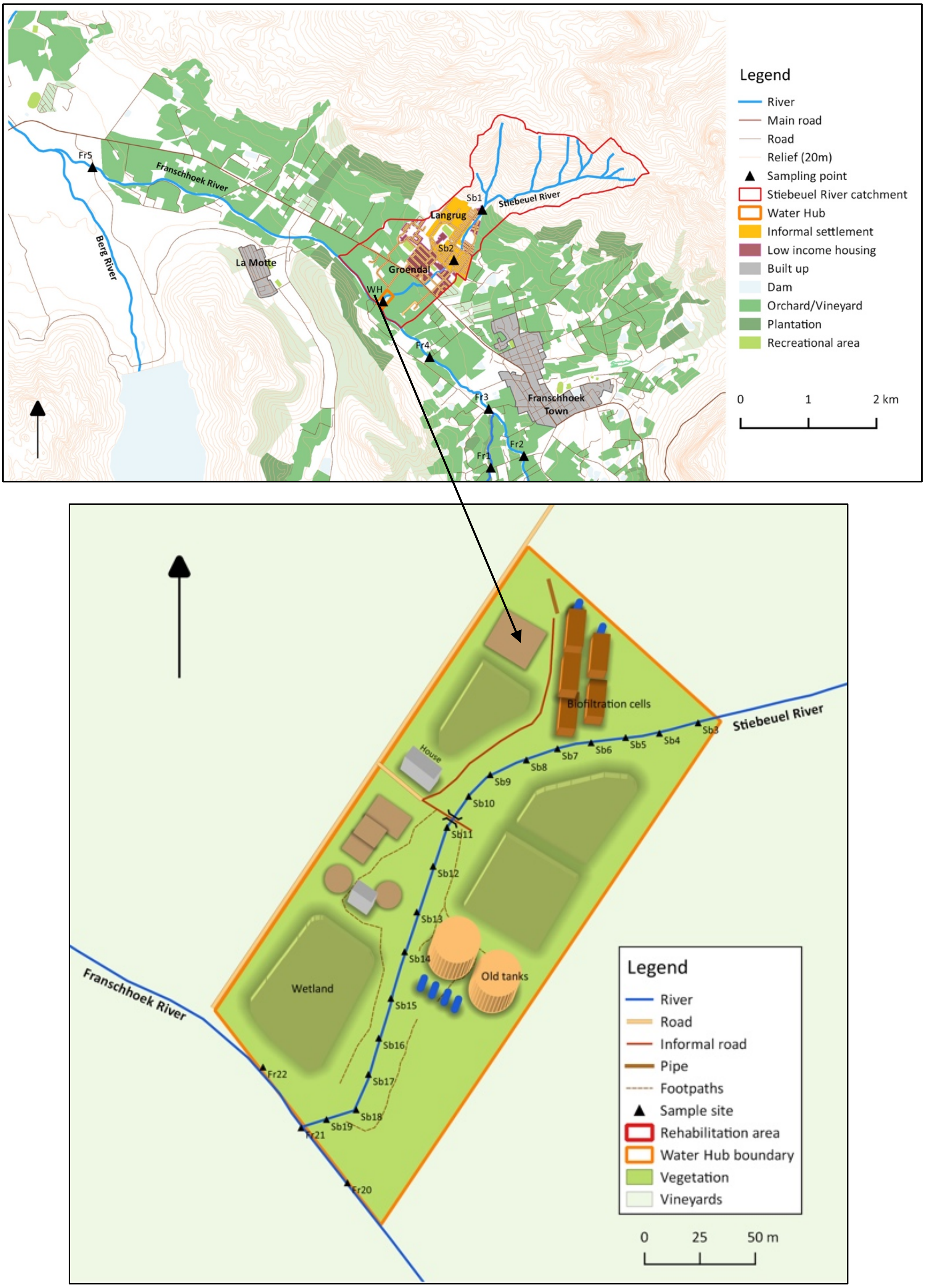

Figure 7: The Water Hub sampling points.

An additional five sites, were sampled along the Franschhoek River seen in Figure 10. Four sites, were above the confluence with the Stiebeuel River and one site was 5km down stream from the confluence. The sites located above the confluence were chosen to provide information regarding the typical condition of a naturally functioning river in the catchment, refer to Figure 8. While the site sampled, 5km down- stream, from the confluence with the Stiebeuel River, was chosen to examine the extent of river recovery and investigate whether the water quality of the Franschhoek River improves over distance and time. The sites were also all chosen based on accessibility and feasibility of sampling in the rivers.

Figure 8: The condition of the Franschhoek River at site Fr4 & Fr5, August 2017.

3.2 Project development

3.2.1 Study area

The Stiebeuel River, the subject of this study, is located in a small informally settled catchment of the Franschhoek Mountains, Western Cape, South Africa. Franschhoek is located 75km outside of Cape Town CBD, and has a Mediterranean climate with hot dry summers and cold and wet winters (Munica & Rutherford, 2006). The mean annual precipitation of the area is 863mm, of which, 80% of the rainfall is in the winter months between April and September (de Clercq *et al*., 2006). The area surrounding the Stiebeuel River is made up of four land use types, which include, naturally vegetated area, agricultural activities, built-up impervious area and the informal settlement, Langrug. Agriculture is the dominant land use of the surrounding area, as Franschhoek is one of six wine regions, that make up the Cape Winelands District. The primary economic activities within the area are agriculture, tourism and hospitality.

The Franschhoek area is drained by three main rivers; the Berg River, the Wemmershoek River and the Franschhoek River. The Franschhoek River flows through the bottom of Franschhoek Town and merges with the Berg River. The Stiebeuel River, a tributary of the Franschhoek River, flows through and drains different land use areas common to South African peri-urban areas that include, naturally vegetated, agricultural, urban/built-up (Groendal) and urban informal settlement (Langrug). The spatial configuration of the area is common in developing countries, where communities with widely varying socio-economic statuses live adjacent to one another and are connected by the river that flows through them.

The Stiebeuel River catchment was selected as the study area because of its unique spatial structure that is made up of multiple land use and land cover areas that reflect their own infrastructure, development densities, economic and social activities. The altered landscape and different land use areas will result in modified hydrological regimes and surface water runoff entering the Stiebeuel River. The effects of such characteristics are unknown, in terms of both, the effects on the area's hydrology and water quality on the functionality and ecosystem biodiversity of the Stiebeuel River.

The highly contaminated surface water runoff from Langrug informal settlement that is discharged into the Stiebeuel River during dry and wet periods has caused severe modifications to the surrounding environment and health of the rivers. Langrug, is characterized by high density living with the prevalence of poverty. Living conditions are desperate, houses are flimsy structures constructed from makeshift materials and are extremely overcrowded, with 6000 residents living in 2500 densely packed shacks. Langrug also lacks a wide range of basic services, and has one formal road, 40 flush toilets and 6 taps, of which most are dysfunctional (Winter, 2017). Rubbish 'bins' and waste removal services are also inadequate and are often left to overfill as seen in Figure 9. A web of compacted footpaths interlinks and connects the informal settlement. These footpaths are functionally impervious.

Langrug, has both formal and informal drainage channels. One concrete lined culvert which runs down the main road has been constructed to drain stormwater. Various informal earth-lined ditches and streams also exist and serve as drainage channels. In these poorly drained areas with inadequate sanitation, urban surface water runoff mixes with excreta, blackwater, discarded greywater and solid waste. The spread of pathogens , in the form of bacteria, viruses or other microorganisms that can cause diseases and rife in the community and the Stiebeuel River which drains the informal settlement is extremely contaminated (Fell, 2017). However, little is known about the causal-relationship between Langrug and the extreme degradation caused to the Stiebeuel River ecosystem (Fell, 2017). The informal settlement of Langrug, has been subject to various upgrading projects in the past.

Figure 9: The living conditions in Langrug, informal settlement.

The Stiebeuel River, once it has flown through Langrug, next flows through the low-income area, Groendal. Groendal is a planned area, that consists of formal housing or low-cost RDP houses. The area has a structured paved road network with conventional stormwater drains. The majority of houses have formal plumbing systems. In Groendal, there is also littering and dumping of, household refuse, building rubble, and other household appliances in close proximity to the Stiebeuel River.

A main road, the R45 forms the boundary between Groendal and surrounding agricultural lands, through which the Stiebeuel River next flows. Wine farms are the main agricultural practice and contribute a diffuse source of pollution into the Stiebeuel River. Roughly 200m before the confluence with the Franschhoek River, the Stiebeuel River flows through the Water Hub, a SuDS Centre, which is being constructed at the bottom of the Stiebeuel River catchment, designed to treat contaminated surface water runoff from Langrug. This SuDS Centre is part of an ongoing project lead by the University of Cape Town and in particular by Dr. Kevin Winter.

The catchment area reflects the ongoing reality of South Africa's inequalities, and provides an appropriate scale to undertake research. This research can be used as a broad framework to assist in the management of rivers draining similar land use areas within South Africa.

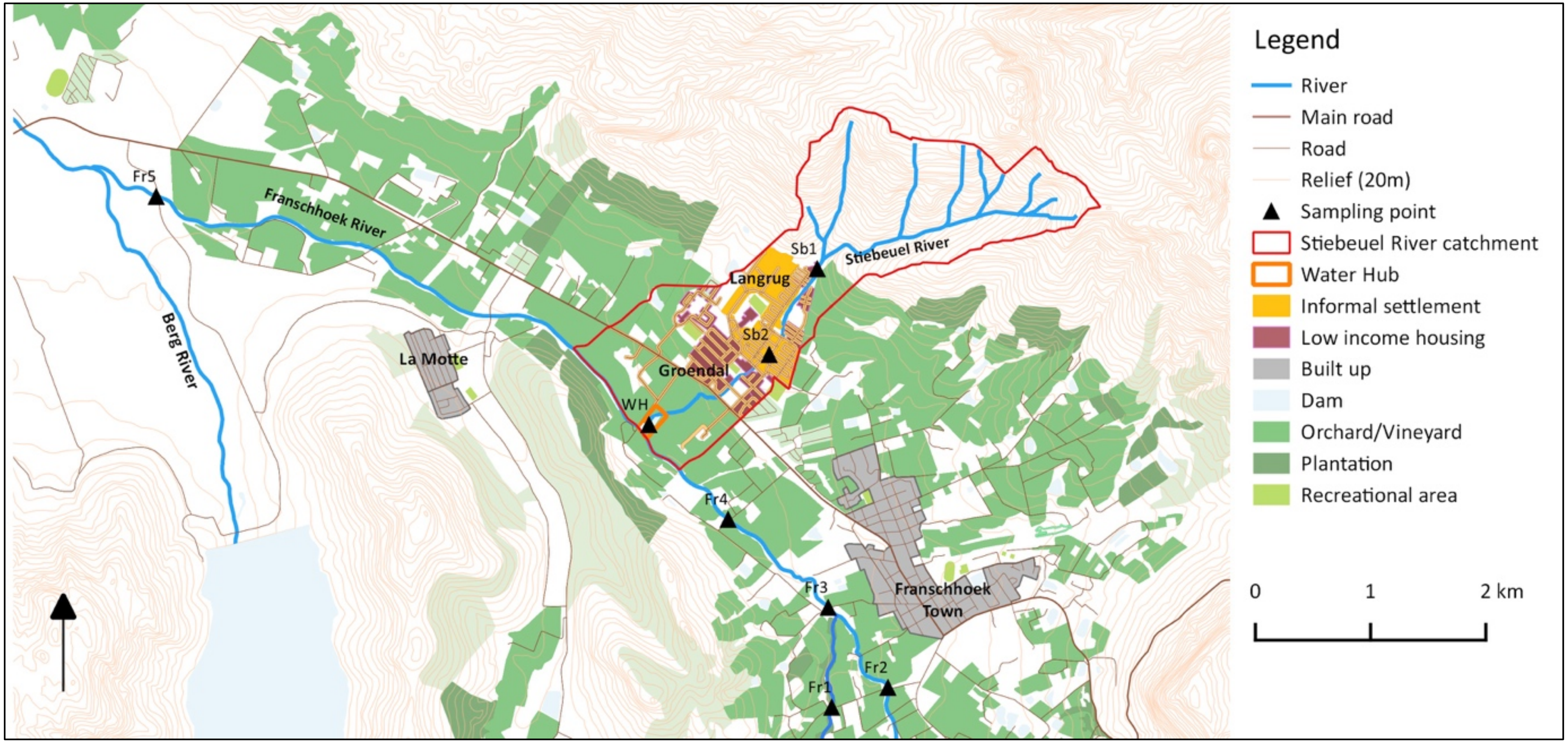

Figure 10: The different land use areas of the Stiebeuel River catchment.

3.2.2 Selection of bio-monitoring methods and water quality parameters

Biological communities are living entities, such as fish, invertebrates, algae and diatoms that make up the aquatic biota (Harding & Taylor, 2011). As biological communities are always in the water, they are exposed to all the different chemical stressors and reactions that are present, and respond to the entire integrated chemical conditions that exist (Harding & Taylor, 2011). This enables biological communities to reflect the overall ecological integrity of aquatic ecosystems (Harding & Taylor, 2011). Aquatic communities are therefore useful in reflecting- to various degrees-, the impacts that physical and chemical disturbances within a catchment have on river ecosystems over extended periods of time (Harding & Taylor, 2011). In turn, these communities are able to provide a measure on the river's health (Chutter, 1998). The two bio-monitoring methods chosen for this study are diatoms and miniSASS.

Diatoms

Diatoms will respond quickly to degraded water quality which is reflected by changes in their biomass and taxonomic composition, in response to even a slight contamination and change in water chemistry (Harding & Taylor, 2011). Diatoms rapid responses to changes in the environment enables them to provide warning signs of increased pollution as well as indicate successful restoration interventions (Harding & Taylor, 2011). Diatoms are reliable indicators of water quality changes, as well as being able to detect eutrophication, organic pollution, metal pollution and acidification (Karthick *et al*., 2010). Thus, the diversity of diatoms in different population densities, overall abundance and composition, provides considerable ecological information of a water sources condition (Harding & Taylor, 2011).

The predictable changes of diatom species, based on their ecological tolerances, makes them a suitable indicator for monitoring fluctuations in water quality such as those found in urban catchments (Biggs, 1989). Since diatoms are able to provide an integrated reflection of water quality under almost any condition, they are suitable indicators of pollution levels in heavily impacted streams. Diatoms have been chosen as the preferred bio-indicators to use in monitoring the pollution gradients along the Stiebeuel River.

Two diatom indices were evaluated: the specific pollution index (SPI) and the calculation of the percentage pollution-tolerant valves (%PT), which forms part of the trophic diatom index, although is not considered to be an independent index (Holmes & Taylor, 2015). The SPI was successfully used in the Mooi River, North-West Province study (de la Rey *et al*., 2004), and the incorporation of the SADI (South African Diatom Index) into the SPI was effectively applied in the study conducted by Holmes & Taylor (2015) in the Great Fish River. According to Blanco & Becares (2010); Blanco *et al*. (2012) the SPI is the most inclusive of all the diatom indices and has been successfully applied worldwide.

miniSASS

miniSASS is a simple tool, based on the prevalence of macro-invertebrate species, to monitor and assess the health of a river (DWS, 2016). The method uses the species sensitivity of different macro-invertebrates to determine the water quality condition (DWS, 2016). Depending on the macro-invertebrate samples collected from the river, groups can be determined based on taxon levels and the general health and water quality of the stream can be derived (Graham *et al*., 2004). Changes in macro-invertebrate communities and consequent groups thus indicates changes in the overall river health condition (DWS, 2016). Macro-invertebrates are good indicators of localized changes in a river's condition over a short period of time

As macro-invertebrates require specific habitats, water quality, and flow conditions, for a considerable amount of their life cycles, sensitive species will disappear from a river system where these conditions have declined (DWS, 2016). miniSASS is based on a scoring system, where the higher the score, the more sensitive the species. Macro-invertebrate sampling was chosen because it is able to reflect the impact of changes on the physical habitat and ecological integrity of the direct environment. Macro-invertebrates have been identified as good indictors of recent events affecting water quality at a site.

miniSASS has also been widely tested and used as a bio-monitoring tool to assess water quality within South Africa (DWS, 2016). miniSASS results, are expressed as an index score (SASS score) and the average score per a recorded taxon (ASPT). These scores can be translated into a river health class (Graham *et al*., 2004). It is a well established, user friendly and cost effective bio-monitoring tool used to determine water quality (DWS, 2016).

Table 6: The table used to extrapolate the miniSASS score of each site into an ecological category.

	Ecological Category (Condition)	**River Category**	
		Sandy Type	Rocky Type
	Unmodified (Natural Condition)	>6.9	>7.9
	Largely natural/ few modifications (Good Condition)	5.8 to 6.9	6.8 to 7.9
	Moderately modified (Fair Condition)	4.9 to 5.8	6.1 to 6.8
	Largely modified (Poor Condition)	4.3 to 4.9	5.1 to 6.1
	Seriously/ Critically modified (Very poor Condition)	<4.3	<5.1

The simultaneous use of multiple bio-monitoring indicators, was used in this study to provide high confidence results of varying conditions.

Water Quality Parameters

The water quality parameters measured in this study include; temperature, pH, electrical conductivity (EC) and dissolved oxygen (DO). These parameters were specifically chosen to provide background information on the Stiebeuel River's water quality. Chapman and Kimstach (1996) note that Dissolved Oxygen, is a fundamental component of any water quality analyses, because of the significant role of oxygen in nearly all biological and chemical processes within water bodies. The measurement of DO, can be used to indicate the degree of pollution caused by organic matter, the level of self-purification of the water and the destruction of organic substances caused to the water source. Chapman and Kimstach (1996) further note the usefulness of EC in establishing a pollution zone and roughly indicating mineral content in a water body when other methods are unavailable. Low EC values, are representative of high-quality, low nutrient waters, while, high EC values are indicative of polluted sites and salinity problems (Heald, 2009).

Four water quality parameters were tested at each sampling site, in the Stiebeuel and Franschhoek Rivers, which included, temperature, pH, electrical conductivity and dissolved oxygen. pH was measured using a hand-held Martini pH55 meter, EC was measured using a hand-held Martini EC59 meter and DO was measured using a Milwaukee MW600 Smart DO Meter. The temperature reading was taken from the DO meter.

Field observations

Multiple field observations were conducted throughout the study. This involved walking and driving within the catchment and specifically along the Stiebeuel River. Numerous activities contributing to the deterioration of the environment and water quality were identified which included, dumping of litter and wastewater directly into the river and greywater flows from Langrug. Inflow pipes and the area surrounding these were also noted.

3.3 Water Quality testing

3.3.1 Data Collection

To determine how the distribution of diatom and macro-invertebrate species respond to improved habitat and water quality, a number of approaches and methods were used.

The baseline reference data was collected in September 2016, site preparation was in October 2017, planting of vegetation was in early November 2017 and final data collection was in mid-December 2017/early January 2018. Overall, this study examined the response of a river rehabilitation intervention over a short 1-2-month period. The selected short time-frame was to understand the rapid response of biodiversity, to return or enrich the Stiebeuel River, through identifying which species were first to recolonise the improved ecological and environmental conditions. In turn, the significant value of rehabilitating the riparian zone of a river to return habitat integrity, biological diversity and improved water quality conditions was demonstrated.

Diatom Sampling

Diatoms were collected using Taylor (2007a), well-established standard method. Five to ten cobbles from within the river bed were collected at 30m intervals along the Stiebeuel River. Additional samples were taken at the sampling points in the Franschhoek River. Each cobble was rinsed in the stream and the diatoms were removed by vigorously scrubbing the upper surface of the cobbles with a tooth brush into a container to dislodge the diatom community. Each diatom sample was decanted into a labelled test tube and taken to the 'Water Analysis Laboratory' at The University of Cape Town for analysis.

miniSASS Sampling

Macro-invertebrates were sampled using the standard method of a miniSASS assessment (Dickens & Graham, 2002). Disturbing the different in-stream habitats by stomping and kicking for roughly 5mins was done to displace the macro-organisms. At the same time, a net was held in the current to catch the dislodged organisms, and the net was then rinsed into a plastic tray. Stones were also lifted out of the current and organisms were placed in the tray for observation. Each group of organisms was then identified using the miniSASS identification guide and scored accordingly. The sensitivity scores were tabulated according to Table 6 ecological categories to determine the average score and relevant health class of the river.

River Rehabilitation

The rehabilitation focused on a 60m stretch of river, above the weir along the Stiebeuel River. The rehabilitation process firstly involved removing all alien invasive vegetation along the river banks. Terraces were then constructed along the river banks and reinforced with logs. Multiple rocks were then placed within the river bed to create habitat. Indigenous vegetation was planted along the terraces and river banks to reintroduce habitat and increase species biodiversity and life in the Stiebeuel River. The river rehabilitation was conducted over a short 6-week period to understand the rapid response of biodiversity, to return and enrich the ecological functioning of the Stiebeuel River.

Figure 11: The section of the Stiebeuel River that was rehabilitated and the sampling sites used to analysis the habitat restoration intervention.

Figure 12: The construction of the rehabilitated section of the Stiebeuel River.

Figure 13: The rocks and plants used to create habitat in the Stiebeuel River.

3.3.2 Laboratory Analysis

Laboratory analyses of diatom samples was conducted in the Water Analysis Laboratory in the Environmental and Geographical Science Department, at the University of Cape Town. Diatom slides were prepared by a standard laboratory technique adapted from Battarbee (1986). This method included the following steps:

Diatom analysis laboratory procedure

- A small quantity of sediment was decanted into labelled test tubes and washed in 20ml of 30% H_2O_2, while being heated in a water bath at 80°C. This step was repeated several times to ensure the complete removal of all organic matter.
- Samples were then diluted with distilled water, centrifuged and decanted in preparation for the next step.
- The samples were treated with 10% HCL , while being heated in a water bath at 80°C. This step was repeated several times to ensure the complete removal of all carbonates.
- The samples were swirled in a beaker to remove all clays and finer mineral matter.
- Following these steps, a final wash with distilled water was done.

Preparing the Slides

- A cover slip was gently heated on a hot plate and three drops of the prepared diatom solution was pipetted onto the clean cover slip. This was then diluted with three droplets of distilled water.
- The water in the solution was left to evaporate on a hot plate at a low temperature of ~40°C.
- Lastly, after all the water had evaporated, the coverslip was mounted onto the microscope slide using a 'resin of high refractive index', for this purpose Pleurax (R.I. = 1.73) was used.

Diatom identification and counting

A Carl Zeiss light microscope at a magnification of 1000x was used for diatom identification and counting. Frustule measurements were obtained using an eyepiece graticule. Taylor *et al*. (2007b), *An Illustrated Guide to Some Common Diatom Species from South Africa* was used to identify diatoms. Sample counts were of 300 valves per slide, which enabled a good representation of the diatom community without excessive repetition (Taylor *et al*., 2007a). Each valve was counted as one unit, and the diatom counts were recorded on an excel spreadsheet before being added into an Omnidia database.

Statistical analysis

Species abundance was calculated using Omnidia v. 5.3 (Lecointe *et al*., 1993) and relative abundance was calculated. Omnidia software was used to tabulate and sort each diatom sample set and enabled the quick assimilation of diatom data and index calculations. Indices used in this study include, the specific pollution sensitivity index (SPI, incorporating the SADI), and the percentage pollution tolerant valves (%PT) which reflects organic pollution and forms part of the UK trophic diatom index (TDI) (Kelly & Whitton, 1995). The South African diatom index (SADI) is a modified version of the specific pollution sensitivity index (SPI), which includes South African endemic species (Harding & Taylor, 2011). The SPI has the highest inclusion rate of taxa of all the indices, with salinity, toxins, organic pollution and eutrophication all being taken into account. The index is calculated using the Zelinka and Marvan (1961) weighted average formula, which is based on two scores; the tolerance score and sensitivity score of the sample which is weighted by the abundance (Taylor *et al.*, 2007c). This index is scored between a range of 0-20, where scores bearing towards 0 indicate increasing levels of pollution or eutrophication. These scores are further used to determine the ecological category and corresponding class of the river (see Table 7). The %PT index has a maximum value of 100, where any value above 20 indicates an increase in organic pollution (Kelly & Whitton, 1995). The %PT is based on the trophic diatom index, which is used to monitor eutrophication in rivers (Kelly & Whitton, 1995).

Table 7: Interpretation of diatom index scores (Eloranta & Soininen, 2002).

Index Score (SPI score)	Ecological Category	Class
>17	A	High quality
14-17	B	Good quality
10-14	C	Moderate quality
6-10	D	Poor quality
<6	E/F	Bad quality

3.4 Data Analysis

Data analyses were conducted to establish the relationship between diatoms and macro-invertebrate responses to improved habitat and water quality conditions.

(i) Descriptive statistics including tables, graphs and diagrams were used to examine water quality and habitat integrity.

- Tilia, was used to analysis the diatom species distribution, on an absence/presence basis across the sampled sites. Through this the water quality category of each site was determined.
- miniSASS scores were tabulated in accordance to the corresponding ecological category.

(ii) Pearson correlation analysis using Stastica 12, between diatom index scores, and water quality parameters, to examine the degree to which the variables are associated.

Through this, the value of the three different types of bio-assessment methodologies in informing rehabilitation of a river system can be assessed. The link between methods as well as the use of a combination of methods, or use of a single method to inform ecological integrity of habitat restoration will be derived.

CHAPTER FOUR: RESULTS

The results chapter is separated into two main parts that analyse the condition of the Stiebeuel and Franschhoek Rivers through three main monitoring methods namely; diatoms, miniSASS and water quality assessments. The first section includes the baseline data set that examines the health of the Stiebeuel River and Franschhoek River. The second section examines the effect of the river rehabilitation intervention on the Stiebeuel River. The two sections are each divided into 3 subsections that correspond to the water quality monitoring methods used.

Section 1: Baseline Data of the Stiebeuel & Franschhoek Rivers

4.1 Diatom Community Composition

4.1.1 Stiebeuel River

A total of 79 diatom taxa belonging to 30 genera were identified in the Stiebeuel River and Franschhoek River sites within the Water Hub boundary, excluding 34 diatoms which were not identified. The Stiebeuel River is dominated by pollutant tolerant diatoms that range from tolerating slight pollution to critical pollution (90%). Most of these species are tolerant of high pollution (17.9%) and critical pollution (69.2%) levels.

Diatom data is presented in figure 14, a Tilia diagram showing diatom species pollution tolerance based on Taylor *et al*. (2007b) literature. *Gomphonema parvulum* has the highest relative abundance of 55.2% across all sites excluding sample site Sb1 and site Fr20. Within the ecological category; critical pollution, *Tabularia fasciculate* was the next most common species and was found relatively abundantly between sites Sb3 to site Sb19. In the ecological category high pollution, *Nitzschia palea* and *Navicula gregaria* were the most prominent species in all sites excluding site Sb1 and site Fr20. Site Sb1 and site Fr20, ecological category's, ranged from clean water to moderate pollution. Site Sb1, the reference site above Langrug informal settlement was dominated by diatom species that are signatures of clean water conditions as well as numerous cosmopolitan species. At this site, diatoms tolerating slight pollution were also recorded. Site Fr20, sampled in the Franschhoek River, 5m above the confluence with the Stiebeuel River, was dominated by diatoms that reflect moderate pollution. At both site Sb1 and site Fr20, no diatoms tolerant of pollution were present.

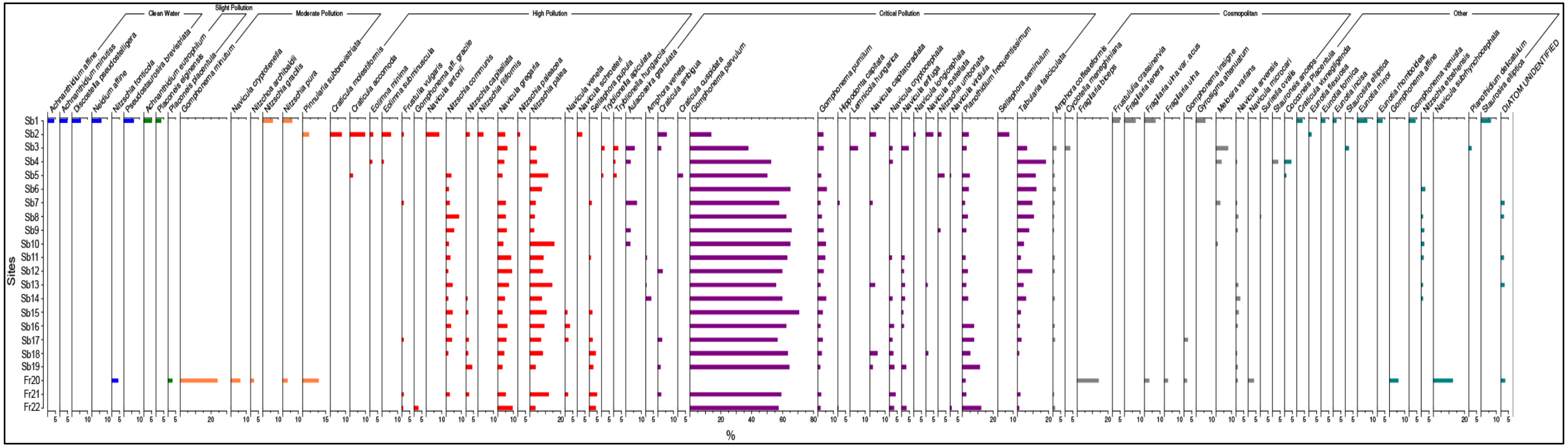

Figure 14: Stiebeuel River diatom species distribution on an absence/ presence basis (Taylor *et al*., 2007b).

The Tilia diagram has been grouped according to diatom species water quality tolerances. Species that do not have a defined water quality preference were further grouped as cosmopolitan species, or other, based on their distribution and ecology defined by Taylor *et al*. (2007b).

4.1.2 Stiebeuel River's water quality

Figure 15 shows the percentage presence of diatom taxa, grouped in tolerance categories at sites over the duration of the study (Septermber 2016 –January 2018). The graph shows a general trend of the Stiebeuel River's water quality to be extremely polluted and in a critical condition. Site Sb1, above Langrug informal settlement and Site Fr20, in the Franschhoek River, 5m above the confluence with the Stiebeuel River, however is in a good condition, with an ecological amplitude ranging from clean water to moderate pollution. Site Fr20, is significant because it shows the condition of the Franschhoek River which is a reliable reference of a natural functioning river in the area. Site Fr21, at the confluence of the Stiebeuel and Franschhoek River and site Fr22, 5m below the confluence with the Stiebeuel River, shows the degree of deterioration caused to the Franschhoek River from the inflow of highly polluted water from the Stiebeuel River. As a result, the water quality at site Fr21 and Fr22 is extremely polluted and the natural functioning of the Franschhoek River has been critically modified. Figure 16 and Figure 17, shows the extent of change in the condition of the Franschhoek River over a distance of 10m.

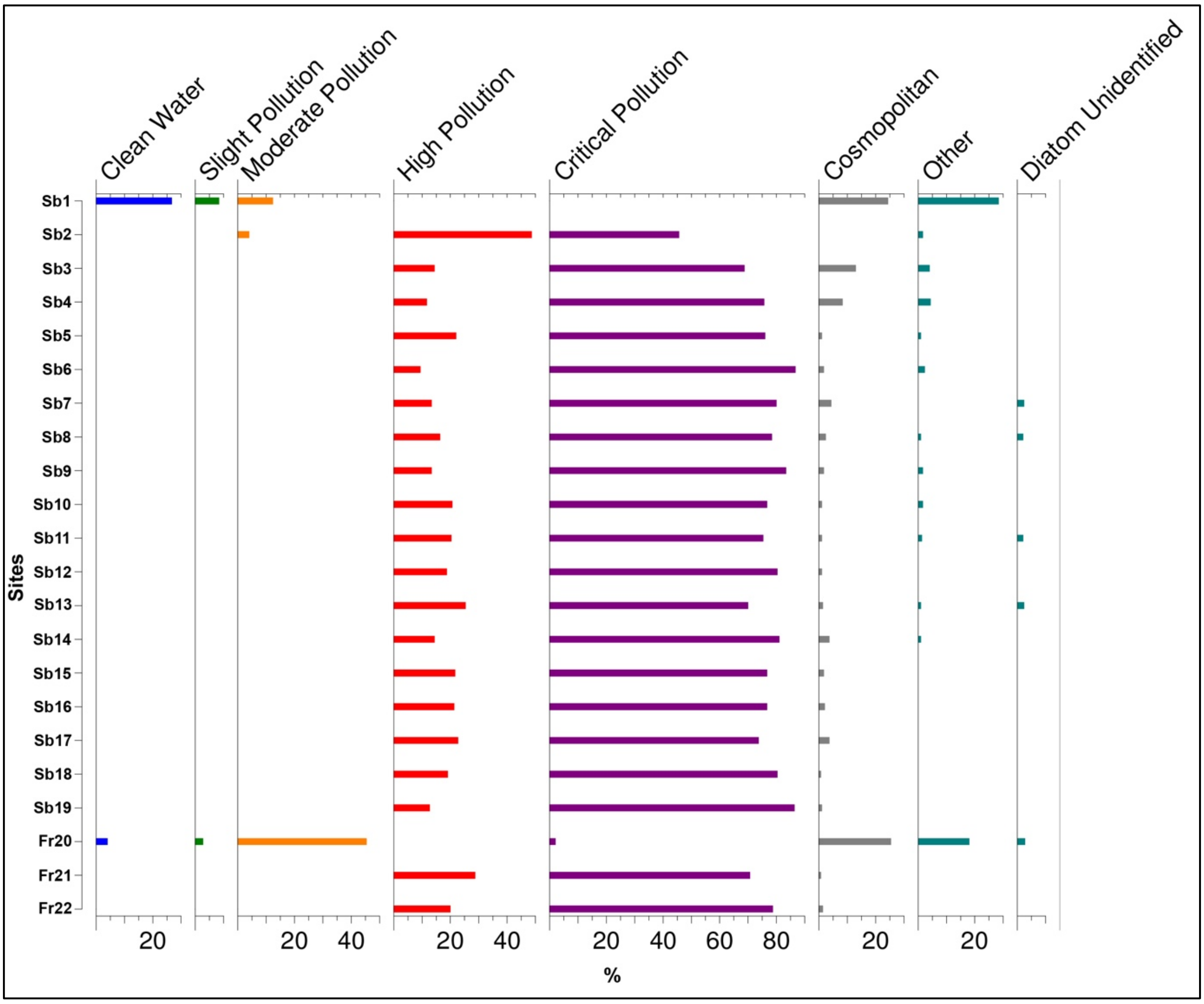

Figure 15: Stiebeuel River's water quality condition at each site.

10m apart

Figure 16: Site Fr20 in the Franschhoek River.

Figure 17: Site Fr22 in the Franschhoek River.

4.1.3 Franschhoek Diatom Community Composition

A total of 58 diatom taxa belonging to 24 genera, were identified in the Franschhoek River excluding 17 diatoms which were not identified. Most of the species were cosmopolitan (38%) and their ecological condition ranged from tolerating clean water to moderate pollution. The overall diatom species distribution was scattered, however, *Navicula rhynchocephala* was the most prominent clean diatom species, *Gomphonema minutum* was the dominant moderate pollution signature species, while *Fragilaria biceps* had the highest overall abundance. There were no pollution tolerant diatom species present in the Franschhoek River.

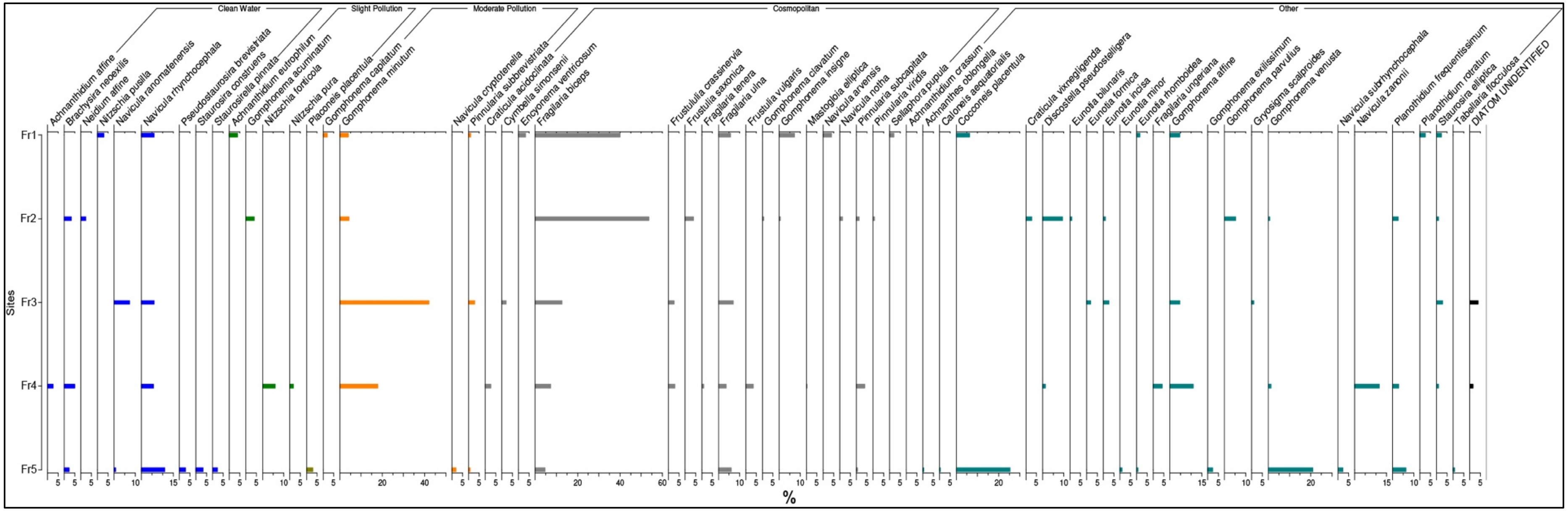

Figure 18: Franschhoek River diatom species distribution on an absence/ presence basis (Taylor *et al*., 2007b).

4.1.4 Franschhoek River's water quality

Figure 19 shows the distribution of water quality across the length of the Franschhoek River based on the accumulative abundance of the diatom species' ecological category. The graph shows the general trend of the Franschhoek River's water quality to be in a good condition. The ecological categories range from species tolerant of clean water to moderate levels of pollution. There is no evidence of high nor critical pollution present. Overall the Franschhoek River reveals the condition of a naturally functioning river.

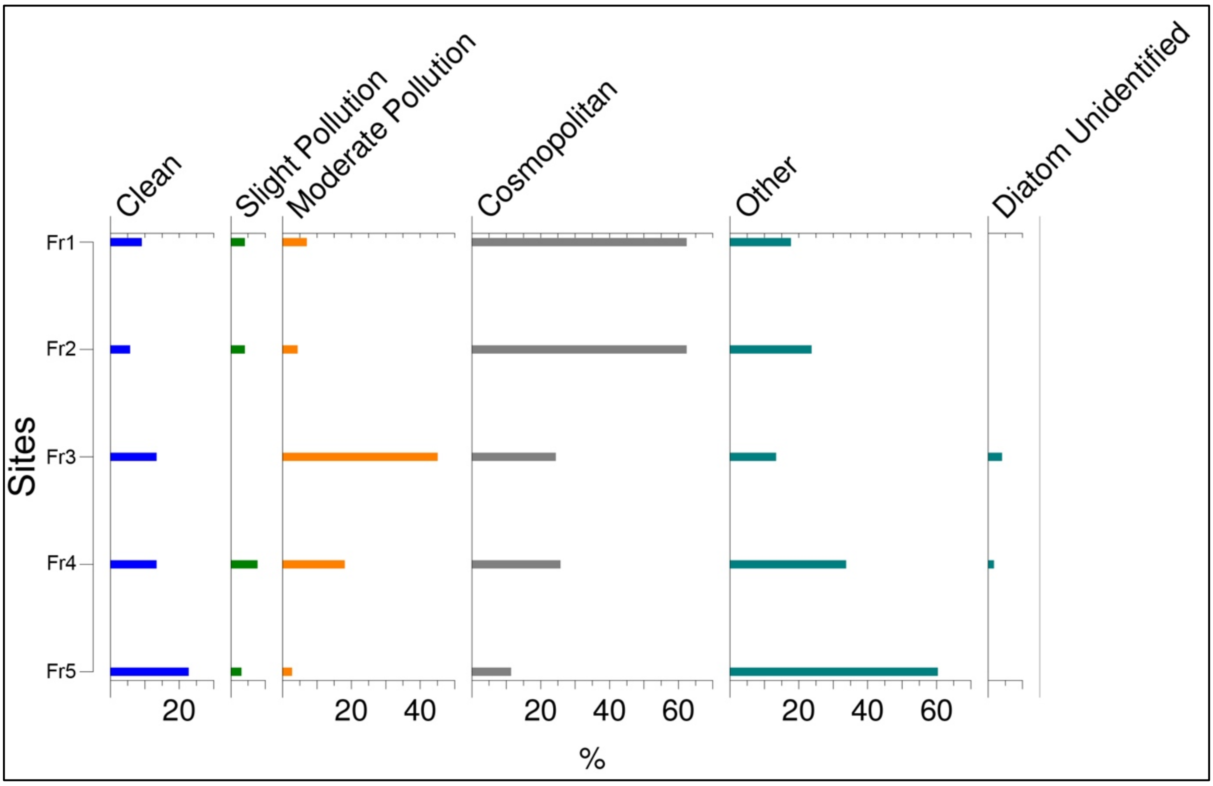

Figure 19: Franschhoek River's water quality condition at each site.

4.2 Diatom index evaluations

4.2.1 Stiebeuel River

The specific pollution index (SPI) scores, ecological category and corresponding water class for each site are presented in table 8. The SPI scores show, that the general trend of the Stiebeuel River's water quality is very poor. Site Sb2 to site Fr22, with the exception of site Fr20, all have low SPI scores, that range between 4.5 and 7.5. These low scores infer the ecological category to be between D and E/F, with poor to bad water quality. This stretch of the river is highly to critically modified and is in a very poor condition. Site Sb1, above Langrug informal settlement, has a high SPI score of 15. Its ecological category is scored as B, with good quality water. This site is largely natural, with few modifications and is in a good condition. Site Fr20, in the Franschhoek River, 5m above the confluence with the Stiebeuel River has a relatively high SPI score of 13.3, with a C ecological category and moderate water quality. At this site the river has been moderately modified and is in a fair condition. Overall the Stiebeuel River is extremely polluted and has become severely degraded.

Table 8: Stiebeuel River specific pollution index (SPI) scores, converted to show the river's water quality and ecological condition.

Site	SPI	Ecological Category	Water Quality Class
Sb1	15	B	Good quality
Sb2	7.5	D	Poor quality
Sb3	7.1	D	Poor quality
Sb4	7.2	D	Poor quality
Sb5	5.0	E/F	Bad quality
Sb6	5.5	E/F	Bad quality
Sb7	6.5	D	Poor quality
Sb8	5.2	E/F	Bad quality
Sb9	5.6	E/F	Bad quality
Sb10	4.8	E/F	Bad quality
Sb11	5.6	E/F	Bad quality
Sb12	6.0	D	Poor quality
Sb13	4.9	E/F	Bad quality
Sb14	5.3	E/F	Bad quality
Sb15	4.5	E/F	Bad quality
Sb16	4.9	E/F	Bad quality
Sb17	6.1	D	Poor quality
Sb18	5.9	E	Bad quality

Sb19	6.2	D	Poor quality
Fr20	13.3	C	Moderate quality
Fr21	5.1	E/F	Bad quality
Fr22	7.4	D	Poor quality

4.2.2 Franschhoek River

The SPI scores of the Franschhoek River shows the river is in a good condition, and is fairly natural with few modifications. The SPI scores are high and range from 12.5 to 15.7. These scores classify the river with a B or C, ecological category, that has moderate to good quality water. Site Fr5 is 2km downstream from the confluence with the Stiebeuel River, has a relatively high SPI score of 14.6, and shows that the river has recovered from the inflow of highly polluted water, and maintains a moderate condition.

Table 9: Franschhoek River specific pollution index (SPI) scores converted to show the river's water quality and ecological condition.

Site	SPI	Ecological Category	Water Quality Class
Fr1	15.7	B	Good Quality
Fr2	14	C	Moderate quality
Fr3	12.5	C	Moderate quality
Fr4	15.7	B	Good quality
Fr5	14.6	B/C	Moderate quality

4.2.3 SPI and %PT indices comparison in the Stiebeuel River.

Figure 20 shows the distribution of pollution across the length of the Stiebeuel River. Of the 22 sites sampled, only 2 sites (site Sb1 and site Fr20) scored below 20% for %PT, indicating that the Stiebeuel River is dominated by pollution tolerant diatom species and there are significant sources of organic pollution within the catchment. Figure 20 compares %PT to SPI, and shows a correlation in the decrease of SPI scores, where the %PT was high. The high organic content implies that the Stiebeuel River receives a discharge of highly polluted, untreated 'sewage' runoff from the informal settlement.

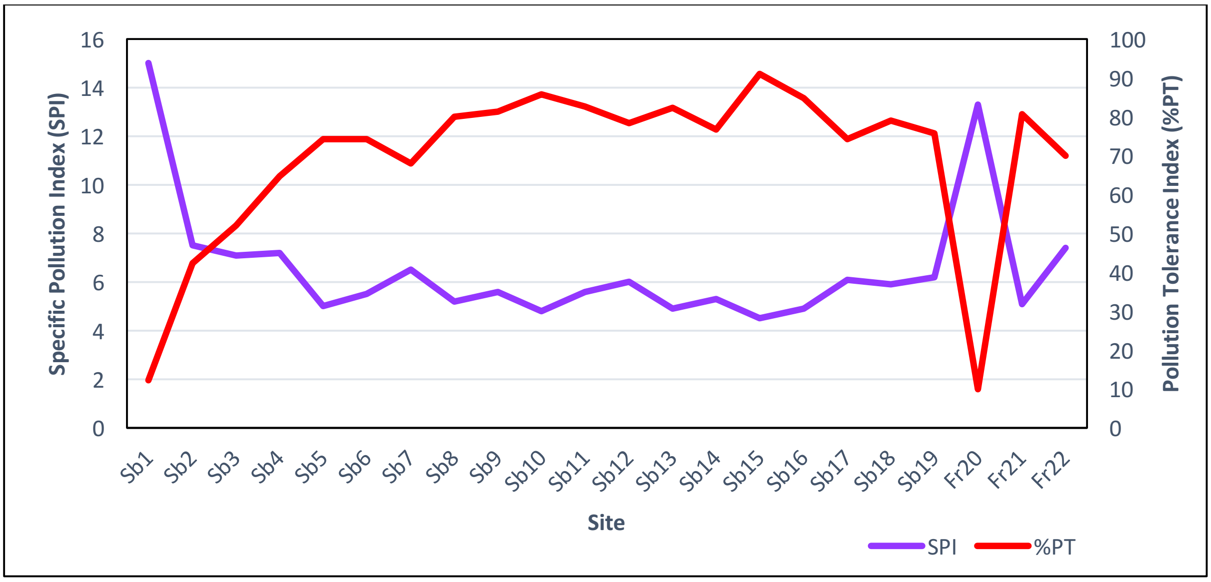

Figure 20: The distribution of SPI and %PT index scores across the length of the Stiebeuel River.

4.3 miniSASS

4.3.1 Stiebeuel River

The miniSASS scores correspond to the SPI scores and confirm the health of the Stiebeuel River to be very poor. Site Sb2 to site Fr22, excluding site Fr20, have low sensitivity scores that range from 2 to 5.3. These sites are in a poor to very poor condition, suggesting that the Stiebeuel River's ecological habitat has been severely altered. Site Sb1, above the informal settlement has a high sensitivity score of 7.2 and is in a good condition. Similarly, site Fr20, in the Franschhoek River above the confluence with the Stiebeuel River also has a high sensitivity score of 6.5 and is in a good condition. The inflow of highly polluted water from the informal settlement is responsible for seriously decreasing the biological diversity and habitat integrity of the Stiebeuel River.

Table 10: miniSASS results showing the ecological condition/health of the Stiebeuel River.

Site	Sensitivity Score	Ecological Category/Condition
Sb1	7.2	Good condition
Sb2	5.3	Poor condition
Sb3	3.2	Very poor condition
Sb4	4.6	Very poor condition
Sb5	5.3	Poor condition
Sb6	3	Very poor condition
Sb7	2.5	Very poor condition
Sb8	4.3	Very poor condition
Sb9	4	Very poor condition
Sb10	2.6	Very poor condition
Sb11	2.5	Very poor condition
Sb12	3.2	Very poor condition
Sb13	4.4	Very poor condition
Sb14	4.6	Very poor condition
Sb15	4.6	Very poor condition
Sb16	4.5	Very poor condition
Sb17	2	Very poor condition
Sb18	5.3	Poor condition
Sb19	3.3	Very poor condition
Fr20	6.5	Good condition
Fr21	4	Very poor condition
Fr22	3.5	Very poor condition

4.3.2 Franschhoek River

The miniSASS scores of the Franschhoek River indicate that the river is in a fair to good condition. The sensitivity scores range from 5.8 to 6.2, and infer that the Franschhoek River is largely natural with few modifications. Under these conditions, the biological diversity and habitat integrity of the river is maintained.

Table 11: miniSASS results showing the ecological condition/health of the Franschhoek River.

Site	Sensitivity Score	Ecological Category/Condition
Fr1	5.8	Fair condition
Fr2	6.2	Good condition
Fr3	5.8	Fair condition
Fr4	6.1	Fair condition
Fr5	6.6	Good Condition

4.4 Correlation Analysis

4.4.1 Stiebeuel River

Pairwise correlations were estimated between each water quality parameter and the SPI and %PT scores. Table 12, shows that dissolved oxygen (DO) and electrical conductivity (EC) correlation coefficients are found to be significantly different from zero, which is indicated in the footnote.

4.4.2 The Specific Pollution Index (SPI)

Correlation analysis illustrated a significant positive correlation between DO and SPI, showing, that as DO concentrations increase, the SPI score tends to increase. Whereas correlation analysis between EC and SPI illustrated a significant negative correlation. This shows that as EC values decreased, the value of the SPI increased, indicating improved water quality conditions.

The correlation coefficient estimates do not indicate a causal link between DO or EC with SPI, such that, it cannot be assumed that an increase in DO will result in increased SPI values; or a decrease in EC will result in higher SPI scores. However, in this case a causal link does seem plausible, because a high DO and/or low EC value is indicative of cleaner water, such that, it would be expected for the SPI values to be high. Given this, the higher the DO value and lower the EC value, the higher the SPI score, and the cleaner the water quality of the river.

The correlation coefficients in table 12, differ in size, but are not near to 1 or -1. DO and EC values do not fully explain the variations in SPI scores along the Stiebeuel River. It is evident that other factors also contribute to changes in diatom species distribution. The correlation coefficient of 0.54 and -0.59, indicates the proportion of SPI variation that is explained by DO and EC respectively.

4.4.3 Percentage pollution-tolerant (%PT)

Pairwise correlations were estimated between each water quality parameter and the %PT value.

Correlation analysis illustrated a significant negative correlation between DO and %PT, showing that as DO decreases so pollution tolerant diatom species increase. Whereas the correlation analysis results for EC and %PT showed a significantly positive correlation. This implies that as the EC values increase, the %PT value also increased, indicating the presence of pollutant tolerant diatom species and poor water quality.

The correlation coefficient also does not suggest a causal link between DO or EC and %PT values. However, in this case it does seem plausible to predict that there is a relationship between DO and EC with %PT, because a low DO value and a high EC value indicates poor water quality, such that the lower the DO value and the higher the EC, the higher the %PT, and the poorer the water quality.

The correlation coefficients in table 12 differ in size but are not near to 1 or -1. DO and EC values do not fully explain the variations in SPI scores along the Stiebeuel River. It is evident that other factors also contribute to changes in diatom species distribution. The correlation coefficient of 0.54 and -0.59, indicates the proportion of SPI variation that is explained by DO and EC respectively. While the correlation coefficient of -0.54 and 0.57, indicates the proportion of %PT variation that is explained by DO and EC respectively.

Overall only two of the physical parameters showed significant correlations with the diatom indices.

Table 12: Correlation coefficients, between water quality parameters and diatom indices in the Stiebeuel River.

	pH	Temp (°C)	DO (mg/l)	EC (µS/cm)
SPI	-0,19261	0,12277	**0,539633**	**-0,592082**
%PT	0,168833	-0,221549176	**-0,539536457**	**0,574223473**
Significance at 0.05 probability level				

4.4.4 Franschhoek River

The relationship between all the water quality parameters and diatom indices were insignificant.

Table 13: Correlation coefficients, between water quality parameters and diatom indices in the Franschhoek River.

	pH	Temp (°C)	DO (mg/l)	EC (µS/cm)
SPI	-0,3134132	0,38278067	-0,2385386	-0,1967509
%PTV	0,2964	-0,6784447	0,34168701	-0,0526995
Significant at 0.05 probability level				

Section 2: Stiebeuel River rehabilitation intervention.

Sampling sites; Sb3, Sb10, Sb15, Fr20 and Fr22, correspond to the original sampling sites taken in the Water Hub boundary, along, the Stiebeuel River and Franschhoek River. Sampling sites Rsb1 to Rsb5 incorporates the section of the Stiebeuel River that was rehabilitated.

Note: A burst sewer pipe from Langrug informal settlement leaked into the Stiebeuel River before the final data collection was taken. As diatom communities respond rapidly to changes in water quality, it is plausible that the inflow of raw sewage may have skewed the results.

4.6 Diatom Community Composition

A total of 50 diatom taxa belonging to 22 genera were identified at the final data collection sampling sites, excluding 33 diatoms which were not identified. The Stiebeuel River is dominated by pollutant tolerant diatom species that range from tolerating slight pollution to critical pollution (75%). Most of these species are tolerant of high pollution (29.7%) and critical pollution (39.4%). *Gomphonema parvulum,* has the highest relative abundance of 32.8% across all the sites. It is classified as tolerating critical levels of pollution and its ecology can be defined as “a cosmopolitan species that is very widespread in a range of waters, from small pools to lakes and rivers and generally considered to be tolerant of extremely polluted conditions” (Taylor *et al*., 2007b: 122). Within the ecological category critical pollution, *Planothidium frequentissimum,* was the next most common species in all sites excluding sites Rsb1 to Rsb5. *Planothidium frequentissimum,* is a “common species in standing and flowing, circumneutral to alkaline waters with a moderate to high electrolyte content and is capable of tolerating critically polluted conditions” (Taylor *et al*., 2007b: 29). The remainder of diatom species tolerant of critical pollution have a scattered distribution across the sites excluding site Fr20. In the ecological category high pollution, *Craticula molestiformis,* was the most prominent species in all sites excluding site Rsb4 and Fr20. *Nitzschia palea,* was the next most common high pollutant tolerant species in all sites excluding site Fr20. It is “a cosmopolitan and very commonly occurring species found in eutrophic and very heavily polluted to extremely polluted waters with moderate to high electrolyte content” (Taylor *et al*., 2007b: 156). Other prominent species tolerant of high levels of pollution, include, *Eolimna* *subminuscula*, *Craticula accomda, Navicula gragaria* and *Sellaphora pupula*. These, are all cosmopolitan species, common in electrolyte rich, strongly polluted rivers. Further more, *Craticula accomda,* is found in strongly organically polluted waters, in particular effluent from sewage treatment works (Taylor *et al*., 2007b: 48). These species were found relatively abundantly in all sites excluding site Fr20. In the ecological category, slight pollution, *Nitzschia fonticola,* is the most common species found at sites Rsb1, Rsb3, Rsb4 and Fr20. Its ecology is defined as “a cosmopolitan species in waters with moderate to high electrolyte content, found in slightly or moderately polluted conditions” (Taylor *et al*., 2007b: 162). Site Fr20 sampled in the Franschhoek River, 5m above the confluence with the Stiebeuel River was dominated by diatoms that reflect moderate pollution despite the graph showing a high presence of *Gomphonema parvulum*. While within the cosmopolitan category, *Cyclotella meneghiniana*, a taxon typically distributed in the benthos and plankton of eutrophic, electrolyte rich rivers were the most prominent species (Taylor *et al*., 2007b: 4). Most other cosmopolitan taxon are all commonly found in electrolyte rich waters.

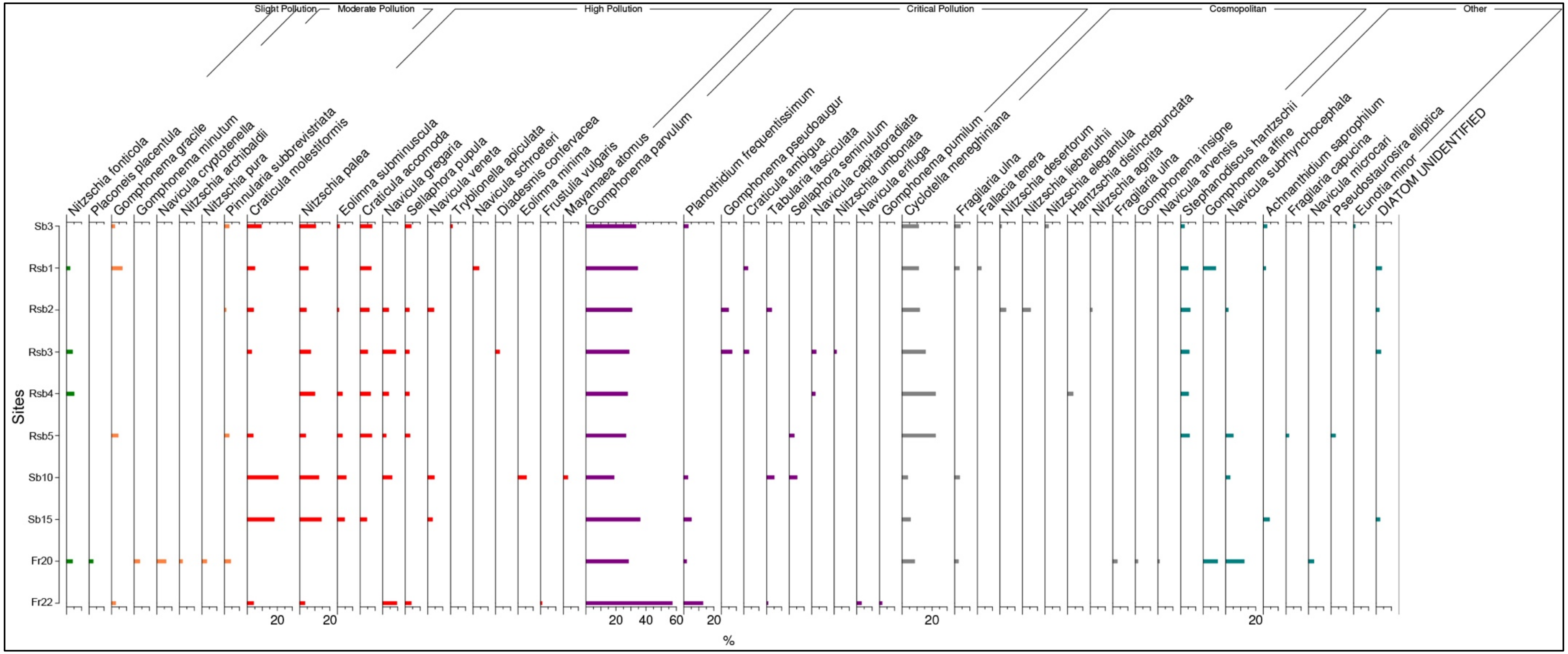

Figure 21: The rehabilitated section of the Stiebeuel River diatom species distribution, on an absence/ presence basis (Taylor *et al*., 2007b).

4.6.1 Stiebeuel River's water quality

Figure 22 shows the percentage presence of diatom taxa grouped in tolerance categories at sites over the duration of the study (September 2016-Janurary, 2018). The graph shows the general trend of the Stiebeuel River's water quality is highly to critically polluted and in a very poor condition. Between, sites Rsb1 to Rsb5, there is a relatively small improvement in water quality, with the reintroduction of diatom species that are tolerant of slight to moderate pollution. Site Fr20 water quality, is in a good condition with no high pollutant tolerant diatom species present. Despite the distribution of species reflecting a large portion of critically polluted water at site Fr20, this is due to the high abundance of *Gomphonema parvulum,* a species which has been categorized as tolerating critical pollution for the purpose of this study, yet, can also be found in a wide range of waters. Site Fr22, in the Franschhoek River, 5m below the confluence with the Stiebeuel River shows the extent of contamination caused to this naturally functioning river from the inflow of highly polluted water from the Stiebeuel River. As a result, site Fr22 water quality is critically polluted and in a very poor condition.

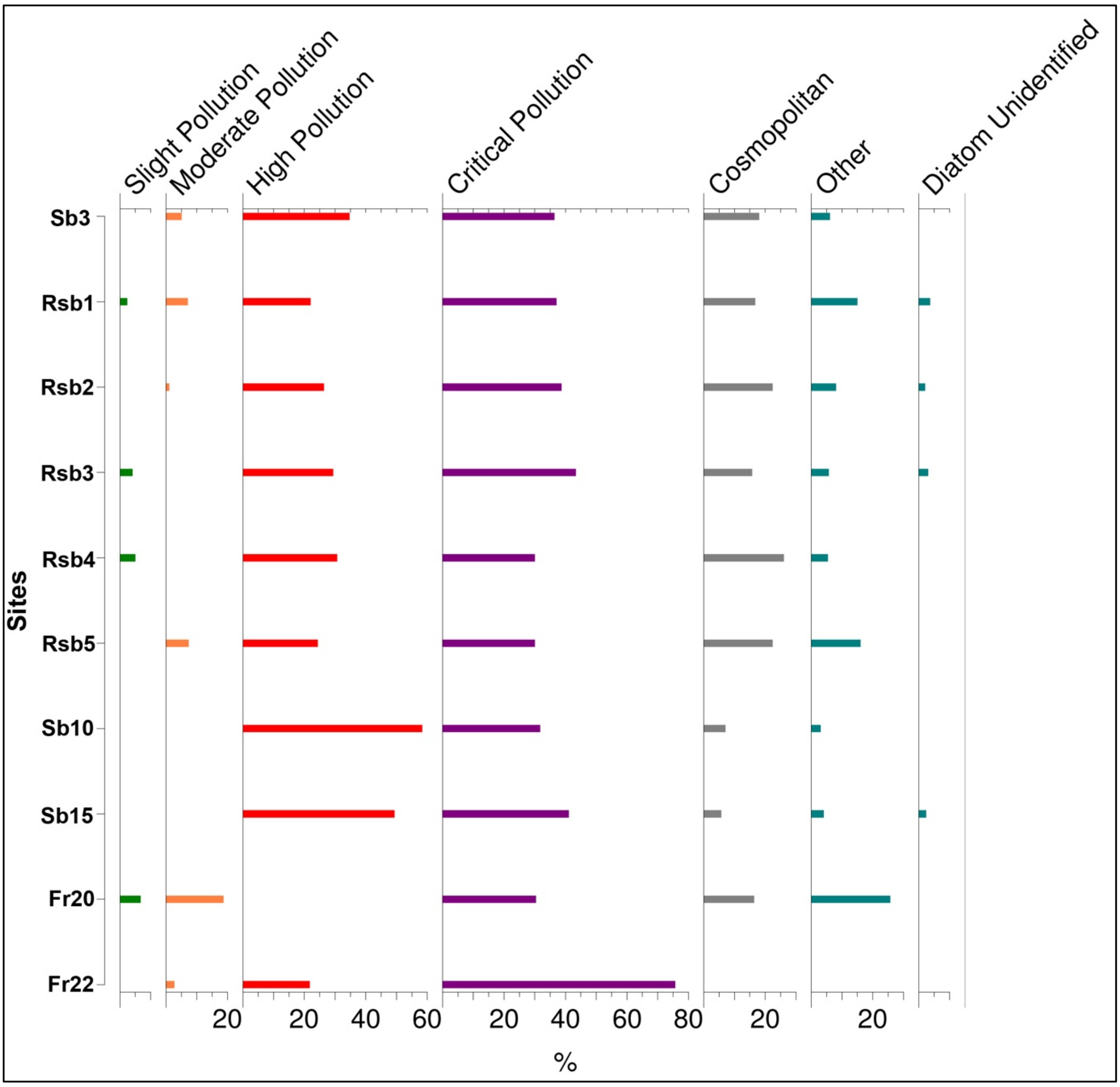

Figure 22: Stiebeuel River's water quality condition at each site in the rehabilitated section and Water Hub boundary.

4.7 Diatom index evaluations

The specific pollution index (SPI) scores, ecological category and corresponding water class for each site are presented in Table 14. The SPI scores, shows that the Stiebeuel River is highly polluted with very poor water quality. All of the sites, with the exception of site Fr20, have low SPI scores that range between 3.8 to 7.5. These low scores infer the ecological category to be between D and E/F, with poor to bad water quality. At these sites, the river is highly to critically modified and in a very poor condition. Site Fr20, in the Franschhoek River, 5m above the confluence with the Stiebeuel River has a relatively high SPI score of 11.3. At this site the Franschhoek River has a C ecological category, with moderate water quality. It appears that the river has been moderately modified and is in a fair condition. Overall the Stiebeuel River remains highly polluted and critically degraded.

Table 14: The rehabilitated section of the Stiebeuel River and additional Water Hub sampled sites, specific pollution index (SPI) scores, converted to show the rivers' water quality and ecological condition.

Site	SPI	Ecological Category	Water Quality Class
Sb3	4.5	D	Poor quality
Rsb1	7.5	D	Poor quality
Rsb2	5.2	E/F	Bad quality
Rsb3	6	D	Poor quality
Rsb4	5.1	E/F	Bad quality
Rsb5	5.9	E/F	Bad quality
Sb10	5	E/F	Bad quality
Sb15	3.8	E/F	Bad quality
Fr20	11.3	C	Moderate quality
Fr22	7.3	D	Poor quality

4.7.1 SPI and %PT indices comparison in the Stiebeuel River and additional Water Hub sampling points.

Figure 23 shows the distribution of pollution across the Stiebeuel River and additional sampling points in the Franschhoek River within the Water Hub boundary. The pollution tolerant index (%PT), at all of the sampled sites have scores above 20%, indicating that the Stiebeuel River and site Fr22, are dominated by pollutant tolerant diatom species, and there are significant sources of organic pollution within the catchment. Site Fr20, has the lowest %PT score compared to the other sites, however it is still relatively high because of the abundance of *Gomphonema parvulum* present in the sample. Figure 23 compares %PT to SPI and shows a correlation in the decrease of SPI scores, where the %PT was high. The high organic content indicates that the Stiebeuel River still receives a discharge of highly polluted, untreated 'sewage' runoff from the informal settlement. It must be noted that the %PT values in the Stiebeuel River have reduced considerably from the baseline data set where most sites ranged from 65% to 92%, to the final data set ranging between 40% to 65%. However, these values are still considered high in terms of %PT. Overall there is an immense distribution of organic content and the Stiebeuel River remains heavily degraded.

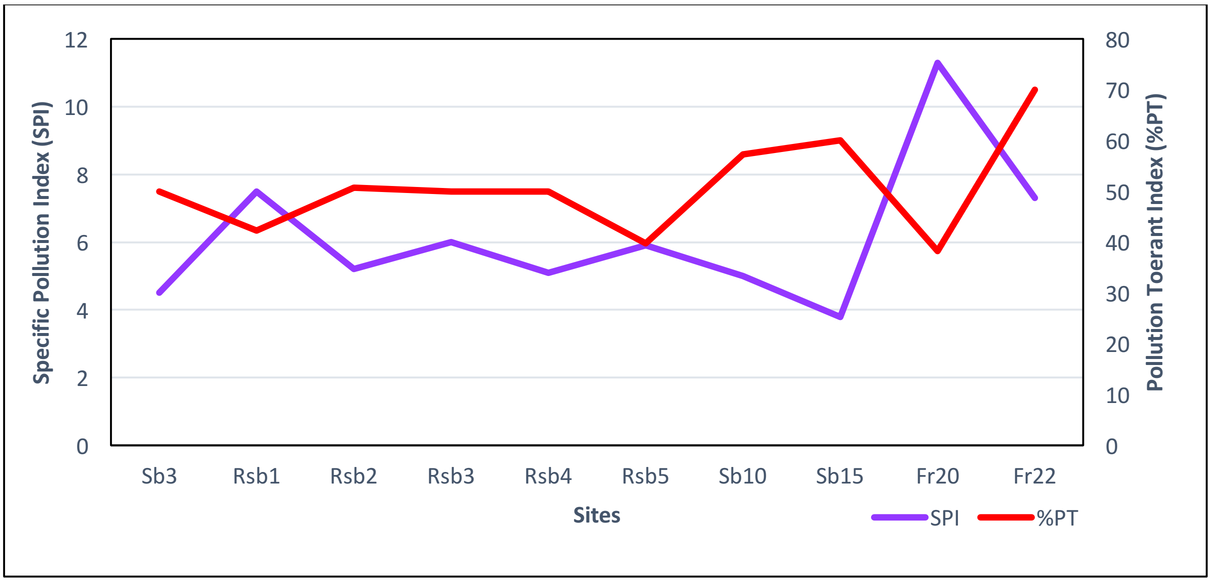

Figure 23: The distribution of SPI and %PT index scores across the length of the rehabilitated section of the Stiebeuel River and additional Water Hub sampling points.

4.8 miniSASS

The miniSASS scores correspond to the SPI scores, and confirm the health of the Stiebeuel River to be very poor. All of the sites, excluding site Fr20, have low sensitivity scores that range from 3.67 to 4.8. These low scores rank the health of the Stiebeuel River and site Fr20, to be in a very poor condition and critically modified. Site Fr20, in the Franschhoek River, 5m above the confluence with the Stiebeuel River has a relatively high sensitivity score of 5.8, and is in a fair condition with some modifications. The results infer that the inflow of highly contaminated water from Langrug, informal settlement, has had a negative impact on the health of the Stiebeuel River, which has altered the ecological corridor and decreased habitat integrity and species biodiversity.

Table 15: miniSASS results showing the ecological condition/health of the rehabilitated section of the Stiebeuel River and additional Water Hub sampling points.

Site	Sensitivity Score	Ecological Category/Condition
Sb3	3.67	Very poor condition
Rsb1	4	Very poor condition
Rsb2	4.25	Very poor condition
Rsb3	4	Very poor condition
Rsb4	5	Very poor condition
Rsb5	4.25	Very poor condition
Sb10	4	Very poor condition
Sb15	3.7	Very poor condition
Fr20	5.8	Fair condition
Fr22	4.8	Very poor condition

4.9 Correlation Analysis

Pairwise correlations were estimated between each water quality parameter and the SPI and %PT scores. Table 16 shows that pH, DO and EC correlation coefficients are found to be significantly different from zero, which is indicated in the footnote.

4.9.1 The Specific Pollution Index (SPI)

Correlation analysis, reveal a significant positive correlation between DO and pH and SPI, illustrating that, as DO and pH concentrations increase, the SPI score tends to increase, inferring better-quality water. Whereas, correlation analysis between EC and SPI showed a significant negative correlation. This shows that, as EC values decreased, the value of the SPI increased, indicating improved water quality conditions.

It must be noted, that, the correlation coefficient estimates do not indicate a causal link between DO, EC or pH with SPI, such that, it cannot be assumed, that an increase in DO and pH will result in increased SPI values; or a decrease in EC, will result in higher SPI scores. However, in this case, a causal-link does seem possible between, DO and EC, because a high

DO and/or low EC, is indicative of cleaner water, such that it would be expected for the SPI scores to be high.

The correlation coefficients in Table 16, differ in size but are not near to 1 or -1. Thus the DO, EC and pH values do not fully explain the variations in SPI scores along the Stiebeuel River. It is evident, that other factors also contribute to changes in diatom species distribution. The correlation coefficient, of -0.23, 0.79, and -0.86 indicates the proportion of SPI variation that is explained by pH, DO, EC respectively.

4.9.2 Pollution Tolerance Index (%PT)

The relationship between all the water quality parameters and %PT were insignificant.

Table 16: Correlation coefficients between water quality parameters and diatom indices in the rehabilitated section of the Stiebeuel River and additional Water Hub sampling points.

	pH	**Temp (°C)**	**DO (mg/l)**	**EC (µS/cm)**
SPI	-0.2477557	0.14052878	0.78692764	-0.8593383
%PT	-0.1541199	-0.0251695	-0.155439	0.16037367
Significance at 0.05 probability level				

The results from both section 1 and section 2 verify that the three methods used to monitor river health are largely integrated. The overlap in diatom, miniSASS and water quality monitoring methods strengthens the results and confirms the health of the Stiebeuel River to be in a critical condition. It is clear that the main factor responsible for the complete degradation of the Stiebeuel River system, is the inflow of highly polluted water from Langrug, informal settlement. Water quality is thus the key driver of species distribution in the Stiebeuel River. The continuous, daily discharge, of highly contaminated water from Langrug, is therefore the reason for the high abundance of pollutant tolerant diatom species, decreased biodiversity and degraded habitat in the Stiebeuel River.

CHAPTER FIVE: DISCUSSION

5.1 Diatom Community Composition

Stiebeuel River community composition

The Stiebeuel River diatom community composition was dominated by *Gomphonema parvulum.* This species had the highest relative abundance across all sites excluding sample site Sb1 and site Fr20, and can be defined as “a cosmopolitan species that is very widespread in a range of waters, from small pools to lakes and rivers and generally considered to be tolerant of extremely polluted conditions” (Taylor *et al*., 2007b: 122). Within the ecological category; critical pollution, *Tabularia fasciculate* was the next most common species. According to Taylor *et al*. (2007b), *Tabularia fasciculate* is a cosmopolitan species with a broad ecological amplitude that appears to favour moderately to high electrolyte concentrations, and has been reported from critically polluted industrial wastewater (Taylor *et al*., 2007b: 19). In the ecological category high pollution, *Nitzschia palea* and *Navicula gregaria* were the most prominent species in all sites excluding site Sb1 and site Fr20. These are both cosmopolitan species that are good indicator species of strongly polluted conditions (Taylor *et al*., 2007b).

Most of the species identified in this study were pollution tolerant. Of these *Gomphonema parvulum,* had the highest overall abundance and was the dominant species tolerant of critical pollution, while *Nitzschia palea,* was the dominant species tolerant of high pollution levels. *Gomphonema parvulum* is described, as being tolerant of extremely polluted conditions and is found in a widespread range of waters (Salomoni *et al*., 2006; Taylor *et al*., 2007b; Szczepocka & Szulc, 2009; Urrea-Clos & Sabater, 2012; Bere & Mangadze, 2014). This species was found at most sites in the Water Hub boundary and is a good indicator species of high organic pollution. In Zimbabwe, Bere *et al*. (2013), found *Gomphonema parvulum,* at cooler, high altitude sites that were less impacted than the sites in this study. However, in a study by Holmes & Taylor (2015), G*omphonema parvulum* had only a slight preference to warmer conditions and was a good indicator species of pollution in the Great Fish River, Eastern Cape. According to Potapova and Charles (2003), *Gomphonema parvulum,* is also a common species occurring in nutrient rich waters with high EC. This was confirmed by the elevated EC levels at all sites in the Stiebeuel River, excluding site Sb1 and Franschhoek River sites in the Water Hub boundary.

Nitzschia palea, has been described by some as a species tolerant of medium pollution- (Kalyoncu & Serbetci, 2013; Bere & Mangadze, 2014; Triest *et al*., 2012), while, Van Dam *et al*. (1994), Salomoni *et al*. (2006), Potapova and Charles (2007), Lavoie *et al*. (2009) and Bere *et al*. (2014), all describe it as an indicator species of hyper-eutrophic water conditions. Due to its affinity with higher EC levels, *Nitzschia palea,* was found at all sites in the Stiebeuel River and additional Franschhoek River sites in the Water Hub boundary, with the exception of the reference sites Sb1 and Fr20. According to Potapova and Charles (2003); Bere and Tundisi, (2009) and Kalyoncu and Serbecti (2013), species such as *Gomphonema parvulum*, *Nitzschia palea* and *Sellaphora pupula* are good indicators of water with high organic pollution, high nutrient levels, poorly oxygenated and have a low percentage canopy cover. *Gomphnema parvulum* and *Nitzschia palea* were dominant species in both the baseline data set and rehabilitative data set, while *Sellaphora pupula* was also a dominant pollution tolerant species in the rehabilitative data set.

It is evident that surface water runoff from Langrug, is severely contaminating the Stiebeuel River's water quality, which in turn is controlling the species distribution within the river. This emphasizes that water quality is the key driver responsible for the absence and presence of diatoms with varying sensitivities in the river. Given this, the highly polluted water is the causal factor responsible for the abundance and dominance of pollutant tolerant species in the Stiebeuel River.

In comparison the overall diatom species distribution was scattered in the Franschhoek River, however, *Navicula rhynchocephala* was the most prominent clean diatom species, *Gomphonema minutum* was the dominant moderate pollution signature species, while *Fragilaria biceps* had the highest overall abundance. *Navicula rhynchocephala* is a cosmopolitan species, found in oligo- to eutrophic freshwaters with low to moderate electrolyte content. This species is tolerant of critical levels of pollution, but lives preferentially in clean waters (Taylor *et al*., 2007b: 71). *Gomphonema minutum* is a cosmopolitan species found in eutrophic waters, but, is not tolerant to more than moderate pollution (Taylor *et al*., 2007b: 126). *Fragilaria biceps* is a cosmopolitan taxon found in the benthos of rivers and lakes, and is often found in mesotrophic to eutrophic waters (Taylor *et al*., 2007b: 13). There were no pollution tolerant diatom species present in the Franschhoek River.

The sites sampled in the Franschhoek River are thus reflective of diatom species tolerant of clean water to moderate pollution. It is known that temperature and pH play a significant role in the structure of diatom communities (Pan *et al*., 1996; Bere & Mangadza 2014). Temperature is a metabolic driver, while pH also influences many other water chemical variables (Taylor *et al*., 2007d). The Franschhoek River's water quality is in a good condition, which is reflective by the presence of diatom species tolerant of clean to moderate pollution and absence of high and/or critical pollutant tolerant species. The Franschhoek River is a useful reference site for this project because it reveals the condition of a naturally functioning river within the catchment. The natural condition of this river explicitly demonstrates the extreme deterioration caused to the Stiebeuel River from the inflow of highly contaminated water from Langrug, informal settlement. This comparison portrays the significant role of water quality in driving species distribution and overall health of a river system.

A study by Szczepocka and Szulc (2009), similarly reflects the response of diatom communities to differing water quality. Two rivers in Central Poland were analysed; the Bzura River and the Pilica River. The Bzura River is strongly contaminated with organic pollution from domestic and industrial sewage, while the Pilica River has been classified as having good water quality. The Bzura River was dominated by diatom species considered tolerant and resistant to organic pollution, including; *Gomphonema parvulum*, *Nitzschia palea*, *Sellaphora pupula*, *Cyclotella meneghiniana*, *Nitzschia paleacea*, *Ulnaria ulna* and *Stephanodiscus hantzschii*. While, in the Pilica River, diatoms from groups sensitive to organic pollution were dominant, such as; *Cocconeis placentula*, *Cocconeis placuntula* var. *lineata*, *Planothidium frequentissimum*, *Pseudostaurosira brevistriata* and *Staurosira pinnata*. The distribution of diatom species tolerant of pollution in the Bzura River, is similar to the taxa present in the Stiebeuel River, while the Pilica River, dominated by diatoms species signatures of good water quality correlates to many of the species found in the Franschhoek River. This study confirms that water quality is the main driver of species distribution within rivers. It further reinforces the important and useful exploitation of diatoms as bio-indictors in assessing ecological states of surface water quality within river systems.

5.2 Diatom Index Evaluations

The SPI and %PT index scores tested in this study, show that water quality in the Stiebeuel River and Franschhoek River significantly deteriorates downstream from Langrug, informal settlement, due to the inflow of highly contaminated, untreated water. This high organic content in the Stiebeuel River shows that the river receives a discharge of highly polluted, untreated sewage water from Langrug, informal settlement. Kriel (2008), and Holmes and Taylor (2015), found these indices to provide valuable insight on the condition of water and accurately reflected the water quality in the North West province and Great Fish River respectively. This study confirms the findings of Taylor (2004), that since the incorporation of SA endemic species in the SADI, the SPI yielded good results, and, is the most inclusive diatom index used under South African conditions. Holmes and Taylor (2015), further note that additional research into the ecological preferences of diatom species under South African conditions would allow these indices to become even more robust for use in local conditions.

5.3 Correlation Analysis

The significant positive relationships between SPI and DO, and %PT and EC, and the negative correlations between SPI and EC, and %PT and DO, points to wastewater discharges from Langrug, informal settlement as a significant contributor to the extreme deterioration in water quality and pollution of the Stiebeuel River. Chapman & Kimstach (1996), assert that DO levels below the value of 5mg/L have an adverse affect on the functioning and survival of aquatic communities. The low levels of DO found in the Stiebeuel River could be attributed to the highly polluted wastewater from the settlement containing high levels of NH_3-N, and through the process of nitrification, DO levels are depleted within the river (Fell, 2017). This is expected because of the toxic mix of wastewater from limited drainage, sanitation and waste removal services in Langrug, polluting the surface water runoff, and discharging highly contaminated water into the Stiebeuel River. Taylor (2004), found a strong correlation between diatom indices and EC in the Jukskei-Crocodile river system. According to Bate *et al*. (2002), EC and pH are the most important environmental variables affecting rivers studied in the Eastern Cape, which is the same finding as those of Bere and Tundisi (2009) in Brazil, Lavoie *et al*. (2004) in Canada, and Imanpour *et al*. (2013), in Iran. Bere & Mangadze (2014), further found that an increase in nutrients and EC levels, and a decrease in DO levels, was linked to low SPI scores, and an abundance of pollutant tolerant diatom species, in a study conducted to assess diatom responses to changes in water quality, Chinhoyi Town, Zimbabwe.

5.4 miniSASS Analyses

Miserendino *et al*. (2011) notes that changes in land use practices have had a significant affect on the integrity and quality of water resources worldwide. A study conducted in Patagonia hypothesized that 'greater intensity of land-use will have negative effects on water quality, stream habitat and biodiversity' (Miserendino *et al*., 2011). Through the use of macro-invertebrates, riparian invertebrates, birds and fish from the riparian corridor, Miserendino *et al*. (2011) found that urban land-use had the most significant changes in streams physical features, nutrients, conductivity, riparian quality, habitat condition and invertebrate metrics. It was further noted that macro-invertebrates were good indicators of land-use impact and water quality conditions, and proved to be a useful tool to provide early warning signs of disturbances in streams (Miserendino *et al*., 2011).

The miniSASS scores link to the SPI scores, and confirm the health of the Stiebeuel River to be in a very poor condition. Alike diatoms, the highly polluted water from Langrug, informal settlement, controls species distribution and determines the presence and absence of species in accordance to their pollution tolerances. The Stiebeuel River's low sensitivity scores, and decreased biodiversity, infer that the ecological habitat has been severely altered, and the river has been degraded and highly modified. Ricciardi *et al*. (2009), notes that the relationship between macro-invertebrate species diversity and water contamination, mainly organic pollution, has been a focus of investigation since the 1980s. In a study conducted in the Llobregat/Besos Basin, Barcelona, Spain, it was found that macro-invertebrate community indices were lower in areas more affected by pollution, however, it was further identified that the reduction in macro-invertebrate species diversity had a stronger link to changes in habitat and physico-chemical parameters than to the presence of toxicants (Ricciardi *et al*., 2009). This finding explains the macro-invertebrate distribution in the Stiebeuel River. Due to the inflow of highly contaminated surface water runoff from Langrug into the Stiebeuel River, the river's water quality is extremely poor, which in turn has severely modified the natural functioning of the ecological corridor and caused a decline in habitat integrity and decrease in species diversity.

Comparably, the Franschhoek River's high sensitivity scores, increased biodiversity and habitat integrity, indicates that the river is in a fair and/or good condition with few modifications. This confirms that water quality is the main driver of species distribution within the rivers. Given this, there is a confirmation in methods; such that the low SPI scores, low sensitivity scores and corresponding poor ecological category of the Stiebeuel River are linked, and emphasizes that the highly polluted water from Langrug, informal settlement controls and determines the distribution of species, and, overall health of the Stiebeuel River.

5.5 River Rehabilitation Analyses

Theory suggests, through creating and enriching habitat, biological species will respond and return. This phenomenon was proved in the study, such that biological species re-colonised the improved ecological habitat and returned over a short period of time. However, because the rehabilitation intervention solely focused on improving habitat integrity and did not address the inflow of highly polluted water from Langrug, informal settlement, the polluted water quality remains the key driver of species distribution in the Stiebeuel River. Consequently, diatom and macro-invertebrate species tolerant of pollution, with low sensitivity scores, were first to re-colonise the improved habitat. Ehrenfeld (2000), notes that landscapes where inputs of physical energy, such as water are a dominating force in structuring the ecosystem, manipulations of abiotic components of the landscape needs to be a pivotal consideration in effective ecosystem and riparian corridor repair. Wissmar &

Beschta (1998), further explain the importance of having a detailed understanding of the spatial and temporal dynamics of a catchment, for effective and sustainable restoration interventions to be implemented.

Liao *et al*. (2018) further notes that ecological degradation of streams is a worldwide environmental concern, and although river restoration efforts have received substantial attention, restoration solely focused on improving physical habitat has not proven to be completely effective. Several small scale studies have also emphasized that effective restoration strategies require a more holistic understanding of all the factors and catchment variables within a watershed. Figure 24 demonstrates how watershed activities influence water quality and physical habitat, which combined will determine the ecosystem health of a river system (Liao et al., 2018). Liao *et al*. (2018) thus emphasizes that successful stream restoration strategies need to consider the interactive effects of multiple environmental stressors, which are tailored to specific sites and/or site types, rather than considering a single stressor or multiple stressors separately (Liao *et al*., 2018). Cook *et al*. (2015) study reiterates this point and states that improving water quality, upland hydrology, and localized habitat structures simultaneously, may be necessary to improve aquatic ecosystem health.

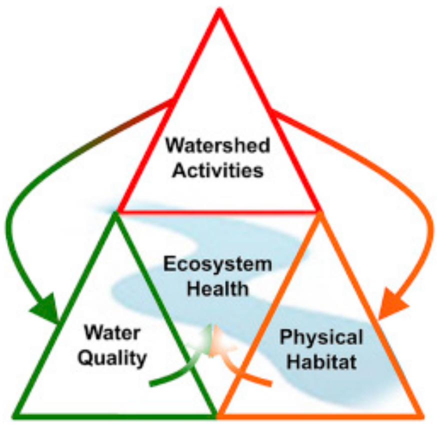

Figure 24: Watershed activities influence ecosystem health of a river (Liao *et al*., 2018).

Given these findings, the complex interactions between Langrug, informal settlement, and the Stiebeuel River's abiotic factors need to be a point of focus to define thresholds that delineate appropriate options for effective riparian restoration within the catchment (Richardson *et al*., 2007). Habitat interventions are thus only an appropriate focus of repair, where the hydrological and geomorphological functioning of a system can support the intended assemblages of species (Hobbs & Harris, 2001). The success of the habitat rehabilitation intervention, is therefore dependent on the improvement of water quality in the Stiebeuel River. Without addressing the main source of surface water pollution from Langrug, informal settlement, any form of river rehabilitation will not be successful.

The continuous discharge of highly contaminated surface water runoff from Langrug, informal settlement, is responsible for driving species distribution and severely degrading the habitat, and river functionality of the Stiebeuel River.

CHAPTER SIX: CONCLUSION

Living conditions in informal settlements are desperate and reflect the reality of people who live in poverty. The characteristic high density living and lack of basic services of these settlements, severely degrades the surrounding area and has a negative influence on the sustainability and functionality of natural environmental processes. In particular, the lack of formal drainage networks results in surface water runoff mixing with excreta, black water, discarded grey-water and solid waste, and being discharged into downstream rivers (Winter, 2017).

Gangoo's (2003) case study on the influence of the Umlazi informal settlement on the water quality of the Umlaas River, confirms the negative impact surface water runoff from informal settlements has on downstream rivers. Samples were taken upstream and downstream of the informal settlement to show the level of deterioration caused to the water quality downstream. High levels of E.coli (120 000- 230 000 cfu/100ml), COD (184 -197 mg.l), turbidity (164 - 197 NTU), EC (171 -197 mS.m), Nitrate (9.5 – 15.8 mg/IN) and phosphorous (156 – 196 mg/IP), compared to upstream readings (table 3), can be linked to the 'open' sewer effect of the informal settlement discharging untreated faecal pollution and other domestic effluents into the river.

Fell's (2017), study further shows the water quality condition at Langrug, informal settlement. Elevated concentrations of NH_3-N (8.4mg/L) and PO_4^{3-} (5.94mg/L) and low DO (3.49mg/L), infer the river to be highly polluted. This is important to note as Chapman and Kimstach (1996) state, DO levels below the value of 5mg/L have an adverse affect on the functioning and survival of aquatic communities. Through Fell's (2017) and Gangoo's (2003) findings, it is evident that rivers draining informal settlements are highly polluted.

This study aimed to understand the value of three methods, namely; diatoms, miniSASS and water quality sampling, which are capable of informing rehabilitation of a river system. The research attempted to determine how these methods are interlinked and are able to assess water quality and support for potential habitat in a highly polluted river. The emphasis is on integrating a combination of well-known methods and to determine how one or more of these methods are capable of providing a stable indicator for habitat support and water quality.

Comparative studies show that macro-invertebrate based indices are more sensitive to changes influencing and affecting structural parameters in a river such as habitat, while diatom indices are more dependent on chemical variables, in particular nutrients affecting water quality and have a wide range of pollution tolerance, ranging from clean water to critically polluted (Soininen & Kononen, 2004; Hering *et al*., 2006; Blanco *et al*., 2007). Furthermore, diatoms are stable signatures in reflecting water quality changes particularly in urban areas. Water quality parameters are also useful indictors for they provide information on the physical, chemical and microbiological determinates of the water source. Through diatom, macro-invertebrate analysis, and water quality monitoring the water quality condition and habitat integrity of a river can be determined (Blanco & Becares, 2010).

6.1 Key findings

The study revealed the current physical and biological condition of the Stiebeuel River to be heavily degraded, and critically modified, with poor river health. Through correlation analysis it was shown that diatoms are effective indicators of water quality in the study area. The low DO levels and high EC levels are correlated to low SPI scores and high %PT scores, which infers that there is a significant amount of organic pollution and nutrients in the wastewater discharges from Langrug, informal settlement. Due to the limited sanitation, drainage and waste removal services in Langrug, surface water runoff is extremely polluted.

The miniSASS scores link to the SPI scores and confirm the health of the Stiebeuel River to be in a very poor condition. Like diatoms, the distribution of macro-invertebrates is determined by the species' ecological tolerances to the highly polluted water. The low sensitivity scores and decreased biodiversity are indicative of the heavily degraded habitat and ecological corridor of the Stiebeuel River. The Stiebeuel River's low sensitivity and low SPI scores are linked to the highly polluted water quality dictating the abundance of pollutant tolerant species. The complimentary use of diatoms and macro-invertebrate species shows the detrimental effect of the contaminated water from Langrug, on the Stiebeuel River's water quality, species diversity, and habitat integrity. Consequently, the Stiebeuel River's ecological category is classified between D and E/F, and is in a critically modified condition.

Environmental assessments using diatoms and macro-invertebrates have been found to often be the most consistent indicators in aquatic environments that provide complementary information (Blanco & Becares, 2010). Diatoms are considered a more reliable and robust indicator of river water quality, especially when assessing organic pollution and eutrophication, compared to macro-invertebrates (de la Rey *et al*., 2004; de la Rey, 2007; Feio *et al*., 2007), as they display a higher sensitivity towards nutrient concentrations and biological oxygen demand (Hering *et al*., 2006). While macro-invertebrates are the preferred species to indicate habitat changes.

Since theory suggests, through creating habitat, species will respond and return to the improved ecological conditions, the ability of the Stiebeuel River to enrich species diversity, following a rehabilitation intervention was investigated. The phenomenon was proven in this study, such that diatom and macro-invertebrate species re-colonised the improved habitat and returned over a short period of time. However, because the rehabilitation intervention only focused on improving habitat and did not address the inflow of highly polluted water from Langrug, the poor water quality remained the driving factor responsible for species distribution in the Stiebeuel River. The biological species that returned were thus pollutant tolerant and indicative of poor water quality. As a result, the Stiebeuel River remains critically modified and in a very poor condition.

The inflow of highly polluted water from Langrug thus completely restricted and negatively influenced the success of the habitat intervention to enrich biological diversity and improve the ecological status of the Stiebeuel River. Understanding and addressing the spatial and temporal dynamics of a catchment is therefore imperative for effective and sustainable river restoration interventions to be implemented. Ehrenfeld (2000), emphasizes the importance of identifying physical inputs in a catchment, such as water or wind, especially when they have a dominating force in structuring the ecosystem. Given this, the inflow of highly polluted water from Langrug needs to be treated before any improvement in the ecological integrity of the Stiebeuel River can be seen. The untreated, highly polluted wastewater discharge from Langrug, informal settlement, was the main limiting factor of the habitat intervention, such that, the Stiebeuel River was unable to enrich the biodiversity of species following the rehabilitation intervention.

Through the use of diatoms, macro-invertebrates and water quality monitoring, a clear link between the three methods was found. This confirms that a combination of methods, opposed to a single method is able to inform the ecological integrity of habitat restoration.

Concluding remarks

This thesis has strengthened the understanding of the link between three different monitoring methods. Up- to date, there has been little literature bringing diatoms, macro-invertebrate and water quality monitoring methods together, however, through this study; the changes in habitat, mobility of macro-invertebrates and the stability of diatoms, despite having different life cycles, shows an overlap in results and confirms the link between the different methods.

This study further contributes to a small, but growing body of knowledge, which proves that surface water runoff from informal settlements is highly contaminated and has a severely negative impact on water quality, habitat integrity and species diversity. By monitoring water quality, through three distinct methods and assessing catchment characteristics, a quantitative relationship between the informal settlement, poor water quality and the distribution of pollutant tolerant species in the Stiebeuel River was established. This relationship strengthens our understanding of the importance of good quality water in optimal functioning river systems and further emphasizes the role of informal settlements in degrading urban rivers in the developing world.

6.2 Recommendations for future study

Nyenje *et al*. (2010), notes that in sub-Saharan Africa, the deterioration of rivers draining informally settled catchments is occurring at a rapid and alarming rate. The authors affirm that the uncontrolled disposal of wastewater, is the primary problem causing severe degradation to the surrounding area and natural environmental processes. Considering this concern, an increasingly important research question is, "how do we get a more comprehensive understanding of the water quality dynamics from informal settlements, in order to implement successful river rehabilitation interventions, in these heavily degraded environments?"

This research has highlighted the following key aspects for future research activity, namely;

- To find effective ways to dilute and/or treat highly contaminated wastewater from informal settlements.
- To determine the success of the habitat intervention on the Stiebeuel River over a longer time period.
- To develop a sustainable river rehabilitation intervention, through considering all the abiotic and biotic factors structuring ecosystem functionality in the Stiebeuel River catchment.

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Appendix

Diatom species acronyms:

Stiebeuel River Baseline Data

Code	Name
ACAF	Achnanthidium affine
ADMI	Achnanthidium minutiss
DPST	Discostella pseudostelligera
NEAF	Neidium affine
NFON	Nitzschia fonticola
PSBR	Pseudostaurosira brevistriata
ADEU	Achnanthidium eutrophilum
PELG	Placoneis elginensis
PPLC	Placoneis placentula
GMIN	Gomphonema minutum
NCTE	Navicula cryptotenella
NIAR	Nitzchoa archibaldii
NIGR	Nitzschia gracilis
NIPR	Nitzschia pura
PSBV	Pinnularia subbrevistriata
CMLF	Craticula molestiformis
CRAC	Craticula accomoda
EOMI	Eolimna minima
ESBM	Eolimna subminuscula
FVUL	Frustulia vulgaris
GGRA	Gomphonema aff. gracile
NANT	Navicula antonii
NCOM	Nitzschia communis
NCPL	Nitzschia capitellata
NFIL	Nitzschia filiformis
NGRE	Navicula gregaria
NPAE	Nitzschia paleacea
NPAL	Nitzschia palea
NVEN	Navicula veneta
NROS	Navicula schroeteri
SPUP	Sellaphora pupula
TAPI	Tryblionella apiculata
THUN	Tryblionella hungarcia
AUGR	Aulacoseira granulata
AVEN	Amphora veneta
CAMB	Craticula ambigua
CRCU	Craticula cuspidata

GPAR	Gomphonema parvulum
GPUM	Gomphonema pumilum
HCAP	Hippodonta capitata
LHUN	Lemnicola hungarica
NCPR	Navicula capitatoradiata
NCYR	Navicula cryptocephala
NERI	Navicula erifuga
NLGC	Navicula longicephala
NROS	Navicula rostellata
NUMB	Nitzschia umbonata
NVIR	Navicula virdiula
PLFR	Planothidium frequentissimum
SSEM	Sellaphora seminulum
TFAS	Tabularia fasciculata
ACOF	Amphora coffeaeformis
CMEN	Cyclotella meneghiniana
FBCP	Fragilaria biceps
FCRS	Frustululia crassinervia
FTEN	Fragilaria tenera
FUAC	Fragilaria ulna var. acus
FUAM	Fragilaria ulna
GINS	Gomphonema insigne
GYAT	Gyrosigma attenuatum
MVAR	Melosira varians
NAMA	Navicula arvensis
NMCA	Navicula microcari
SOVI	Surirella ovalis
STAN	Stauroneis anceps
CPLA	Cocconeis Placentula
CVIX	Craticula vixnegligenda
EFLE	Eunotia flexuosa
EFOR	Eunotia formica
EINC	Eunotia incisa
ELSE	Staurosira elliptica
EMIN	Eunotia minor
ERHO	Eunotia rhomboidea
GAFF	Gomphonema affine
GVNU	Gomphonema venusta
NETO	Nitzschia etoshensis
NSRH	Navicula subrhynchocephala
PTDE	Planothidium delicatulum
SELI	Staurosira elliptica
XXXX	DIATOMEE NON IDENTIFIEE

Franschhoek River Baseline Data

Code	Name
ACAF	Achnanthidium affine
ADCR	Achnanthidium crassum
ADEU	Achnanthidium eutrophilum
AOBG	Achnanthes oblongella
BNEO	Brachysira neoexilis
CACD	Craticula acidoclinata
CAET	Caloneis aequatorialis
CPLA	Cocconeis placentula
CSMO	Cymbella simonsenii
CVIX	Craticula vixnegligenda
DPST	Discostella pseudostelligera
EBIL	Eunotia bilunaris
EFOR	Eunotia formica
EINC	Eunotia incisa
EMIN	Eunotia minor
ENVE	Encyonema ventricosum
ERHO	Eunotia rhomboidea
FBCP	Fragilaria biceps
FCRS	Frustululia crassinervia
FSAX	Frustulia saxonica
FTEN	Fragilaria tenera
FUAM	Fragilaria ulna
FUNG	Fragilaria ungeriana
FVUL	Frustulia vulgaris
GACU	Gomphonema acuminatum
GAFF	Gomphonema affine
GCAP	Gomphonema capitatum
GCLA	Gomphonema clavatum
GEXL	Gomphonema exilissimum
GINS	Gomphonema insigne
GMIN	Gomphonema minutum
GPVL	Gomphonema parvulius
GSCA	Gryosigma scalproides
GVNU	Gomphonema venusta
MELL	Mastogloia elliptica
NAMA	Navicula arvensis
NCTE	Navicula cryptotenella
NEAF	Neidium affine
NFON	Nitzschia fonticola
NIPR	Nitzschia pura
NIPU	Nitzschia pusilla

NNOT	Navicula notha
NRAN	Navicula ranomafenensis
NRHY	Navicula rhynchocephala
NSRH	Navicula subrhynchocephala
NZAN	Navicula zanonii
PLFR	Planothidium frequentissimum
PPLC	Placoneis placentula
PSBR	Pseudostaurosira brevistriata
PSBV	Pinnularia subbrevistriata
PSCA	Pinnularia subcapitata
PTRO	Planothidium rotratum
PVID	Pinnularia viridis
SCON	Staurosira construens
SELI	Staurosira elliptica
SPIN	Staurosirella pinnata
SPUP	Sellaphora pupula
TFLO	Tabellaria flocculosa
XXXX	DIATOMEE NON IDENTIFIEE

Stiebeuel River Rehabilitated Data

Code	**Name**
ADSG	Achnanthidium saprophilum
CRAC	Craticula accomoda
CAMB	Craticula ambigua
CMLF	Craticula molestiformis
CMEN	Cyclotella meneghiniana
DCTG	Diadesmis confervacea
EOMI	Eolimna minima
ESBM	Eolimna subminuscula
EMIN	Eunotia minor
FTNR	Fallacia tenera
FCVA	Fragilaria capucina
FUAM	Fragilaria ulna
FUAC	Fragilaria ulna var. acus
FVUL	Frustulia vulgaris
GAFF	Gomphonema affine
GGRA	Gomphonema gracile
GINS	Gomphonema insigne
GMIN	Gomphonema minutum-
GPAR	Gomphonema parvulum

GPSA	Gomphonema pseudoaugur
GPUM	Gomphonema pumilum
HDIS	Hantzschia distinctepunctata
MAAT	Mayamaea atomus
NAMA	Navicula arvensis
NCPR	Navicula capitatoradiata
NCTE	Navicula cryptotenella
NERI	Navicula erifuga
NGRE	Navicula gregaria
NMCA	Navicula microcari
NSHR	Navicula schroeteri
NSRH	Navicula subrhynchocephala
NVEN	Navicula veneta
NIAR	Nitzchia archibaldii
NAGN	Nitzschia agnita
NDES	Nitzschia desertorum
NELE	Nitzschia elegantula
NFON	Nitzschia fonticola
NLBT	Nitzschia liebertruthii
NPAL	Nitzschia palea
NIPR	Nitzschia pura
NUMB	Nitzschia umbonata
PSBV	Pinnularia subbrevistriata
PPLC	Placoneis placentula
PLFR	Planothidium frequentissimum
SPUP	Sellaphora pupula
SSEM	Sellaphora seminulum
PSSE	Staurosira elliptica
SHPA	Stephanodiscus hantzschii
TFAS	Tabularia fasciculata
TAPI	Trybionella apiculata
XXXX	Diatom unidentified

miniSASS information sheets used to sample macro-invertebrates.

SITE INFORMATION TABLE	
River name:	Date (dd/mm/yr):
Site name:	Collector's name:
GPS co-ord Lat(S): Long(E):	School/organisation:
Site description: e.g. downstream of industry	Notes: e.g. weather, impacts, flow, etc.
pH: Water temp: ^{o}C Dissolved oxygen: mg/l Water clarity: info at www.minisass.org	

GPS co-ordinates as degrees, minutes, seconds (e.g. 29°30'25" S / 30°45'10" E) **OR** as decimal degrees (e.g. 29.50694°S / 30.75277°E) If you don't have a GPS, upload your results at **www.minisass.org**, find your site on the map, click to upload your result and the co-ordinates are saved for you!

Scoring

1. On the table, circle the sensitivity scores of the identified organisms.
2. Add up all of the sensitivity scores.
3. Divide the total of the sensitivity scores by the number of groups identified.
4. The result is the **average score**, which can be interpreted into an ecological category given below.

Interpret the miniSASS score:

Although an ideal sample site has rocky, sandy, and vegetation habitats, not all habitats are always present at a site. If your river had no rocky habitats that were sampled, use the **sandy type** category to interpret your scores.

GROUPS	SENSITIVITY SCORE
Flat worms	3
Worms	2
Leeches	2
Crabs or shrimps	6
Stoneflies	17
Minnow mayflies	5
Other mayflies	11
Damselflies	4
Dragonflies	6
Bugs or beetles	5
Caddisflies (cased & uncased)	9
True flies	2
Snails	4
TOTAL SCORE	
NUMBER OF GROUPS	
AVERAGE SCORE (miniSASS Score)	

Average Score = Total Score ÷ Number of groups

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

Now, upload your results at www.miniSASS.org or use the miniSASS App (download from the miniSASS website) or send a scan of this page to info@minisass.org!

miniSASS STREAM ASSESSMENT SCORING SYSTEM

miniSASS is used to monitor the health of a river and measure the general quality of the water in that river. It uses the make-up of macro-invertebrates (small animals) living in rivers and is based on the sensitivity of the various animals to water quality.

NOTE: miniSASS does NOT measure the contamination of the water by bacteria and viruses and thus does not tell us if the river water is fit to drink.

Equipment list

- Net (see www.minisass.org)
- white container / tray / ice-cream box
- magnifying glass
- pencil
- shoes/gumboots
- hand wash / soap

www.minisass.org
Version 3.0 – September 2015

Method

The best sites have rocks in moving water (**rocky type** rivers). Not all sites have rocks, but may be largely sandy (**sandy type** rivers).

1. Whilst holding a small net in the current, **disturb** the stones, vegetation, sand etc. with your feet or hands.
2. You can also lift stones out of the current and gently **pick** organisms off with your fingers or forceps.
3. Do this for about **5 minutes** whilst **ranging across the river to different habitats** (biotopes).
4. Rinse the net and turn the contents into a plastic tray. **Identify** each group of organisms using the identification guide (see insert: start with the dichotomous key, then use the identification guide for more information).
5. Fill in the site information and **mark** the identified organisms off on the scoring sheet (back page).
6. **Add up** the sensitivity scores and determine the **average score**.
7. Interpret your miniSASS score.
8. Remember: **WASH** your hands when done!

https://www.youtube.com/channel/UCub24hwrLi52WR9C24uTbaQ

Don't have a net? Make your own – it is easy!

Take any piece of wire, for example an old clothes hanger, and bend it into the shape of a net. Then tie the netting (which can be any porous material) to the wire with a piece of string. Alternatively cut the bottom out of an ice cream container and staple netting to the bottom. Now you have a net!!

Macroinvertebrates

What are they?

Macroinvertebrates are animals that have no backbone and you can see them with the naked eye.

Why are they used for biomonitoring?

- Different macroinvertebrates have different sensitivities to water quality conditions. More sensitive "nunus" will disappear from a river system where water quality has declined. On the score sheet, the higher the score, the more sensitive the "nunus" are.
- They are generally easy to collect and identify.
- They are relatively sedentary which allows the source of pollution to be detected.
- They indicate the water quality conditions at a site, providing an overall measure of the "health" of a river.
- They provide a picture of recent events affecting water quality at a site.

Why is water quality monitoring & management important in South Africa?

Fresh water is essential for life on earth. Water is also used in all spheres of human life, namely agriculture, industry, biodiversity conservation, sanitation and hydration.

However due to the amount of rainfall South Africa receives, it is classified as a water-stressed country. This means that if we do not monitor, manage and conserve our current water resources, we will be placing them and the population under tremendous stress in the future!

Get ready to put your crab on the map!

Load your site at: www.miniSASS.org

Glossary

Biomonitoring: the monitoring of biodiversity using biological organisms

Biodiversity: diversity within species, between species and of ecosystems

Conservation: the maintenance of environmental quality and functioning

Ecosystem: a complete community of living organisms and the non-living materials of their surroundings

Sedentary: inactive, motionless, not moving

River safety

Take special care in polluted waters. Beware of dangerous animals (crocs/hippos!) and fast flowing waters. Wear protective gear when necessary and wash your hands regularly with soap and clean water wherever possible!!

What can you do?

As the general public, we play a part in making a difference to managing freshwater resources in our communities. miniSASS has the potential to be a powerful 'red flag' indicator to identify aquatic pollution sources. By using miniSASS we can actively take an interest in the management of the health of freshwater bodies in our community.

Your interest and knowledge can be enhanced by adopting a local river in your community and monitoring it over time, identifying sources of pollution and taking local action to make a difference. You could also encourage more members of the community to take positive action towards monitoring and conserving water.

Contribute to the picture of river quality in South Africa

Download miniSASS resources and upload data at

www.minisass.org or use the miniSASS App

For queries, comments or assistance email info@minisass.org

Also available from Share-Net: www.sharenet.org.za Tel (033) 3303931

History of the miniSASS tool

South Africa is a world leader in biomonitoring techniques using macro-invertebrates. The most successful of these is the South African Scoring System version 5 (SASS5). miniSASS is based on SASS and uses the presence of macro-invertebrates to indicate "river health". Where SASS5 contains over 90 different macroinvertebrate taxa, miniSASS uses 13 taxa, allowing for simpler identification and understanding. miniSASS provides similar indications of "river health" status as the more comprehensive SASS5 assessment, providing a good method to generate useful biomonitoring data. miniSASS Version 1 was developed using roughly 2 000 SASS4 data records. miniSASS Version 2 was based on over 6 000 SASS5 records, making it more robust & more widely applicable in Southern Africa. Version 3 has updated Ecological Categories to be more closely aligned with SASS5 results.

Key words for further reading

macroinvertebrate, benthic, water quality, conservation, biodiversity, river health, aquatic pollution, SASS, taxa, invertebrate classification, ecological monitoring

Additional resources and partners

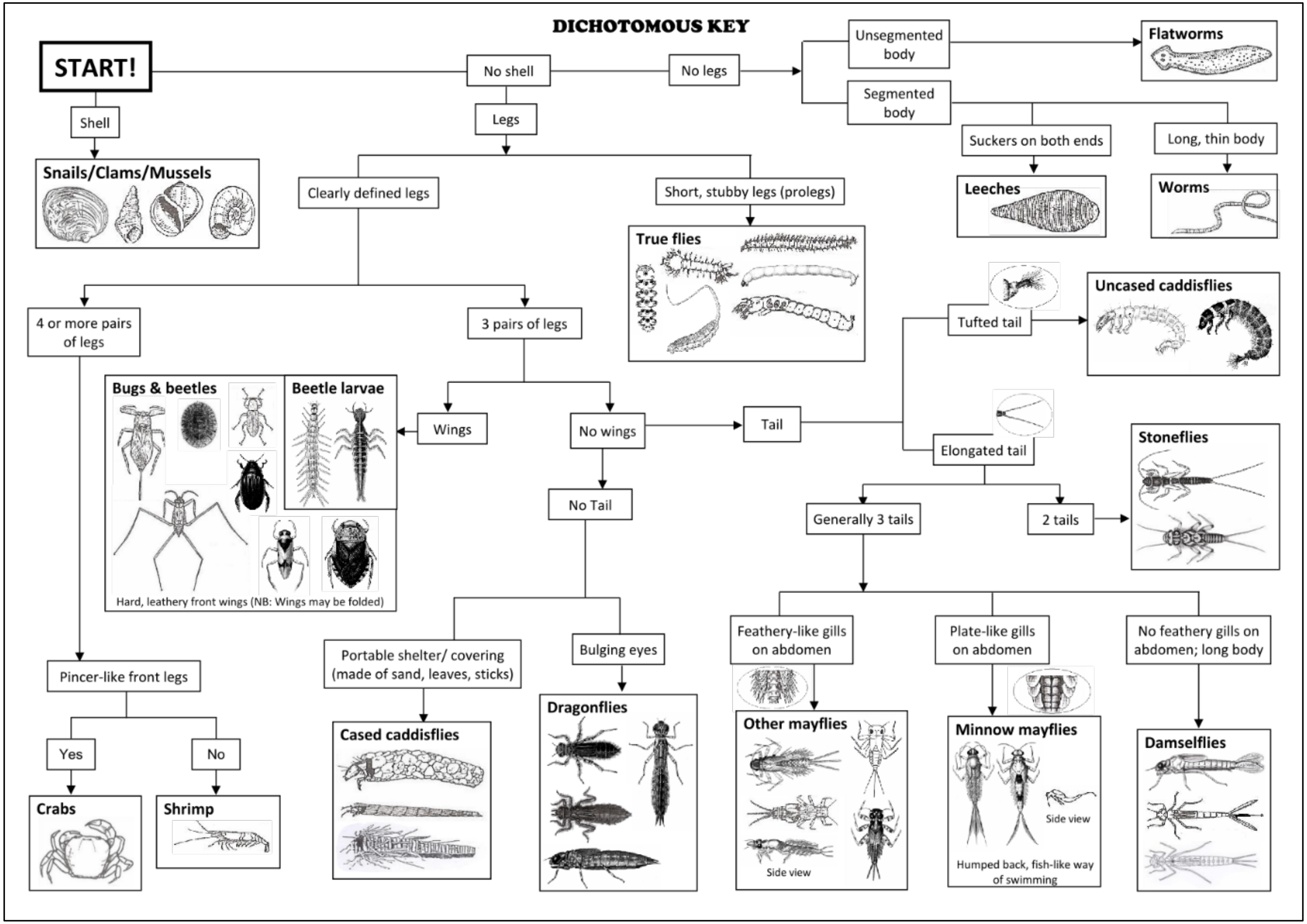
WATER RESEARCH COMMISSION www.wrc.org.za

WESSA www.wessa.org.za

GroundTruth Water, Wetlands and Environmental Engineering www.groundtruth.co.za

water & sanitation, Department: Water and Sanitation, REPUBLIC OF SOUTH AFRICA www.dwa.gov.za

science & technology, Department: Science and Technology, REPUBLIC OF SOUTH AFRICA www.dst.gov.za


DICHOTOMOUS KEY
START!
Shell
Snails/Clams/Mussels
No shell
No legs
Unsegmented body
Flatworms
Segmented body
Suckers on both ends
Leeches
Long, thin body
Worms
Legs
Clearly defined legs
Short, stubby legs (prolegs)
True flies
4 or more pairs of legs
Pincer-like front legs
Yes
Crabs
No
Shrimp
3 pairs of legs
Wings
Bugs & beetles
Beetle larvae
Hard, leathery front wings (NB: Wings may be folded)
No wings
No Tail
Portable shelter/ covering (made of sand, leaves, sticks)
Cased caddisflies
Bulging eyes
Dragonflies
Tail
Tufted tail
Uncased caddisflies
Elongated tail
2 tails
Stoneflies
Generally 3 tails
Feathery-like gills on abdomen
Other mayflies
Side view
Plate-like gills on abdomen
Minnow mayflies
Side view
Humped back, fish-like way of swimming
No feathery gills on abdomen; long body
Damselflies

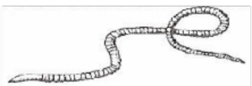
Flat worms

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

Leeches

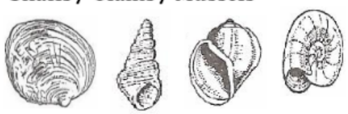
Leeches are segmented organisms that have very flexible bodies. When moving they expand to become long and thin, and then contract to become short and stubby. They have suckers on both ends of the body used for feeding and locomotion. Leeches are variable in colour, from grey, to red-brown and black.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

Worms



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

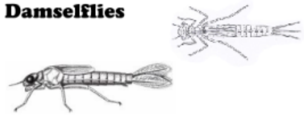
Snails / Clams / Mussels



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

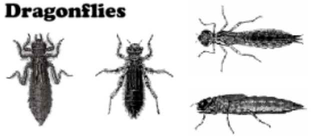
Images not to scale

Damselflies



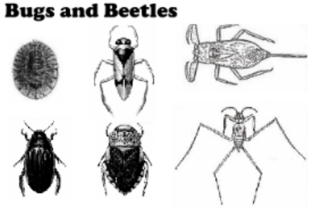
Damselflies have elongated bodies generally with three broad tails/gills on the tip of the abdomen. Damselflies are carnivorous and have a 'mask' over the lower part of the face, which hinges out to reveal a pair of pincers used to catch their prey. They are often found in vegetation growing on the edges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

Dragonflies



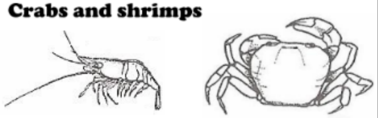
Dragonflies are robust creatures that are stout and have a large head and protruding eyes. Some have short legs whilst others have long legs. They do not have tails, but swim using 'jet propulsion' by forcefully ejecting water from the abdomen. Dragonfly nymphs are usually the largest organisms found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

Bugs and Beetles



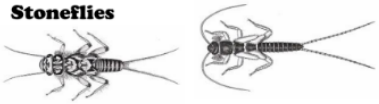
Bugs can be defined as having a piercing and sucking beak for mouthparts, and two pairs of membranous wings. Beetles on the other hand have 'jaws' and outer wings that are hardened to protect the inner wings. Some bugs and beetles are well adapted to swimming, such as water boatmen, backswimmers, pond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

Crabs and shrimps



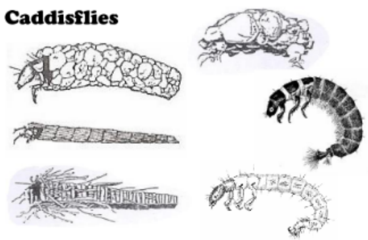
Crabs and shrimp form part of the order Decopoda (ten legs) and have bodies and legs hardened to form a tough shell. They have four or five pairs of legs. Their eyes that are carried on stalks and are movable. Crabs are scavengers that feed mainly on leaf litter but will feed on animals when given the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

Stoneflies



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

Caddisflies



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

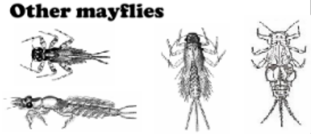
Mayflies

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

Minnow mayflies

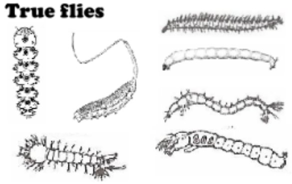
These mayflies have a narrow head and a small, slender, but not flattened body. They have leaf shaped gills on both sides of the abdomen and two but more commonly three tails, depending on the species.

Other mayflies



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

True flies



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

Images not to scale